Light Coal: Development of a Torrefaction Reactor and Business System for Himalayan India

Reactor Testing, Pine Needle Fuel Evaluation, End User Value Propositions and Logistics System Design

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Challenge the future

Light Coal: Development of a Torrefaction Reactor and Business System for Himalayan India

Reactor Testing, Pine Needle Fuel Evaluation, End User Value Propositions and Logistics System Design

By

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ABSTRACT

A three month long field research brought to light that the lack of livelihood opportunities in the Kumaon region of Uttarakhand is leading to outmigration of people from the state. There is a major need to develop sustained income and employment opportunities for the people in the region. The monoculture of pine forests shed huge amounts pine needles on the forest floor during the summer months. These pine needles, however, are the reasons for frequent forest fires in the region, strongly impacting its biodiversity. This makes a perfect case for the establishment of a business employing local people to produce energy out of pine needles. In light of this need, the prospect of biomass Torrefaction to produce a commodity fuel to meet the thermal energy needs for a variety of end users was investigated. This project was done in collaboration with Avani Kumaon, an organization working to create sustainable livelihood opportunities for the people living in the region.

Pine needles procured from the Kumaon region were Torrified in a direct convectively heated packed bed reactor, a muffle furnace and a TGA (Thermo-gravimetric Analyser) setup at TU Delft to quantify Mass Yields at Torrefaction temperatures of 230°C, 250°C, 270°C and 290°C and residence times of 15 minutes, 30 minutes and 45 minutes. The Torrified product obtained was checked for its calorific value in a bomb calorimeter and the Energy Yields were established for the different process conditions. A Differential Thermo-gravimetric Analysis (DTGA) for the raw and Torrified pine needles was also performed to understand the trends in Mass Yields and this was compared to the trends in Mass Yields obtained for verge grass through a similar set of experiments. It was found that pine needles by themselves are a better fuel than verge grass, undergoing lesser amelioration of fuel properties (in terms of delayed and lower levels of degradation of volatile fraction of hemicellulose and cellulose) through Torrefaction. However, Torrefaction of pine needles is still justified as they are found very wet and prone to rot. Long term storage of pine needles for year- long sale of a fuel further underscores the need for Torrefaction. During field research in India, two batch reactor designs were also built and tested for Torrefaction using pine needles. The designs gave moderate -poor results for heat transfer to the pine needles, leading to the production of non-uniformly Torrified product. This underscores the need for further research on other reactor designs. However, the second reactor built gave better heat penetration than reactor 1 and hence its geometrical and operational parameters were selected for calculation pertaining to the business model. A final selection of process parameters gave an isothermal Torrefaction temperature of 250°C for a residence time of 15 minutes. This was based on the trends in Mass Yields, Higher Heating Values (HHV) and Energy Yields obtained through Torrefaction experiments and DTGA analysis. The impact of different process conditions on the business profits and the overall efficiency of the reactor also played a role in choosing this process condition.

Field research in the Kumaon region was carried out to find out the value proposition for a variety of end users, from domestic cooking to gasification based power plants. The needs and preferences of the end users were established through interviews, generative "Design Sessions" and cookstove demonstrations. In the end it was established that commercial kitchens that use commercial LPG for cooking would benefit most from the use of Torrified pellets, as the cost of commercial LPG is high and its supply chain is not well established in remote areas. Due to the concentration of these businesses in the urban areas, it was decided to focus on the market in these towns. Initial market penetration of 5% gave a daily fuel demand of 1072 kg/day and a raw biomass demand of 8055 kg/day. A cumulative reactor volume 21 m³ would be needed to meet this demand. A logistics system was designed in which the pine needles will be collected on foot by women collectors at 1 Re/kg¹, aided by a ropeway system. The transportation of the fuel to the market using factory owned pick-up trucks was found to be the most feasible. A 6 year

¹ Throughout this these the symbol 'Re' will be used to represent the unit of a single Rupee and 'Rs' for higher values.

payback time was fixed to recover the capital cost of the plant. Overall, the business gave marginal profits in the first 6 years and strong profits after 6 years, underscoring the business potential for this concept.

Although further research is needed to develop the technology before realization of the project, this novel method of simultaneous development of the technology and business system with contextual consideration has produced a promising foundation of a business with much potential.

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CHAPTER 1: INTRODUCTION

This chapter gives an introduction to the major socio-economic problems in the middle Himalayan region of the Kumaon, Uttarakhand, India. Based on these issues, the major needs of the people will be highlighted and the role of biomass Torrefaction as a business in serving those needs will be presented.

Field research was carried for three months in the Kumaon region of Uttarakhand with the support of Avani Kumaon. Avani is a local organization that works towards creating sustainable livelihood opportunities for people living in the Kumaon region. The research of the socio-economic context in this chapter is based on actual field experiences and interviews with villagers, employees of Avani, environmentalists, village heads (gram pradhan), people running businesses in the local area and government officials.

1.1 PROJECT IMPLEMENTATION: NON-PROFIT VS FOR -PROFIT, TOP DOWN VS BOTTOM UP

The traditional paradigm of providing financial aid or essentially donations to governments and non-profit organizations has limitations and sometimes serious problems in the way poverty alleviation is fought in developing countries. Most aid agencies fall short of delivering effective solutions because they attempt utopian goals and develop large scale top down plans with little input or accountability from those they desire to help. Usually, 'one size fits all' strategies are adopted by these organizations, with very little working knowledge/engagement with the situation on the ground[1]. This leads to money and effort going to projects that may not be doing the best work possible or, even worse, doing more harm than good. Non-profit based projects don't have major revenue streams and are hence dependent on external funding. They directly inherit the disadvantages of the aid/charity system and the project suffers due to lack of feedback and accountability between the two partners. Additionally, if the funding is lean, the project cannot be implemented to its full capacity. The poor are essentially treated as beneficiaries, and not as consumers. If the poor don't pay for the products and services that they are getting, they will not see much value in it. Furthermore, non-profit organizations end up spending a lot of time and effort on searching and applying for funding than concentrating more on working for the poor. This makes the entire existence of the project futile.

Hence, the need of the hour is to have homegrown, market based solutions, and projects that specialize on solving one particular problem, while being constantly engaged with the end users. Any product or service that has been paid for will have a higher chance of being maintained well by the end user/customer and thus will not fall into disuse. Moreover, this will give the customer the right to demand better quality products and services from the organization providing them, leading to liabilities on both sides. This will greatly enhance the financial and operational sustainability of the project. Additionally, consumers will only buy a product if they see any value in it[2]. Thus it is very important for any intervention for the underserved to have a market driven solution that would be self-sustaining through its own profits, thus making it an independent and long lasting project. For- profits have socially inclined investors rather than donors, and thus would expect returns on their investment, keeping the company always on its toes to perform well in the market, while achieving its social goals. The poor are willing to pay for products and services, provided they are helped with doorstep financing and doorstep maintenance services.

To get the consumer interested in purchasing the product/service, it is very important to understand his/her needs. Once it is established that the intervention can bring economic value to the consumer, the consumer starts seeing benefits in using the product/service. Over and above that, it is crucial to get an

idea of the income generating patterns of the consumer, as most of the time the poor do not have a fixed monthly salary. Once these basics are established, it is the responsibility of the company to provide customized loans through regional rural banks and micro-finance institutions based on the income generating patterns of the customers. This leads to a bottom up approach to bringing about an intervention, while carefully accounting for the needs and preferences of the consumer. Adopting methods of 'co-creation' are also the way to go as they involve the end users in the design of interventions.

To add to the above points, it is very important to assess environmental, cultural, political factors that affect the design of the technology and the service system. Moreover the ethics of bringing about the intervention should also be questioned. For example, in the case of selling a Torrified fuel to rural households, one can ask:

Is it justified to sell a lower standard fuel to poor rural households just because they have no other option? Shouldn't they have a better access to cleaner fuels like LPG, just like how most of middle and upper class India does?

1.2 RESEARCH GOALS AND EXPECTED OUTCOMES

This master thesis is an investigation into the prospects of Torrefaction technology, which has been developed in the context of the western world, being adapted to the socio-cultural context in the rural areas of Kumaon, Uttarakhand. The goal of this project is two-fold:

- 1. Design an appropriate Torrefaction reactor concept by taking into account local manufacturing and maintenance capabilities to provide for the thermal energy needs of the community.
- 2. Identify value propositions for the use of such a fuel for a variety of end users and design a service system for the technology, to be run by an entrepreneur, for addressing major socio-economic issues in the region.

Design Problem

As mentioned earlier, there are two stages to the design process in this project: The design of the Torrefaction plant itself, and the service system and business model design.

Technology Design

This part of the research essentially involves the basic concept design and testing of a Torrefaction reactor, which will utilize pine needles to produce a commodity fuel. The technology should be designed according to the local manufacturing and maintenance capabilities, and locally available materials. This is essentially important as the Pithoragarh district in the Kumaon region is very remote, and in the event of a breakdown getting heavy and sophisticated equipment from long distances can be very costly. Adding to the cost is the time taken for equipment to reach as a consequence of the difficult mountain terrain, causing long downtimes. The breakdown of a blower at Avani's gasification plant took more than a month to be replaced because of this reason. The limited technical capabilities that exist in the region would not be able to provide much support in carrying out maintenance work in the plants. Technicians would have to be called from the plains, a minimum 12 hour road journey away. This can again cause significant downtimes for the factory. Thus, the reactor design should be simple enough to be capable of being built and maintained locally.

Business System Design

The design of any biomass based business should carefully evaluate the different options for collection of raw biomass, storage of raw biomass and the final product, and the transportation of the final product. In the Himalayas, moving vast amounts of pine needles from the forests to the plant can be a challenge due to the difficult mountain terrain and hence innovative logistics systems need to be designed, both on the pine needle supply side as well as the distribution of the product. The business management structure adopted to run the factory is also essential for its effective management. The best possible business management structure needs to be chosen based on a combination of local work culture and good western management practices. Through a socio-economic analysis of the region, major needs of the area need to be identified to see if a Torrefaction factory and the product it produces are able to meet those needs. Additionally, other needs in terms of cooking and heating requirements of possible end users such as households, small restaurants or *dhabas*, hotels, local industries etc. need to be chosen, while not compromising on the social impact of the project. Finally the best possible service system needs to be chosen incorporating all final stakeholders in the project and the most efficient logistics system.

This project is a joint venture between two master students of TU Delft, Ryan Helmer and Vidyut Mohan. And hence, there are areas of research which are common to both and other areas which are distinct. The task division between the two students is given in Appendix 1.

1.2 SOCIO-ECONOMIC CONTEXT OF UTTARAKHAND

This research is focused on the mountainous state of Uttarakhand, usually called '*Dev Bhoomi*' or the land of the gods. The state is located in the Northern part of Himalayan India, sandwiched between the state of Himachal Pradesh and Nepal (Figure 1). The eastern and western parts of the state are known as Kumaon and Garhwal respectively, each being an administrative division with 13 districts in total, 95 blocks and 15,761 villages. Majority of state is hilly (90% of the total area) with 66% of the state's geographical area being covered with forests, making it one of the most densely forested states in India. The field location for this research is the Pithoragarh and Almora districts, with the base for the research being Avani Kumaon campus, Tripuradevi, Pithoragarh District.





FIGURE 1: THE STATE OF UTTARAKHAND, INDIA[3]

The Indian states that have the lowest Human Development Index and the highest incidence of poverty are shown in Tables 1 and 2. Uttarakhand's HDI is ranked 14th out of 28 states[4] and the Below Poverty Line (BPL) rank is 10 out of 28 Indian state. According to the University of Oxford's multidimensional poverty Index, which employs indicators that account for living standards, infrastructure, health and education, Uttarakhand fares a decent 6th position out of 21 states that were evaluated[5]. Thus, Uttarakhand is definitely not one of the poorest states in India; however its Human Development Index can still be considered to be quite average.

MPI Rank	States	Population (in millions) 2007	MPI	Proportion of Poor	Average Intensity	Contribution to Overall Poverty	Number of MPI Poor ³ (in millions)
1	Kerala	35.0	0.065	15.9%	40.9%	0.6%	5.6
2	Goa	1.6	0.094	21.7%	43.4%	0.0%	0.4
3	Punjab	27.1	0.120	26.2%	46.0%	1.0%	7.1
4	Himachal Pradesh	6.7	0.131	31.0%	42.3%	0.3%	2.1
5	Tamil Nadu	68.0	0.141	32.4%	43.6%	2.6%	22.0
6	Uttaranchal	9.6	0.189	40.3%	46.9%	0.5%	3.9
7	Maharashtra	108.7	0.193	40.1%	48.1%	6.0%	43.6
8	Haryana	24.1	0.199	41.6%	47.9%	1.3%	10.0
9	Gujarat	57.3	0.205	41.5%	49.2%	3.4%	23.8
10	Jammu And Kashmir	12.2	0.209	43.8%	47.7%	0.7%	5.4
11	Andhra Pradesh	83.9	0.211	44.7%	47.1%	5.1%	37.5
12	Karnataka	58.6	0.223	46.1%	48.3%	4.2%	27.0
13	Eastern Indian States ⁴	44.2	0.303	57.6%	52.5%	4.0%	25.5
14	West Bengal	89.5	0.317	58.3%	54.3%	8.5%	52.2
15	Orissa	40.7	0.345	64.0%	54.0%	4.3%	26.0
16	Rajasthan	65.4	0.351	64.2%	54.7%	7.0%	41.9
17	Uttar Pradesh	192.6	0.386	69.9%	55.2%	21.3%	134.7
18	Chhattisgarh	23.9	0.387	71.9%	53.9%	2.9%	17.2
19	Madhya Pradesh	70.0	0.389	69.5%	56.0%	8.5%	48.6
20	Jharkhand	30.5	0.463	77.0%	60.2%	4.2%	23.5
21	Bihar	95.0	0.499	81.4%	61.3%	13.5%	77.3
	India	1,164.7	0.296	55.4%	53.5%	-	645.0

TABLE 1: MULTIDIMENSIONAL POVERTY ACROSS INDIAN STATES[5]

The population of the state increased from 8.5 million in 2001 to 10.1 million in 2011, making it the 20th most populated state in India, with 69.77 % of the population still living in rural areas[6]. As one would expect in hill topography, the population is fairly scattered with low density..

The state has a higher literacy rate as compared to some other states in the country. The overall literacy rates in Uttarakhand rose to 79% in 2011 from 72% in 2001. The female literacy rate increased from 63% to 67% and the male literacy rate rose from 81% to 87.4%, indicating a significant gap in literacy levels between the male and female populations.

TABLE 2: THE NUMBER AND PERCENTAGE OF POPULATION OF EACH STATE THAT LIVES BELOW THE
POVERTY LINE (BPL), IN ASCENDING ORDER[7]

				(No	of People in	100,000)	
States	Rur	Rural		n	Total		
	% of	No. of	% of	No. of	% of	No. of	
	Population	People	Population	People	Population	People	
Goa	11.54	0.6	6.9	0.6	8.7	1.3	
Jammu and Kashmir	8.1	7.3	12.8	4.2	9.4	11.5	
Himachal Pradesh	9.12	5.6	12.6	0.9	9.5	6.4	
Kerala	12	21.6	12.1	18	12	39.6	
Sikkim	15.51	0.7	5	0.1	13.1	0.8	
Punjab	14.61	25.1	18.1	18.4	15.9	43.5	
Meghalaya	15.34	3.5	24.1	1.4	17.1	4.9	
Tamil Nadu	21.18	78.3	12.8	43.5	17.1	121.8	
Tripura	19.84	5.4	10	0.9	17.4	6.3	
Uttarakhand	14.85	10.3	25.2	7.5	18	17.9	
Haryana	18.56	30.4	23	19.6	20.1	50	
Nagaland	19.32	2.8	25	1.4	20.9	4.1	
Mizoram	31.12	1.6	11.5	0.6	21.1	2.3	
Andhra Pradesh	22.75	127.9	17.7	48.7	21.1	176.6	
Gujarat	26.65	91.6	17.9	44.6	23	136.2	
Karnataka	26.14	97.4	19.6	44.9	23.6	142.3	
Maharashtra	29.51	179.8	18.3	90.9	24.5	270.8	
Rajasthan	26.42	133.8	19	33.2	24.8	167	
Arunachal Pradesh	26.16	2.7	24.9	0.8	25.9	3.5	
West Bengal	28.79	177.8	22	62.5	26.7	240.3	
Madhya Pradesh	41.98	216.9	22.9	44.9	36.7	261.8	
Odisha	39.2	135.5	25.9	17.7	37	153.2	
Uttar Pradesh	39.36	600.6	31.7	137.3	37.7	737.9	
Assam	39.87	105.3	26.1	11.2	37.9	116.4	
Jharkhand	41.56	102.2	31.1	24	39.1	126.2	
Manipur	47.42	8.8	46.4	3.7	47.1	12.5	
Chhattisgarh	56.13	108.3	23.8	13.6	48.7	121.9	
Bihar	55.33	498.7	39.4	44.8	53.5	543.5	
Total India	33.8	2782.11	20.9	764.7	29.8	3546.8	

Discussions with staff at Avani and other NGOs in the region also revealed that as a general picture, the kind of abject poverty that is seen in the plains of India, where people even struggle for food is rarely seen in the mountains. However, a significant portion of the population does not earn enough to have enough money for emergencies or to make investments. The other smaller segment of the population has food, shelter and water, but is barely able to make ends meet.

 $^{^2\,}$ The total India figures are greater than the figures for the sum of the states as they include data for Union Territories and the National Capital Region of Delhi

1.3 ECONOMY OF THE STATE OF UTTARAKHAND

The economy of Uttarakhand has followed a steady growth path since the state's inception in 2000. The state has witnessed an impressive increase of 11.6% per annum in its Gross State Domestic Product (GSDP), during the period 1999-00 and 2004-05. This growth, as illustrated in Table 3, is largely due to the growth in secondary and tertiary sectors of the economy of the state.

TABLE 3: GROWTH OF DIFFERENT INDUSTRIAL SECTORS IN UTTARAKHAND[8]

by Indu	stry in Uttarakhand	
Industry	Grow	th rate
	1993-94 to 99-00	1999-00 to 2004-05
Agriculture & allied activities	2.33	1.81
Mining & quarrying	3.75	29.18
Manufacturing	-4.52	13.99
Electricity, gas & water supply	8.46	19.23
Construction	2.00	20.42
Trade, hotels & restaurants	1.19	10.39
Transport, storage & communication	5.39	16.28
Banking & insurance	6.92	7.87
Community and social services	6.01	12.81
A11	3.17	10.03

Annual Compound Growth of GSDP (At 1993-94 Prices) by Industry in Uttarakhand

Source: CSO (2006).

As can be seen from Table 3, the organized manufacturing sector has been the major driver in the growth of the GSDP, registering an annual increase of 17% per annum during this time period. The annual growth of GSDP for the services sector doubled as well to 10% during this time. However, one can see that the process of growth has hardly touched the agriculture sector, which saw a growth of 2% in GSDP during 1999-00 and 2004-05. This growth progress has been limited to the three plain districts of the state. The hill districts, where about 53% of the population of the state resides, has largely been untouched with high growth. These districts, thus, continue to remain deprived in terms of credit flows and other opportunities for employment, with low yield agriculture and manual labour work being the major source of employment in those regions. This is true as one goes more remote into the mountains, beyond the big tourist town of Almora and into Pithoragarh district, where traditional ways of life based on agro-forestry are still practiced. Economic development hasn't really reached these areas and one can see the consequences in terms of outmigration of people from their villages to the cities in Uttarakhand or outside the state.

1.4 THE STRUGGLE FOR LIVELIHOODS

Traditionally, the economy of the middle Himalayan region of Kumaon has been agriculture dependent, with subsistence agriculture being practiced almost everywhere. There has always been a strong link between the forests, the crops grown and the management of cattle through the traditional knowledge base of managing biomass flows between the forests and the fields. The forests provide fuel wood, medicines and fodder for the cattle. The cattle would provide manure for the fields and the fields in turn would provide more fodder for the cattle in terms of grasses and by products (Figure 2). The Kumaoni people have traditionally been experts in maintaining the forests from which they get their livelihood, with lopping and grass cutting done in a very planned and sustainable manner. In many patches of oak forests, rules prohibited lopping of leaves in the hot weather and the cutting of grass by each family was strictly regulated. The penalty for infringement of these rules included boycott and/or exclusion from the forest. Planting of timber trees was a fairly common phenomenon and the jungles were guarded by the nearby

villages as their entire livelihood depended on these forests. Many villages had fuel reserves on the common land, which were cut in regular rotation based on common consent. The villages exercised total control over the forest, with the native kings just asking for a small cess for the forest produce. Such high control over the forests by different villages could only be possible through collective cooperation between people within the village, and between villages as well, to manage the forest resources around them. For example, every village had fixed boundaries within which the villagers enjoyed rights of using the forest produce to meet their various needs, majorly fuel, manure and fodder. Sometimes even adjoining villages would share a common piece of forest and would protect them with great zeal. This distinctive agrarian structure was institutionalized through the village *panchayat*, or the elected village council, which played a very effective role in managing forest produce use[9]. This entire agro-system has been the back bone of the livelihood system of the middle Himalayan region in Kumaon for centuries. Thus, people here have respected the forests with devotion, with temples dedicated to certain tracts of forests. Religion, stories, songs, folklore talk deeply about the environment and this has over the years created fear (of the local devi, or the goddess) among the people to cut trees unnecessarily. Entire chunks of forests would be "given" to the gods so that people do not take anything from it. Even, today one can see temples with a good patch of oak trees around it. Informal management practices regulated the utilization of forest produce by the community.



FIGURE 2: TRADITIONAL HIMALAYAN AGRO-SYSTEM[10]

Both men and women performed complimentary and equal tasks associated with the household and subsistence production. The men were responsible for ploughing the fields or doing stone masonry work in the village. Some were blacksmiths and masons working for several villages. The women were responsible for household work, caring for the cattle, sowing and harvesting, and collecting fuel wood, broad based leaves for manure and fodder. But the patriarchal structure of the society still left men in charge of most household decisions. The construction of the day was based on supporting the family and maintaining health and village relations[11]. Kedar Singh, one of the senior employees at Avani says that even as early as during his father's time, the economy of the village was predominantly based on barter than on cash transactions. He says the sense of community feeling was strong, with households helping out each other in the fields and in household chores. Everything that was needed could be found locally, be it grain, vegetables, milk products, local masons (or *mistrys*) for construction etc. Every family had a patch of land and cattle, which is a sign of wealth. With no television, community entertainment such as gramophone recitals and plays (such as Ram Leela during the festival Dussera) were very common.

1.4.1 PROBLEMS WITH MODERN DAY AGRICULTURE IN UTTARAKHAND

Even today, in remote regions such as in Pithoragarh district in the middle Himalayas, the local economy is still predominantly agrarian, but does not bring in any economic returns. There are many reasons for this.

Agriculture was practiced on small and fragmented, terraced land holdings, making the yield from the land very low. As the size of the families also increased, the land holdings got divided between the different family members (usually the brothers) and the land holdings became even smaller. Additionally, different members of the family would be allocated pieces of land that would not be contiguous with each other and would be very scattered in nature. As a result, irrigating these different patches of land became a difficult task for a farmer as there would be no continuous channel for water to flow from one land to the other without irrigating the neighbouring land, which would not be belonging to the farmer. Moreover, the middle Himalayan region of Kumaon is water stressed, with the situation being worsened by the monoculture of pine forests encouraged by the forest department. Locals say that the lands on which pine trees are found to grow are generally drier than lands that have oak trees on them. Consequently, irrigation here is not developed much and agriculture is mostly dependent on rainfall.

The traditional joint family structure is now being replaced by a more nuclear one. Different members of the family use to share different responsibilities in the fields, but now with the families becoming smaller, there are fewer people to lend their hands in the fields, making farming a non-lucrative and laborious task to pursue. The families now are hardly able to produce enough to meet their own food grain needs for the entire year[12]. Even if the joint families are not divided, increase in population has put greater pressure on the same patch of land to produce more.

Thus, with relatively small land holdings (giving lower productivity and hence lower economic returns), water scarcity, complicated irrigation procedures and fewer people in the family to help in the fields, agriculture is no longer a preferred livelihood option as far as income generation is concerned. Even if an excess harvest is produced, there are no proper channels or markets where the farmers can sell their crops. The sight of empty step farms has become quite common, with the families leaving the village to pursue a life in the city.

1.4.2 POOR INFRASTRUCTURAL FACILITIES

Due to the remoteness of the region and the difficult terrain, the mountainous parts of the Kumaon region suffer from a severe lack of infrastructural facilities. The poor quality of roads and public transport, insufficient medical facilities, dearth of good quality schools and colleges, erratic electricity supply, low water availability and the absence of markets and marketing facilities is adding to the woes of the people in the region and is pushing them towards urban centres in the plains. Most essential commodities such as vegetables, cooking gas, grocery items are imported from the plains and there is very little that is locally produced and sold in the markets. The hotels and industries in the region have to get most of their supplies from the Haldwani, a town in the plains or from Delhi. According to the District Magistrate of Almora, earlier everything that was needed was available in the villages. He says that nothing is available locally now and everything has to be imported from the plains. The disconnectivity of the region has prompted people to move out. The disconnectivity also makes it harder for the people to get back to the mountains.

Education facilities in the mountains are also lacking as compared to avenues available in urban centers in the plains of the country. The children, who cannot afford expensive private schools with school buses, have to travel long distances, sometimes a daily walk of two hours, in the tough mountain terrain.

Moreover the staff at Avani says that the quality of education in the mountainous part of the state is generally poor. During visits to schools in the area, a severe lack of good teachers and teaching infrastructure was felt.

Good medical facilities are concentrated in bigger towns such as Almora or Haldwani, and for complicated medical procedures and emergencies, one has to travel 3-4 hours to reach a big hospital. This would also often involve a trek from the village till the road head.

1.4.3 WIDENING OF GENDER ROLES AND THE BEGINNING OF OUTMIGRATION

New systems of labour established by local rulers and followed by the British colonists brought significant changes to peoples' lifestyles in the region. The Gorkha rulers from Nepal (1790-1815), introduced the concept of forced unpaid labour or *begar*, and in order to escape this, men would migrate to towns and cities of the plains. This started the trend of migration of men in Kumaon. The British took advantage of the existing patriarchal system by recruiting only men into the army and at the same time continuing the practice of *begar*. Thus, with extensive male outmigration, it became the sole responsibility of the woman to manage the household and the fields in the village, while the men would work either in the army or in low paying jobs in the bigger towns [13]. This initiated a division of gender roles with the woman only responsible for the fields and household work, whereas the men should be doing more "manly" jobs such as joining the army, police, or leaving the village to work in cities. Agriculture was no longer considered a job meant for men.

In modern day Kumaon, with the widening of gender roles, the men do not see agriculture and other traditional livelihoods as a career option. Alongside these practical difficulties is the notion among the youth (particularly the men) that traditional forms of livelihood options are archaic and are not respectable professions to pursue. Agriculture, dairy farming, animal husbandry, traditional textile work etc. are looked down upon as careers. The feeling is that such traditional occupations are meant for someone who is not educated enough and one would lose respect within the village community circle. Indeed such ideas are encouraged by the families and village elders themselves, who want to see their children work in a company with a stable salaried job. Due to poor industrial development in the mountainous regions of the Kumaon Himalayas, there are few employment options other than traditional occupations, which the youth look down upon. They see no other options in the village other than to work as a daily wage labour or as a taxi driver. As a result, they have no other option but to migrate to urban areas in the plains or urban areas in the mountains in search for alternate options. There is a sense of pride associated with having a salaried job in the city.

Santoshi, an employee at Avani says that all the boys want to leave the village and become 'Sahabs' (or masters) in the city and they think they will only get respect if they do so. The boys do not associate with the village life much and people here in general do not appreciate the value of staying in the village with their families and working. Ambika, who runs a homestay in Kumoan says that people will end up doing labour work in the cities of the plains, because no one knows them there and they have no social status to maintain. However, the men will be very apprehensive in doing labour work in their very own villages.

1.5 LIVELIHOOD CRISIS IN MODERN DAY KUMAON

Agriculture is the still the main livelihood opportunity in the Kumaon region. However, it has lost its credibility as a job to pursue for income generation for a variety of reasons mentioned in the previous sections. With few other opportunities for employment in the region other than labour work (privately or for government schemes such MNREGA) or driving public taxis, most men do not see any value in staying in their villages and working (Appendix 2 lists the major outmigration reasons). The high aspirations of people are not being met with adequate income and employment generation activities in the area. As a result, the region is witnessing large scale outmigration. Some staff at Avani, like Kedar Singh lament that a village typically had 20 families at a time, but now they are mostly empty. Such is the extent of migration that there are no traditional skilled masons left and migrant masons from other states such as Bihar are earning a good livelihood out of it. In fact, they are earning so well that they are able to send their children to good schools in their home states. Appendix 3 shows different household employment options in rural and urban Uttarakhand.

Most young men aim to join the army, which has been the trend since colonial times. Those families that manage to get their boys into the army do well economically and have considerably improved their standard of living. On retirement, these men get a pension, and they return to Kumaon to live with their families, often to build new houses near urban centres. Migration of the man of the house has in fact been beneficial to these families. Those who are graduates and post graduates, tend to get government or teaching jobs locally. However, a large number of the men migrating are not very educated (high school graduates in the best cases) and hence if they are not able to get army jobs, they end up doing low paying jobs in cities such as a daily wage labour, mechanic, clerical job, working as cook/waiter in a hotel or restaurant etc. It has been found that the money that they remit from these jobs is not high enough, and migration has in fact proven financially unfeasible for them. Appendix 2 gives details regarding remittances for different jobs taken up by migrants. Moreover, there are stories that that these men are not very happy away from their families in the villages and with the conditions of work being miserable most often than not, they long to return to their villages. In fact there are many songs in the Kumaoni language that talk about the yearning of these migrants to return home. Employees at Avani believe that such people can earn a similar income by staying in the village itself. In fact, then they will be able to save more as a family, doing local labour work as the expenses in the village are very few. Moreover, they also get to be with their families.



FIGURE 3: DIFFERENT JOBS TAKEN UP BY KUMAONI MEN ON MIGRATION[12]

Most of the migrants belong to higher castes such Rajputs and then followed by Brahmins[12]. Very few migrants belong to the socially "weaker" scheduled castes, as their economic conditions do not allow them to generate the finances needed for migrating. Poor financial condition is also the reason for their

poor educational status, and migration may not guarantee a job for them in the urban area. These people usually end up doing labour work in the local area either privately or through government schemes such as the National Rural Employment Guarantee Act (MNREGA). Through field surveys it was found out that these people earn 2000-3000 Rs/month as labour for construction work in the village. Deepa, who lives in the village of Murari in Pithoragarh district, is an example that comes to mind. With her small land holding, she is only able to produce around 130 kg of rice in year. Her husband does labour work for MNREGA, with usually 5-10 days of work in a month and some months go by with no work at all.

Some of these young men and boys who go to the city to find work, and are unsuccessful, end up returning to the villages doing nothing. This is because they end up having half- baked skill sets. They neither know how to (or rather don't want to) practice agriculture/dairy farming, nor are they educated enough to earn money through other means. Hence one can see a lot of men (many of whom are young), wasting productive days of their lives either playing board games or, indulging in alcoholism, which is a major symptom of the mass unemployment in the region and a major cause of concern for many families in the region.

Subsistence agriculture, though, is still the backbone that supports the members of the families staying in the villages. The women of the house continue to be solely responsible for managing the house in the village that involves doing the household chores, working on the fields and going to the forests to procure firewood, fodder for the cattle in the form of grass, leaf litter to make manure etc. Additionally, going to the forest and working in the fields has become so much part of a woman's identity that it has become a test of a good wife/daughter- in- law within most families[13]. The women feel it is their duty to cultivate and go to the forests for its produce.

The remittances from the men in the cities are not high enough for most of the women to procure their daily needs from the markets. There is data also to show that a large number of females also migrate to the city, but this is mostly other than for employment reasons. The main reasons for migration of girls and women is marriage, following their family (husband, father or son) or for education. So young men or boys from the house usually migrate out from their village and remit money back to their families when they start earning. If they are well settled, they encourage their family to stay with them as well[12]. However, these families will always keep the land in the village as it is a sign of their roots.

Through interviews with the local people there, the *gram pradhans* (village heads) and the employees at Avani, it was found out that though the government scheme of employment provision through labour work (MNREGA) does help in providing income to the families, there are arguments that the program is counterproductive as it has made people lethargic. They can get easy and quick money for a few hours of work from the government. This has affected the local economy as people are not interested in doing persistent hard work, as would be required in agriculture, textile work and dairy production. According to the District Magistrate of Almora district, the Public Distribution System (PDS), that provides food grain to the poor at highly subsidized rates has also played role in taking people away from agriculture.

Thus, one can conclude that there is a major need for productive and sustained income and employment generation in the rural mountainous regions of Uttarakhand to reduce outmigration to urban parts of the country. Keeping in mind the terrain of the region, small scale market based solutions to farming related businesses should be encouraged to sustain agriculture and the interaction of people with the forests (organic farming would be the way to go forward). This will not only generate employment, but also might help in conserving the forests as these organic farms will be heavily dependent on them. Other options include cultivation of medicinal plants, which grow in plenty in the region, and their sale as raw materials for medicines. As the area is endowed with great natural surroundings, Tourism should be encouraged to generate income and employment in the region. Small scale industries can play a supportive role in providing employment to people in the region. However, they should not be promoted

at the cost of undermining the traditional way of life in the region (agro-forestry, dairy farming) and the forests, as both of these are a big part Kumaon's cultural identity.

The traditional ways of living with agro-forestry at the heart of it, gave Kumaon an identity. This way of life is getting destroyed really fast due to interaction with ways of life in the urban areas. The author's coworker at Avani, Girish Pant, passionately argues that with the destruction of traditional forms of livelihood, Uttarakhand is going through an identity crisis. These practices need to be given a modern and aspirational twist, and run in a market based model to generate income and employment and retain people who might see a future in these careers. The government needs to improve the education and health infrastructure massively to retain people in the mountains and enable them to make informed decisions on how they want to lead their lives. To encourage farm based businesses, land reforms need to be brought about and irrigation facilities need to be provided. One size fits all, centralized growth in the cities of the plains is not the answer to improve the lives of the people staying in rural areas such as Kumaon.

However, not everyone can be involved with farm and forest based businesses. Just like in other part of India, other avenues for employment also need to be created. If new industries are setup, they will automatically lead to economic and infrastructural development in the region. However, these businesses should be decentralized in nature owing to the dispersed nature of settlements here and poor transportation facilities to move between locations. Moreover, the setting up of these new businesses should not make people look down upon their traditional occupational heritage such as agriculture and other forest based livelihoods. Most men now will hesitate in getting back to any of these occupations. However, if they are given other opportunities for employment locally, they get a chance to stay at home, and this would lead to increased chances of them helping out other members of their family in, say, farming as well.

1.6 GENERAL OVERVIEW OF FUELS FOR COOKING IN UTTARAKHAND

This section gives an overview of the fuels used in Uttarakhand for cooking. Since cooking fuels can be a potential application for Torrified biomass pellets/briquettes, it is important to give a general overview of the fuels used for cooking in Uttarakhand before delving deep into it in chapter 2. Figure 4 shows the distribution of usage of primary cooking fuels in urban and rural areas of Uttarakhand. In rural parts of Uttarakhand, 77.1% of the households use firewood and wood chips for cooking, and 18.3% of the households use LPG for cooking. The LPG proportion is above the national average of 11.7% for households. The relatively higher percentage of population using LPG for cooking maybe due to the fact that Uttarakhand is not one of the poorest states in India, enabling people to afford LPG cylinders. Again, in urban areas of Uttarakhand, it can be seen that LPG is the preferred primary fuel choice and its percentage (69.7%) is again above the national average (57.2%) due to the same reasons.

Primary (Urban -	Cooking fuel Uttarakhand
Fuel	Urban
Charcoal	0.0%
Coke/Coal	0.0%
Dung cake	0.9%
Electricity	0.1%
Firewood & Chips	21.6%
Gobar Gas	0.7%
Kerosene	4.9%
LPG	69.7%
No cooking setup	2.0%
Other	0.0%

FIGURE 4: PRIMARY COOKING AND HEATING FUELS IN RURAL UTTARAKHAND (2004-05)[14]

Figure 5 shows the percentage of households adopting LPG over the years in rural and urban India. It is evident that adoption of LPG as a fuel is very rapid in urban areas due to increased affluence. In rural areas, lower income levels and access to free firewood does not make LPG a viable fuel for the people and hence there is a very mild reduction in firewood usage for cooking. However, most families in India aspire to have an LPG connection as it is quick and easy to use and burns cleanly. Additionally, it reduces the drudgery associated with collecting firewood or other biomass sources.



FIGURE 5: FUEL TRENDS IN RURAL AND URBAN INDIA

Figure 6 indicates that firewood is mostly free for households using it as a fuel for cooking and heating. For rural Uttarakhand, 9.80% of the households who use firewood pay for it. Additionally, only 8.4% of the households pay for firewood. As far as LPG is concerned, 99.7% of the households that use LPG pay for it and only 24.90% of the households use and pay for LPG.

Fuel	Avg Expenditure Per household (Rs.)	% of users who pay	% of households use and pay
Candle	10.79	98.30%	11.80%
Charcoal	37.52	85.00%	0.90%
Coal	83.55	100.00%	0.40%
Electricity	121.02	98.10%	64.70%
Firewood	200.82	9.80%	8.40%
Gobar Gas	209.51	6.30%	0.10%
LPG	201.01	99.70%	24.90%
Matches	7.45	99.50%	97.80%
Other Fuel	31.55	100.00%	0.70%
Cow Dung	69.12	19.60%	3.70%
Kerosene			
Others	44.31	98.10%	6.40%
Kerosene PDS	37.32	100.00%	85.10%

FIGURE 6: EXPENDITURE ON DIFFERENT FUELS IN RURAL UTTARAKHAND (2004-05)[14]

Figure 7 again underscores the fact firewood is mostly collected for free in the rural parts of Uttarakhand, and is the fuel used by households that cannot use LPG as a primary fuel for cooking.

Fuel	Only Purchase	Both Purchase & Home Grown Stock	Only Free Collection	Only Home Grown Stock	Other
Dung					
cake	18.70%	0.90%	15.20%	62.70%	3.00%
Firewood	9.30%	0.50%	80.80%	6.80%	3.00%

FIGURE 7: EXPENDITURE ON SOURCE WISE FIREWOOD COLLECTION

The answer to whether a Torrified fuel could be a substitute for firewood or LPG for cooking purposes in answered through a holistic assessment in the next chapter.

1.7 THE PROBLEM OF INDOOR AIR POLLUTION

Extensive use of biomass fuels for cooking and heating purposes is a major public health problem for underserved communities in rural and urban India. Burning of solid fuels causes indoor air pollution due to emission of harmful substances such as particulates, carbon monoxide, benzene and formaldehyde at levels which are up to 100 times higher than what is prescribed by WHO[15]. The most damaging pollutant in terms of combined effect of toxicity and quantity emitted during combustion of solid fuels is particulate matter, having statistically significant associations with morbidity and pre-mature mortality. The World Health Report, issued by the World Health Organization (WHO), estimates that indoor air pollution from household use of solid fuels is the 4th leading health risk with high mortality (WHO 2002)[16]. Worldwide exposure to smoke emissions from the household use of solid fuels is estimated to result in the death of 1.6 million deaths annually. Recent estimates suggest that the annual impact of solid fuel use by households in India is approximately 500,000 deaths and nearly 500 million cases of illnesses[16]. The health effects that have been linked to household fuel smoke in developing countries include acute upper and lower respiratory illnesses (which are the leading cause of child mortality under the age of five in India), chronic bronchitis, chronic obstructive pulmonary disease, asthma, cataracts (of which India has the highest incidence among women), and tuberculosis[16]. Majority of the cooking

activity in households in India is done by women and young girls, who put their health at risk by cooking on simple stoves that do not burn the biomass in a clean way. Burns from open fires and unsafe cookstoves are another risk. More than 500,000 women suffer moderate to severe burns every year in India, primarily due to unsafe cookstoves[15].

The health impact of indoor air pollution is exacerbated by burning solid fuels indoors in poorly ventilated conditions. This increases the risk of inhaling harmful smoke, gases and particulates. If the kitchen is indoors, it is usually separated from the rest of the house by a half wall, leading to smoke filling the entire house and impacting other members of the family as well. Women also like to keep their young children close to them while cooking, exposing them to harmful emissions and the risk of burns[15].

Figure 8, shows an all India estimate of the number of households burning biomass fuels indoors as compared to outdoors. The statistics are clearly skewed towards indoor



FIGURE 8: DISTRIBUTION OF HOUSEHOLDS USING BIOMASS FUELS TO COOK INDOORS VS OUTDOORS[15]

cooking, signifying the extent to which these populations are exposed to harmful emissions. During field visits to villages in Uttarakhand, one could typically see a separate construction made out of wood and straw outside the house, where the women of the house would cook. These are semi-enclosed structures, with a roof and side walls. These constructions were seen in relatively well- off families as well and they would be used only to cook on wood. There will, typically also be a separate kitchen area, inside the house, where cooking will be done using LPG. Such well to do families, also sometimes have wood burning *chulhas* or stoves together with the LPG cooking setup in one kitchen which is integrated with the house. Poorer families, who use only wood to cook, prefer to cook outside their homes when the weather allows them to do so (not very cold, not raining). Other times, they have to cook indoors. Thus, poor ventilation and the small size of the house increases the health risk associated with burning firewood indoors.

Thus, sale of a biomass based solid fuel, such as Torrified pellets to households should be accompanied by the sale of cookstoves that carry out cleaner combustion and the company should also look into providing services to improve the design of the kitchen for better ventilation, as per the tastes and preferences of the end user.



FIGURE 9: THE OUTDOOR KITCHEN AT DEEPA DI'S HOUSE

1.8 THE NEED TO LOOK BEYOND LPG

Liquefied Petroleum Gas (LPG) is a really good fuel for cooking. It scores better than all traditional biomass fuels on all health indicators pertaining to indoor air pollution. With LPG usage, there are not only significant reductions in emissions from biomass and coal burnt in open fires, but also lower emissions from improved biomass cookstoves. In a study carried out assessing LPG with fan stoves, chimney/rocket stoves, simple improved stoves and open fires, it was shown that LPG was the only fuel with whose emissions were below the critical level of $10\mu g/m^3[17]$. In addition to these health benefits, LPG offers fast cooking through very fast start up time and quick & easy control of the flame, thus providing greater convenience to the end user.

Majority of India still cooks on traditional biomass fuels, whose usage is associated with public health concerns over indoor air pollution. Thus, it has been the effort of government of India for over 30 years to provide a bottled fuel in the form of Liquefied Petroleum Gas (LPG) to be used for cooking in households and commercial units. India is heavily dependent on imports to acquire this fuel. As can be seen from Figure 10, which shows the production, imports and exports of crude oil and petroleum products, stagnant domestic crude production has led to increased import of crude oil by refineries. Such high dependence on imports for a fuel would place the country's energy security as risk, especially when a large proportion of the urban population is switching to LPG. The domestic LPG cylinders, which are intended for household use, are heavily subsidized by the government out of the



FIGURE 10: CRUDE OIL AND PETROLEUM PRODUCTS: PRODUCTION, IMPORTS AND EXPORTS[18]

desire to shield consumers, especially poor households from high and often volatile international fuel prices [18]. The difference between the Import Parity Price (911.5 Rs) and the regulated subsidized price (410.5 Rs) for the year 2012 is 501 Rs, showing the steep extent to which LPG is subsidized in India (Table 2). This subsidy, which has been rising as the years pass by to keep the price regulated for the consumers (Figure 11), is causing a greater current account deficit for the Indian Government [19].



(In rupees per liter)									
	Import Parity Price	Regulated Price	Difference	Percent of Regulated Price					
Kerosene	46.9	14.8	32.1	217.4					
.PG	911.5	410.5	501.0	122.1					
Diesel	57.0	47.2	9.8	20.9					
Gasoline	72.7	68.1	4.7	6.8					

Source: IMF staff estimates

FIGURE 11: EVOLUTION OF LPG PRICES AND SUBSIDIES[18]



The government, in its endeavour to provide clean cooking fuel to people in India and has been singularly promoting LPG as a cooking fuel, which is evident through the steep subsidy on the domestic LPG cylinder. This total lack of diversification in the cooking fuel mix of India can have serious consequences for energy security, especially when this fuel is being imported.

The LPG sale and distribution network in big cities in India is very good, with door to door delivery of domestic LPG cylinders. In remote rural areas, peri-urban towns and small cities, the access to an LPG connection is reasonably good, but with deficiencies in the last mile delivery of LPG cylinders in remote villages. For example, the small hill city of Almora in Uttarakhand has its own LPG warehouse, and the warehouse delivers domestic and commercial LPG cylinders to certain pockets in the city 2-3 times a month. People nearby have to go themselves to collect their cylinders from the drop off point, and haul the heavy cylinders to their homes. For remote villages in Uttarakhand, the delivery truck would leave from a warehouse in a bigger town (like Almora) and stop on the road head in a bigger village for people from smaller villages to collect their cylinders and haul the heavy cylinders back to their homes in the valleys. Other users, who are not able to go all the way to the drop off point, wait for the truck's return journey on the road close to their homes/commercial businesses. If the truck has enough cylinders left for sale, it will stop and those end users can have their LPG cylinders. These LPG cylinders are dispatched only once or twice a month (on fixed days) to these remote areas and it is often through word of mouth people get to know when the truck is going to pass close to their homes/establishments on the day it is supposed to arrive. Thus, there are last mile problems in LPG delivery to end users in remote rural areas due to logistical constraints imposed by the economic burden on the government and the top-down nature of the entire LPG distribution network. However, overall, the access of LPG connections to people in the villages is good. One can now have access to an LPG connection even in the remotest parts of the country.

The subsidy on the domestic LPG cylinder has other ramifications as well. Firstly, studies have shown that the subsidies have mostly benefitted people who are financially well to do and poorer sections of the population are not able to take due advantage of the subsidy policy. This is due to the fact that richer people tend to consume more LPG and hence benefit more from the subsidy. For LPG, 70% of the subsidy benefits accrue to the top two quintiles [18]. LPG is still very expensive for poorer sections of the society. For example, during field visits in the Kumaon region, it was interesting to observe that though most households in the village had an LPG connection, the women would still prefer to cook on firewood to save money. Typically, lunch would be cooked on LPG cylinders as the women are busy during the

day doing chores in the fields and the forest and one can cook faster using LPG. Otherwise, LPG is also used for preparing small items such a tea and other snacks, which again need to be prepared quickly. The poorest households can't afford LPG and rely on firewood for cooking. Thus, the subsidies encourage LPG use within the income group that is already able to afford it. As a result, the entire rationale behind providing an affordable clean fuel to ALL is undermined by the flaws in the subsidy policy of the government. Secondly, there is a clear bias shown by the government in promoting LPG as a fuel by subsidizing the domestic usage so heavily. This can have a significant impact on innovative projects trying to provide clean and renewable fuels to meet cooking energy needs. These projects lose out on cost competitiveness due to the heavy subsidy on domestic LPG. Completely liberalizing LPG prices will not only reduce the fiscal deficit of the government, it will encourage entrepreneurs to come up with innovative solutions to provide solutions to cooking energy needs in a competitive way, both for underserved communities and well off families.



FIGURE 12: A WOMAN CARRYING HER LPG CYLINDER FROM HER HOME IN THE VALLEY TO THE ROADHEAD

Different parts of the country have different socio-economic contexts and different energy needs. It is thus imperative that people are given a wider choice of fuels to choose from for cooking based on their needs and preferences and the promotion of one fuel with a one size fits all policy should be avoided.

Thus, LPG with its high import dependence and implications of a rising current account deficit, concerns over energy security, increasing subsidy burden on the government and poor last mile delivery of cylinders to households and commercial outlets in remote villages, raises questions over its long term sustainability for the entire country. Indeed LPG is a clean fuel and should be promoted in areas which have no other fuel options and have the potential for a strong sale and distribution network. At the same time, while LPG is being promoted and adopted, it is necessary to research other possible clean fuel sources and technologies (biomass pellets and stoves with cleaner combustion, biogas etc.) for areas with other potential cooking energy options and evaluate their suitability to provide clean and affordable means of cooking to a variety of end users. There is a need for a greater mix of cooking energy solutions that need to be made available in urban as well as rural areas for people to choose from. Small decentralized fuel production and distribution systems would be the way to go forward for remote rural areas with the logic of reducing the costs associated with the transportation of fuel and plug the last mile

gap in the supply of fuel to far flung villages. The extent of decentralization is a matter of research and depends on the socio-economic context and the infrastructure facilities (for example, a good road network) available in that region. However biomass based cookstoves (even biogas) should not remain in the realm of "Appropriate Technology" for the poor in urban and rural areas just because it is easy to sell it to them. The technology should be made so aspirational and easy to use that even middle and upper class households in cities consider using it.

1.9 THE NEED FOR MORE EFFICIENT BIOMASS FUEL UTILIZATION

As biomass is a readily available resource in rural parts of India, it makes sense to find sustainable ways of utilizing this biomass to meet various energy needs: for domestic/commercial cooking needs as well as for industries (combustion for boilers, gasification for electricity generation etc.). However, when compared to modern fossil fuels, raw biomass is a very poor quality fuel and systems and services need to be generated on the ground that upgrade the biomass to a commodity fuel. Biomass is a poor fuel compared to coal for the following reasons[20]:

1. **Low Bulk and Energy Density**: Raw biomass has low bulk density (kg/m³) compared to fossil fuels, making the biomass very voluminous in nature for a particular weight. This in turn makes the storage and transportation of raw biomass very expensive, thus reducing the portability of the fuel. A low calorific value of the biomass (MJ/kg) would also mandate the use of higher amounts of fuel in the process, thereby increasing the costs. High moisture content in the biomass also reduces the calorific value of the fuel.

2. **High Moisture Content**: High moisture content in raw biomass reduces the efficiency of the thermal conversion process. It also leads to the natural decomposition of raw biomass, resulting in degradation of the biomass and other storage issues such as off- gas emissions. High moisture content also leads to the uncertainty in the biomass's physical and chemical properties. High moisture content can also lead to inconsistent products in thermo-chemical processes and the formation of condensable tars which can block gas pipelines.

3. **Irregular biomass shapes**: This creates flow and heat transfer related problems during gasification and co-firing of biomass with fossil fuels.

4. **Poor grinding performance**: The process of grinding helps to achieve a constant particle size. However, the presence of moisture inhibits the process of grinding, making the process impractical for biomasses with high moisture content. High moisture content can also lead to inconsistent particle sizes (particularly when the particle sizes are less than 2mm), which may react inconsistently thereby decreasing the efficiency and increasing the cost of the thermal conversion process. Additionally, the milled powder produced might have sharp edges and splinters, which reduce feeding properties [21].

5. **High Oxygen content**: Raw biomasses have relatively high oxygen contents with respect to carbon and hydrogen, which does not add to the calorific value of the biomass, and thus contributes negatively to the same. The high oxygen content prompts the over oxidation of raw biomass during gasification, thus increasing the thermodynamic losses of the process [22]. This makes raw biomass less suitable for thermo-chemical conversion processes.

6. **Harmful emissions on combustion**: Combustion of raw biomass leads to the emission of certain acidic volatile compounds which can be harmful to health.

All these properties of raw biomass render it difficult to be used on a large scale. These impact the logistics (biomass collection and storage) and energy efficiency greatly. Hence any energy project that

aims to use biomass for energy generation using thermo-chemical means would require the fuel to be pretreated and upgraded, not only for better energy efficiency during thermal conversion, but also to increase the shelf life of the biomass (it should not decompose) and reduce the cost associated with transportation and storage of the biomass.

1.10 ENVIRONMENTAL CONSEQUENCES OF CONTROLLED FORESTRY

The coniferous forests of the middle Himalayas were in terms of extent and ready access the most commercially valuable in the country. Shortage of timber for the railways urged the colonial state to start taking control over these forests and use the wood of *chir* pine and *deodar* for commercial timber production. The *chir* pine was found to have other uses in terms of a resin extract (raw material in paints and varbishes) and the possibility of antiseptic treatment of its wood for railway sleepers[9]. The forest department constituted by the state started to exercise control over certain blocks of forests, which belonged to the communities living in those areas. Large tracts of forests were usurped by the state without any legal settlement of rights. Thus "scientific" and formal management of forests came into being in the forests of Uttarakhand in the form of silviculture, to selectively grow and protect those trees that maximized commercial timber production and revenue.

The monoculture of forests encouraged by the colonial and Indian governments has led to overwhelming tracts of *chir* pine reserves in the Kumaon region of Uttarakhand. It has become very rare to see the mixed forests that once existed in the region. Oak forests have diminished to a great extent due to the deliberate deforestation polices of the state towards other trees during colonial times and in the 60s and 70s. With the limited accessibility of pine forest for use by the locals, oak forests were under severe stress due to extensive utilization of forest produce. The villagers in some instances became apprehensive that the allotment of village forests (*van panchayat* forests) as a method of appeasement would be followed by the government taking over other wooded areas from their control, were in certain areas deforesting woodlands[9]. A large fraction of the village community also lost the zeal they had in protecting the forests as they now no longer had vested interests in them.

Today, the pine needles that fall on the forest floor from these monocultures during the three summer months of April, May and June, form a layer over the top soil and hinder the growth of other tree and plant species. This has significantly affected the bio-diversity of the region in terms of flora and fauna. However, one of the major consequences of these vast pine monocultures is forest fires. In fact these forest fires are mainly to due deliberate anthropogenic reasons. Traditionally, when these pine forests were smaller in number, villagers and grazers would set fire to the forest floors during the pine needles shedding season, to allow the fresh grass to grow as fodder during the monsoons. However, at that time there were other varieties of forests as well which had sufficient undergrowth. With the monoculture of *chir* pine trees, there are few areas left for cattle to graze, leaving no option for the grazers but to put fire to the pine needle bed. Moreover the pine needle covered forest bed is also very slippery for the cattle to stand on. In extreme cases putting fire to the forest is still an act of vandalism in the form of protest towards state control of the forests in remote parts of Uttarakhand such as Pithoragarh district. It is also believed that the forest department sets fire to the pine needles as a tool to reduce the severity of fire during the summer season. Accidental reasons include cigarette butts being thrown on the forest floors and burning of crop remains in the fields nearby.

In 1995, forest fires had destroyed 3.75 million hectares of forest wealth in Uttarakhand. Over 8.2% of the forests are affected by frequent fire and 44.25% by occasional fire. The burning of these forests is a source of methyl bromide, which is an ozone depleting substance. Other effects include danger to humans lives, flaura and fauna, and the excessive heat generated during the summer months[23].

For more details on the control of local forests by the state and its social consequences, refer to Appendix 4.

1.11 AVANI BIO-ENERGY AND THE RESOURCEFUL UTILIZATION OF PINE NEEDLE WASTE

Uttarakhand is home to more than 340,000 hectares of pine forests. It has been estimated the 823,000 tonnes and 80,000 tonnes of pine needles is available in just van panchayat and civil government forests. The reserve forests contain a staggering 343,000 hectares of pine forests, which produce about 2, 058,000 tonnes of dry pine needles annually[24]. Every hectare gives on an average 6 tonnes[25] of pine needles within the forests. This leaves a vast reserve of pine needles, which are harmful to the environment, to be used for productive purposes such as energy generation. If local people are employed in pine needles collection and its productive utilization, it can not only be a tremendous boost to the local income and employment situation, but would also help in mitigating forest fires which are harmful for the environment.

Avani Bio-energy has taken the step to set up local biomass gasification units to produce electricity and sell the power to the state grid. They have set up their first plant in the village of Chachret in the Pithoragarh district of Uttarakhand. This 120 kW gasifier, consumes 120 tonnes of as received pine needles annually. Due to pine needle collection and forest fire prevention, many other species of trees and plants have started to grow around the plant. Apart from electricity generation, the charcoal produced as a by-product of the gasification process is being pelletized to be sold as a cooking fuel in villages around the plant along with stoves designed for the same purpose. The plant employees 8 permanent workers together with women pine needles collectors from the villages and men hired as labour for pine needle collection.

This attempt proves that the vast amounts of pine needles can be utilized for productive energy generation. Apart from electricity generation, these pine needles, once given proper treatment, can be pelletized/briquetted and sold as a fuel to meet cooking and heating energy requirements in village households and commercial entities such as hotels, small eateries or *dhabas*, local industries, school and college canteens, dormitories and hostels etc.

However, since these pine needles are produced only in the summer months, any project which wishes to utilize them must think of innovative ways of storing them for the rest of the year. On visits to the Avani plant, the pine needles were found to be wet below the top surfaces of their piles as it rains very often. As a result of this moisture content, the pine needles start rotting very fast. Other bottlenecks include the transportation of these pine needles from the forest floor to the production plant. Pine needles have very low bulk density and as a result, transporting those using vehicles has proven to be expensive. This has been one of the reasons for failure of many briquetting projects in the past. Foot collection of pine needles by people themselves, mostly women, seems to be the way forward as this can bring collection costs down tremendously. However, the topography of the region makes the collection a tedious process and smarter solutions need to be thought of to make the collection process easier.

Thus, there is tremendous potential in the utilization of these pine needles. However, the failure of past projects creates a great scope for research of the applicability of modern biomass pre-treatment and handling processes to generate effective systems on the ground for the utilization of pine needles for energy generation.

It is worth noting though, that other than pine needles, there are no other biomass waste streams that can be utilized for energy generation. Agriculture is largely subsistence and hence there isn't enough agricultural residue produced after harvest.

1.12 BIOMASS TORREFACTION

The challenges in handling logistics of pine needles in the difficult topography of the Himalayas and the poor qualities exhibits by raw biomass as fuel strengthens the case for biomass pre-treatment and upgradation technologies in the upstream processing of biomass. Biomass Torrefaction is one such pretreatment process which upgrades the biomass to a commodity fuel and makes the properties of the biomass suitable to be used in energy applications such as combustion and gasification.

The Torrefaction process is targeted at producing a high quality fuel out of biomass waste streams, such as wood chips, rice husks, wheat straw or pine needles. This process enables the conversion of raw biomass into a fuel that resembles coal in many aspects, such as fuel density, moisture content, and grind-ability. Thus, the fuel produced from this process, called 'Bio-Coal', is more applicable in many thermochemical processes than unprocessed raw biomass. Also, this process is milder than charcoal production, which loses much energy from the biomass in the production process; this energy, on the other hand, is retained in Torrified fuels.

Torrefaction is defined as slow heating of biomass in an inert environment (in the absence of oxygen) and temperature range of 200-300°C. It is a partially controlled process of isothermal pyrolysis of biomass occurring in the temperature range of 200-300°C[20]. Essentially, Torrefaction is a light roasting process, similar to charcoal or bio-char production, but occurring at a lower temperature range. The amelioration of physical and chemical properties of raw biomass is in terms of increased bulk density, increased calorific value, low moisture content, increasing the hydrophobic nature of the biomass, reduction in energy needed for grinding and hence the possibility of achieving a uniform particle size, homogenization physico-chemical properties of different biomass and thus increasing the possibility of using different feed-stocks in a process. It also reduces the oxygen content of the fuel and removes certain acidic volatile compounds that can be released during combustion and be harmful to health[26]. Hence, Torrefaction brings an improvement to the negative qualities of raw biomass fuels mentioned in section 1.9 and makes it possible to have cheaper collection, storage and transportation of biomass and more efficient energy conversion. Since pine needles are generated only for 3 months in a year, it becomes imperative to pretreat them so that they have a high shelf life for the remaining of the year and not decompose.

Bio-coal obtained from Torrefaction of biomass can be used for a variety of applications. The product has potential to be a better substitute (in terms of energy density and biomass handling) for wood and charcoal/coal fuel based applications such as cook-stoves, brick kilns, pottery kilns, small scale industries that might require an alternate and cheaper fuel for heating, biomass based rural electrification projects etc. A lot of these applications might need solid fuels with different levels of carbonization depending on the combustion rate and temperatures needed, underscoring the need for Torrefaction and pyrolysis of biomass.

The traditional solid fuels used in rural India for cooking have been firewood, charcoal and cow dung cakes. Firewood and cow dung cakes, though easily available and cheap, are very crude fuels with poor combustion characteristics, leading to problems of air pollution both in the outdoors and inside homes. As an alternative fuel to be used in a cook-stove, Torrified pellets, which resemble lower grade coal offer multiple advantages [26], mostly:
- Higher energy density (19-24 MJ/kg) compared to raw biomass or cow dung cakes being used in rural parts of India. Thus, lesser biomass fuel would be required to meet he same energy need.
- The fuel has a long shelf life as it is hydrophobic and doesn't absorb moisture so easily.
- Cleaner fuel as compared to raw biomass or cow dung cakes as some of the acidic volatiles are released during the Torrefaction process. Therefore, these volatiles are not released in big quantities during combustion in cookstoves. Pine needles have a resin in them which on combustion would stick to the cooking vessels (as told by the locals). Torrefaction could devolatilize these resins and solve the problem.
- The fuel can be produced from locally available biomass in the form of agricultural waste, forest residue and raw biomass streams from agriculture based industries.
- Though producing charcoal is also an option, the fuel burns slowly as compared to raw biomass and Torrified pellets, and may suit only certain cooking styles (slow and continuous heating). A Torrified fuel on the other hand can burn faster and may be more suitable for fast and continuous cooking.
- The pine needles obtained are usually very wet and would involve drying them before grinding them and pelletizing. Drying is an energy intensive process, and thus it makes sense to expend little more energy on Torrefaction to improve the fuel quality.

The technology can be run as business by a local entrepreneur who produces the 'Bio-Coal' pellets/Briquettes and sells them to households for cook-stove use and to other rural industries /electrification projects. The product produced can also be exported out of the village area to other bigger urban centres to be used as a fuel for cooking by *dhabas* (local eateries), street food vendors, fuel for barbeques etc. The scale of the local business can be of the order of a few villages with carefully planned biomass collection and Torrified product distribution systems. The supply chain of the fuel to the end users, though, has to be excellent to beat the deep market penetration of LPG..

1.13 NOVELTY OF RESEARCH AND SCIENTIFIC RELEVANCE

On the **technical design** side, this project focuses on exploring Torrefaction as an option for fuel generation in developing countries. Over the past, much of the research for Torrefaction has been carried out for applications in the developed world, particularly for co-firing in large scale centralized power plants[26]. The Combustion, Gasification and Propulsion Laboratory at the Indian Institute of Science did design a multi-batch scale Torrefaction reactor for processing bamboo waste in Northeastern India, this being the only such initiative being published in literature[27]. The research carried out in this project aims to gauge the feasibility of Torrefaction in developing countries, particularly in resource constrained rural areas on applications other than large scale power plants, such as for use in domestic cooking and heating, commercial cooking and heating applications and small scale rural industries.

The design of the reactor would be very different from traditional designs existing in literature as the technology currently is designed to contexts in developed countries. The design of the reactor will be based on local manufacturing and maintenance capabilities and hence would essentially be a simple design as opposed to more sophisticated technology employed by Torrefaction companies till now such as screw conveyors, multiple hearth furnace, Torbed reactors, belt conveyors etc.[28]. In addition, there isn't significant literature available on the physico-chemical properties of pine needles as a fuel itself, such as calorific values, thermal degradation behavior (using Thermo-Gravimetric Analysis) and the mass and energy yields for Torrefaction. Through experiments at the Process and Energy faculty at TU Delft, under realistic rather than ideal modes of heat and mass transfer, more information on these properties of pine needles will be revealed for Torrified and non-Torrified pine needles.

Though there is a sufficient amount of R&D in the design of Torrefaction reactors by roughly 40-50 companies around the world[29] and a brief outline of the technology that they have used, limited information is available on the actual real time testing of prototypes. An attempt is made in this project to design and build prototypes in rural Uttarakhand and test their performance through Torrefaction experiments of locally procured pine needles.

On the **business design** aspects, most socially oriented projects have concentrated on the design of only products or service systems for underserved communities. Other attempts have focused on the environmental sustainability aspects of these products and service systems using tools such as Life Cycle Analysis (LCA)[30]. 'Conceptual Design' in chemical engineering, particularly in the field of product and process design, look not only at the technical design of the process but also on the optimization of the entire value chain starting from various upstream and downstream processes such as raw material collection, storage and transportation to the final end use of the product[31], [32]. Emphasis is also given on the operations optimization during manufacturing. However, these are mostly economical assessments of plant operations. This project on the other hand aims to design a holistic "business system "by taking into account socio-economic, cultural, environmental factors together with logistics design, business management structure design and the study of financial and political systems. Additionally, the design process adopted will be a very dynamic one with the technical and business design influencing each other. For example, the Mass Yields and calorific value of pine needles obtained through their lab testing will help in establishing the price of the fuel. This can further be used in calculating the economic value propositions to different end users.

Furthermore, there are vacancies in literature which talk about the process of holistic design for the technical and business aspects of a socio-entrepreneurial project. Most of the literature is on case studies of different social enterprises and their interventions and do not talk about the process of designing their intervention[33]–[35]. Other kinds of literature exist which theoretically describe the process of co-creation with underserved communities[33], [36] or methods to balance profits and social impact (i.e. creating an inclusive business)for the case of social enterprises[37]–[39] .Other literature talk about different institutional forms of social enterprises[40] or very theoretical assessments on various aspects of social enterprises such as management, economics, operations etc.[41]. This research aims to provide more insight on the design of an actual intervention for underserved communities by describing in detail the complete process of design adopted, both for the design of the technology as well as for the business model, with both influencing each other during the design phase.

Finally, in this age of a globalized economy, there is a significant amount of cross cultural interaction between people and businesses from different countries. Western companies working in the developing world have to take into account local culture and skill sets for effective management of their business. The process of co-creation will lead to the design of any technical or business system that merges the best cultural practices of both worlds. Moreover the exchange of knowledge between the different cultures is a tremendous learning experience for both groups. This project aims to design its technology and business system in a similar way, through a synthesis of technical know-how in the Netherlands and the Kumaon region of Uttarakhand. Similarly western business cultures will be assessed along with work culture in India and the best possible business structure will be chosen. Such projects will bring greater exposure to remote rural populations as well as people from other regions and cultures trying to run businesses with them.

1.14 CONCLUSIONS

Based on field research carried out in the region, the major needs that have been identified are:

- Productive and sustained income and employment generation in the rural mountainous regions of Uttarakhand to reduce outmigration to urban parts of the country. Keeping in mind the terrain of the region, small scale market based solutions to farming related businesses should be encouraged to sustain agriculture and the interaction of people with the forests (organic farming would be the way to go forward). This will not only generate employment, but also might help in conserving the forests as these organic farms will be heavily dependent on them. Other options include cultivation of medicinal plants, which grow in plenty in the region, and their sale as raw materials for medicines. Small scale industries can play a supportive role in providing employment to people in the region. However, they should not be promoted at the cost of undermining the traditional way of life in the region (agro-forestry, dairy farming) and the forests, as both of these are a big part Kumaon's cultural identity.
- Productive utilization of pine needles waste generated every year by using it as a fuel for energy generation. This will help in preventing forest fires that affect the bio-diversity of the region.
- Provision of an alternate fuel and cookstove system to people to meet their cooking and heating needs. Though wood is available in plenty in most areas and is free of cost, open burning of wood is a major health hazard in households. Thus, cleaner burning fuels and/or cookstoves need to be provided to minimize indoor air pollution.
- Provision of alternate fuel for other industries, where solid fuels can be utilized to meet thermal energy needs.

Biomass Torrefaction can play a role in upgrading pine needles to a higher quality fuels that can used for energy generation or producing pellets/briquettes to be used in cooking and heating applications. Besides, if a large scale business is set up, this pre-treatment technology has the potential to reduce the costs associated with logistics and thus the fuel can be stored for longer periods of time in warehouses and possibly reduce the costs associated with transportation of the fuel to end users. The commodity fuel thus produced will also be utilized more efficiently in thermo-chemical energy generation processes such as gasification and boiler systems.

At this stage the major needs of the area have been identified. The next chapter looks deep into whether a Torrified fuel can bring any value to the end users who have these needs.

CHAPTER 2: BUSINESS SYSTEM DESIGN

It was established in the previous chapter that the major needs of the area are meaningful income and employment generation and the protection of bio-diversity of the region through the utilization of pine needles. However, for any socially oriented business to be successful, it is very important to also understand the needs and preferences of the end users. The business will do well if the product or service it is trying to introduce brings any value to the end users. This value can be monetary or in terms of time savings, health benefits, environmental benefits, beneficial social interactions etc. and needs to be in congruence with the aspirations of the people. However, the value propositions to the end users should also be balanced by a good market proposition for the chosen end users, considering the fact that profits need to be made. This chapter delves deep into the value propositions that a solid biofuel would bring for a plethora of end users. Those end users that would benefit the most (based on a qualitative and quantitative assessment of factors) on using this biofuel will be selected as the initial market. This will be followed by the sizing of the market for the production of Torrified biofuel.

An assessment of different logistics schemes follow, that outline methods to collect raw biomass, deliver the final product to the market and methods to store raw biomass and the fuel prepared. This research not only takes into account economic factors, but also cultural factors and the preferences of the people who will be involved in the collection of the biomass. Other stakeholders are researched that can play a role in supporting the project, such as financing institutions and government institutions.

Important aspects of a new venture such as internal structure of a business, the internal operation and maintenance of the factory, cost and revenue streams and Life Cycle Analysis of the entire project is carried out by the colleague of the Author, Ryan Helmer.

The chapter concludes with the final outline of the service system and the business model canvas, which give an overall picture of the business and its main motivations and benefits to all stakeholders involved.

2.1 THE IMPORTANCE OF CO-CREATION IN DESIGN

A significant portion of the design process adopted in this research is based on principles of generative design described by the book 'Convivial Toolbox'[42]. This is essentially the process of co-creation, which is important, because as designers we are people from outside, our perspectives are limited and the end users themselves will have the best perspective on what will work and what won't. The people for whom the product or service is being created are made a part of the design process to arrive at a final product/service that best fits the needs of the consumers.

The authors argue that "people need only to obtain things, they need above all the freedom to make things among things they can live, to give shape to them according to their own tastes, and put them to use in caring for and about others". In this globalized world, there is a big need to combine the skill sets and knowledge of engineers and designers from outside with what the end users can offer.

Design styles are essentially characterized by two dimensions: participatory vs expert design and design led vs research led. The difference between participatory and expert design lies in how active or passive the end users are in the actual creation process. Generative design focuses on a participatory mindset, where the "user" is seen as partners or active co-creators.

The four basic principles of generative design are: All people are creative, All people have dreams, people will fill in what is unseen and unsaid based on their own experience and imagination, Ambiguity and incompleteness allow for people to fill in their own meaning. The author argues that there are different

levels of knowledge that an end user can express: Explicit (can be stated in words), Observable (thoughts and ideas that can be obtained by others watching you), Tacit (knowledge people carry but cannot verbally communicate) and Latent (thoughts and ideas that people haven't experienced yet but can form opinions on based on past experiences). The goal of generative design is to bring about tacit and latent knowledge. The very fact that people think best in terms of stories and not abstract concepts is utilized to make people express themselves better.

Annamiek van Boeijen in her research titled 'Crossing Cultural Chasms'[43] applies the method of generative design to developing countries, with a special emphasis on evaluating cultural values and norms in the larger context. The author adds an addendum to the generative design process by arguing the importance of cultural values in this increasingly globalized economy. For setting up a biomass Torrefaction business in the Kumaon region, it is very important to understand the local cultural context. Understanding how people view relationships, time and the environment around them will not only throw light on the best possible internal management structure of the business, but will also provide a lens to examine the value proposition of the product or service delivered from a cultural perspective. The book provides a general framework or tool to help engineers and designers understand how culture can be taken into account for the design of products and systems.

The author argues that cultural disparities between that of the designer and the end user can result in a product or service that is perceived by the end user differently than what the engineer/designer intended, the importance of culture is underscored when dealing with underserved communities in remote areas. In these projects, the cultural gap between the designer and the end user is usually large as these projects occur in regions which the designers are usually not familiar with.

The point is put forward that the notion of culture should be framed within the context of a design project. The theory of cultural anthropology can be applied to develop a generative design process to contribute to the creation of future products and services.

The book Riding on the Waves of Culture by Fons Trompenaars and Charles Hampden - Turner gives insights into how culture plays a major role in solving problems associated with day to day management of a business operating outside its region of cultural origin[44]. This theory can be of significant practical importance in the design of the internal work structure and management of a future Torrefaction business. However, it can also be applied to relationships with end users. Culture represents a shared set of meaning of values, i.e. shared assumptions between a group of people. Practically, culture becomes a shared set of methods for that region, to solve day to day problems. These problems present themselves in terms of relationships, the notion of time, and the view towards the environment and circumstances. Culture plays a big part in how people approach these issues and it is important for a foreign business from a different culture to have an understanding of the various layers of culture in the region for better internal business management and to ensure that the product or service that they are trying to introduce is perceived in the right way by the people in that region.

In *relationships between people*, the notions of *universalism vs particularism* are described. In a universalistic culture, what is good and right can always be defined and always applies. In particularism, attention is given to obligations of relationships and unique circumstances. Less attention is given to abstract social codes. The idea of *individualism vs collectivism* in cultures toggles with the questions such as: What is more valuable, the benefit of the individual or the benefit of the group as a whole? Do people work better individually or collectively? What defines a "group", do people identify more closely with one group than another[44]?

The question of *Neutral vs emotional* in relationships delves on to what extent people like to be objective and detached while working in the organization or dealing with customers. Or is the nature of business

conduction a human affair, with the expression of emotions having a stronger impact on making decisions and choices? The notion of *specific vs diffuse* can be understood in many ways: Do people relate to each other in very specific contexts, and that nature of relationships function only within that context? Or, do people relate to others in diffuse ways, so that those whom they know are connected with all aspects of their life? Are relationships allowed to function the same way in various contexts, or categories of life? For example, In America, a student would respect a professor within the classroom, but in a neutral location, such as the grocery store, the interaction might be more on a peer/friend level. In Germany, a doctor receives the same respect at the hospital, at the store, or anywhere. The concept of specific vs diffuse can also interpreted as whether people in the region generally like to focus at one work at a time, or is it common to handle multiple tasks simultaneously (such as it might by okay to pick up a phone during a meeting, or switch topics in the middle of a discussion). *Achieved vs ascribed* status in culture points to whether people accord more importance to someone based on what they have done or based on who are what they are[44].

The *attitudes of people towards time* can be seen in terms of *sequential vs synchronic*: Do people see time as a linear sequence of discrete events happening in succession? Is there a critical path to reach a defined goal in sequential steps? Or is time seen as something circular, so that cycles of time are constantly repeating? Is one task completed at a time or are people used to completing many activities in parallel?

The discussion of time can also be *past centric vs present centric*. Some cultures might find it more important to reflect on the past and maintain those traditions in the present. Others might want to move on, with different notions of modernity and aspirations and build their futures accordingly. How far do people think in the past and future is also falls under this category.

Lastly, there are other general questions associated with the notions of time in a society as to how important it is for people to be punctual and not lose time, and the importance of giving time to relationships.

The final important dimension discussed by Fons Trompenaars on how people like to engage with each other and solve day to day problems is their notions towards the *external environment and circumstances*. Some important questions in this category are:

- 1. Should man seek to control nature and impose their will on it or should man seek to be in harmony with nature and develop/industrialize accordingly?
- 2. To what extent are external factors held accountable for any happening to a person?

In the book Cultures and Organizations[45], other dimensions to culture are also mentioned. These include:

- 1. *Power Distance*: It expresses the degree to which less powerful people in society accept and expect that power is distributed unequally.
- 2. *Masculinity vs Femininity*: The masculinity side of this dimension represents a preference in society for achievement, heroism, assertiveness, and material reward for success. Its opposite, femininity, stands for a preference for cooperation, modesty, caring for the weak, and quality of life[43].
- 3. Uncertainty Avoidance
- 4. Indulgence vs Restraint

On a fundamental level, it is also important to understand that there can be many layers to culture. Hofstede's Onion model is a good depiction of this concept. The outermost layer of the onion,

information about a culture that is easy to perceive, are the symbols and heroes. These include behavior customs (good- bad, dirty – clean etc.), products and services, architecture, fashion, role models etc. What follows are the day to day rituals of people, which might take time and more interaction to perceive. The innermost part of the onion is what the people of a particular culture subconsciously value. These are not very tangible and people do not express them directly or tangibly[43], [45].

The above onion model can be applied to different categories of culture as mentioned by Hofstede: On a national level, on a regional/ethnic/religious/linguistic level, gender level, generation level, social class level, culture in different types of organizations people work in (corporate, government etc.) and cultural variations within organization depending on position of work, education level etc.[45].

Other ways of layering culture are in terms of human nature (inherited and universal), regional (learned), individual (based on personality and can be inherited or learned)[43], [45].

Overall, people can value different products and services in different ways, of which culture plays a small part. These are important to identify before introducing the product/service in the market. These are: utilitarian, symbolic, cultural, environmental, symbolic, cultural, environmental, economic, aesthetic, brand, historical, social, emotional, political[43].

The research methodology used for the business system design in this thesis tries to evaluate what people value and prefer, which may be explicit or tangible, or implicit and intangible (like cultural values). This is done through semi-formal interviews, product demonstrations, and "generative design sessions" (based on suggestions from Convivial Toolbox and Crossing Cultural Chasms) to find out the intangible or latent values. These exercises were done for people belonging to different genders, age groups, socio-economic classes, urban-rural upbringing and levels of education and training. The information gathered is then applied to the design of the internal business structure/culture (Ryan Helmer), operation and maintenance of the plant (Ryan Helmer), value proposition of the product/service to different end users (Vidyut Mohan) and the design of the logistics system (Vidyut Mohan).

2.2 RESEARCH METHODOLOGY

Research to understand the needs and preferences of the end users was carried out during the three month field visit to the Kumaon region in Uttarakhand, with a specific focus on the Pithoragarh and Almora districts. The various methods used to carry out the research were as follows:

2.2.1 INTERVIEWS

Field interviews were carried out not only with a wide variety of stakeholders who could be interested in participating in the fuel business, but also people who are deeply knowledgeable about the local context and needs of different possible end users. The list of people to interview was prepared based on recommendations provided by the staff at Avani and were carried out over a period of three months. The main category of people/institutions that were interviewed is shown in Table 3. Most interviews were semi-formal in nature with a pre-planned list of questions. Domestic end users were interviewed to find out their general socio-economic conditions which included understanding the pattern of their income flows, their major expenses, their savings, their current employment status etc. Specific information on fuel usage was also sought from them to get an idea of their expenditure on fuels for cooking and heating and the amount of time and effort they have to put in to procure them. Small business owners, who owned mostly commercial kitchens were asked similar general questions on their major expenses, their income flow pattern and about their savings. Other questions revolved around the nature of food items they prepare to assess the suitability of a Torrified fuel to be used as a cooking fuel by them. The third category of questions were based on the current fuel they use for cooking, the costs associated with them and the time and effort to procure them. Most of the interviews for the above two categories were very dynamic in nature as the questions asked sometimes deviated from the pre-planned list based on the information provided by the interviewee. It was tried as much as possible to establish a rapport with the end users before carrying out any serious interviews with them to get the most truthful answers. As far as possible, it was tried not to have the pre-planned list of questions on hand or have direct video/audio recordings during initial few visits to establish comfort levels with these end users. Due to the unpredictability associated with the visits to these remote rural villages (villagers would not show up on time, they would be busy and hence would leave in between to work in the fields) and the variability of responses given by people, repeated visits were made to the same, as well as different people of the same end user type. This gave more coherence to the information being collected. The help of employees from Avani was taken as they already had an established relationship from the people in the villages and some of the small business owners.

The visit to institutions and small industries were essentially one time with the focus to find out information on the costs associated with their current fuel use, the ease/difficulty in procuring the fuel and assess the feasibility of replacing the current technology for heating/cooking to accommodate new technology that would run on Torrified pellets/briquettes.

In order to get more information on the competition to a potential Torrified fuel business, fuel outlets such as LPG warehouses and government ration shops (shops that sell subsidized kerosene and essential commodities to people who hold a 'below poverty line' card) were visited, where information on the supply chain and overall numbers on sale of their products was procured. Meetings with managers at financial institutions provided information on loans and subsidies for establishment of small scale businesses in rural areas as well as financial support schemes for end users to purchase and use a biomass based cooking/heating system.

Domestic End Users	Institutions
Villagers	Schools
Peri- urban residents	University campus and its dormitory
Migrant workers	Military campus
Small Businesses	Small Industries
Small eating joint (dhabas) owners	Workers at Avani's gasification plant
Restaurant owners	Iron smiths
Hotel/resort owners	Biscuit factory
	Dairy Plant
Fuel Outlets	Financial Institutions
LPG warehouses	State Bank of India regional office, Almora
Kerosene/LPG ration shops	Uttarakhand Grameen Bank, Pithoragarh
Government Officials	Non- Governmental Organizations (NGOs) in Kumaon
Divisional Forest Officer (DFO) and Forest Ranger, Almora	Various managers and workers at Avani Kumaon, Tripuradevi
District Magistrate of Almora	Founders of Himalprakriti, Munsiyari
Van panchayat (village forest council) sarpanch (head) of Bhandari Village	Founder of Aarohi, Sitoli village
Gram Pradhan (village council head) of	Other social activists and people
Belada Agar Village	knowledgeable about the local context

Government officials and NGOs provided a plethora of information on the local context and the major socio-economic problems in the region. The possible support of the government in establishing a biomass fuel business was gauged through questions directed at the District Magistrate of Almora and the *Gram Pradhan* (village head) of Belada Agar village near Tripuradevi (our campus).



FIGURE 13: INTERVIEW WITH A DHABA OWNER IN ALMORA

2.2.2 GENERATIVE DESIGN SESSIONS AND CONTEXT MAPPING

For this project the authors employed methods developed and used in the Industrial Design Engineering Faculty at the TU Delft, suggested by researcher Jairo de Cost Junior from TU Delft. These methods are called generative design (or context mapping) and are outlined in the recently published book Convivial Toolbox and Crossing Cultural Chasms.

The general idea of this method is to use activities and discussions to gain insights into the values and preferences of a target group of people, usually potential users of a product or a system. These activities are typically hands- on, and help people to reflect on their daily lives and past experiences, and enable them to participate in the design of an ideal future situation. Overall, it helps in the expression of their values and preferences that they might otherwise have difficulty putting into words. The role of the "designer" is to facilitate the co-creation process and aiding the participants (end users and other important stakeholders) to express these values and preferences which they are not used to thinking about or expressing.

There are various types of activities that can be planned to understand the needs, preferences and cultural values of the participants. These are: Do Activities (where the researcher can observe the habits and tendencies of the participants actually doing a normal activity, such as watching how someone cooks), Say Activities (discussions or interviews related to the target topic), or Make Activities (where the participant is invited to create something related to the target topic). Participants are given a special set of materials or a "Toolkit", which is often built of basic school materials - paper, pencils, crayons, stickers, images, glue, etc. Images (photos, clip art, etc.) are also often part of the activities are documented to whatever extent possible, ideally using video/audio recording, photos, and the created artefacts themselves (whatever collages or created designs the participants generated). These artefacts are used after the sessions to analyze the information and draw conclusions and inferences regarding the preferences of the end user and their deeper values.

Thus, drawing on the resources of Convivial Toolbox and Crossing Cultural Chasms, three sequences of activities or, three "design sessions" were developed, for each of the following areas: Pine Needle Collection (logistics of biomass procurement), Daily Life and Domestic Cooking, and Local Business/Work Culture. However, the activities were kept as open ended as possible to complement the specific information on needs and preferences aimed from that activity with more general information on deeper cultural values of that set of participants. The artefacts collected were analyzed after several weeks and conclusions were drawn on the needs, preferences and cultural values of the participants. For the scope of this report, the activities on pine needle collection, daily life and domestic cooking are relevant to understand the needs, preferences and some cultural values pertaining to biomass collection logistics and end user value propositions for domestic cooking. Detailed cultural conclusions have been drawn by Ryan Helmer on his study of business culture from "Design Sessions" on Business/Work Culture Assessment and other sessions as well.

Business/Work Culture Assessment (results in the report of Ryan Helmer)

In order to understand peoples' preferences and values specific to work culture, the participants were made to do activities which were past centric, present centric and future centric. This train of thought would help them reflect on their past and present experiences at work, and thus enable them to reflect more deeply to design an ideal future situation. These activities were carried out at different points of time with 3 male employees (2 Avani employees and 1 school principal), 3 female employees (all three work at Avani) and rural women working at Avani's weaving center in the village of Chankana. These different sets of people were chosen based on gender differences and differences in levels of exposure/training.

"Current" Centric Activity

In this activity, the participants had to think about their relationship with some of their coworkers and other people whom they interact with on a daily basis. They had to think about their experiences (good or bad) in working and interacting with these people on a day to day basis. They had to express themselves on a sheet pf paper, by writing their names in the center of the sheet and the names of their coworkers/non-coworkers on other corners of the sheet. Under the names of these people, they were to write their experiences working and interacting with them in point form. They were given images depicting various human moods and emotions, just in case they were uncomfortable writing or needed something more to express themselves. While writing, they were asked to think on the following questions: Who is the person? How do they know them? How do they interact with them (what do they talk about, where do they do talk with them)? What is their relationship like with them? What do they like/dislike about their work attitudes? Are they the same gender and caste as them?

At the end of the activity, they were asked to discuss their depictions.

"Past" Centric Activity

In this activity, the participants had to think of 2-3 memories that they had about interacting with a supervisor, coworker, or a subordinate at work. They had to include both good memories (such as encouragement given, acknowledgement of hard work, etc.) and bad memories (a frustrating situation, and ignorant supervisor etc.). They had to think on the lines of the following questions: What happened? What did each person say? How did they treat each other? How did they feel during and after the interaction? These were discussed once they had thought about them.

Future Centric Activity

In this activity, the participants had to take part as a group and resolve imaginary scenarios/problems that one might encounter while working in a relatable business in Kumaon such as a sweet shop (for men) and a weaving center (for women). The activity was done to assess power distance, supervisor approachability, taking responsibility for one's actions, independence in decision making and interaction between genders.



FIGURE 14: BUSINESS STRUCTURE ACTIVITY WITH AVANI'S WEAVERS

Daily Life and Domestic Cooking

The activities under this theme were aimed at getting information on the day to day work schedule of rural women, together with their preferences for fuels and kitchen articles. Knowing the work schedule of women is very important to evaluate how pine needle collection can influence their daily work. Moreover, women tend to manage all the household work in the villages and this information can bring to light how working for the plant can benefit/harm their families.

Activity 1-Illustrative Timeline (conclusions given in the "practical considerations" section of pine <u>needles logistics</u>)

In this activity, the women had to make a timeline of the things they do as work, starting with waking up and ending with going to sleep. They could put down whatever activities they thought were important and illustrate them. They could write, draw or use the images provided. They had to make three timelines: For a normal day in January, May and August. In the end, they had to discuss their schedules by reading from their timelines. The months were chosen according to prior information on their seasons for wood collection (winter months) and crop harvest (May and August).

This activity was performed with a group of rural women from the village of Chankana.



FIGURE 15: DAILY LIFE ACTIVITY

Activity 2-Kitchen Design Game (conclusions given in the value proposition for domestic cooking)

In this activity, the women were divided into two teams, A and B. Each team had two members from Avani's weaving center in the village of Chankana. These participants were different from activity 1.

Each team had the task of designing the ideal dream kitchen. There was a "store" from which they could chose different items for the kitchen, such as stoves, utensils, utility items and decorative items. However, there was limit of 10,000 Rs imposed as the maximum they could spend on their kitchen. Imaginary prices were given to different items, with the cost of biomass based stoves slightly biased by making them cheaper. This was done to see if they would adopt a biomass based modern stove (Avani's charcoal stoves and biogas systems) purely based on economic reasons.

The teams were given a set of images representing the kitchen items, and they had to stick the chosen images on a large sheet of paper. At the end of the game, each team had to discuss the reasons why they chose their respective items.



FIGURE 16: KITCHEN DESIGN ACTIVITY

Pine Needle Collection (conclusions given in the section on Logistics)

These activities were aimed at understanding the current pine needle collection process and taking suggestions from the women on how the process can be improved.

<u>Activity 1- Map Making (conclusions given in the "practical considerations" section of pine needles</u> <u>logistics</u>)

In this activity, the pine needle collectors were required to give a description of the route that they take in the process of collecting the pine needles. They were given sheets of paper, on which they could write, draw or just stick the set of images provided. They had to essentially draw a map of their journey of collecting pine needles, starting from the village, through the forest, and ending at Avani's pine needle gasification plant.

This activity was performed with a group of women from the village of Chachret, a village where some of Avani's pine needle collectors stay. However, the women were not too comfortable with writing or drawing and thus gave a verbal account of their route.

Within the same activity, the women were also asked to describe some good (rewarding moments, fun experiences, etc.) and bad (frustrating moments, tiring moments, lonely moments, etc.) memories associated with pine needle collection. They were free to speak, act, draw or use images given to describe these memories.

Activity 2-Improving the Pine Needle Collection Process (conclusions given in the "practical considerations" section of pine needles logistics)

In this activity, the group of women was split into two teams.

One team had to design a tool or a device which would help in making the collection of pine needles easier. They were given an assortment of materials to build a small model. Alternatively, they could also draw or use the set of images showing some basic tools that could be used to build new tools.

The other team had to design a process to take the pine needles. They had to essentially think of: What is a better way of moving the pine needles? What and how many people will be needed in the process? How is this better than the current process? They were free to express their thoughts verbally or on paper, by either writing or using some of the images of possible useful collection tools provided.

These activities were conducted in the villages of Murari and Chachret on separate days, each with a different group of pine needle collectors. In Chachret, the women were very uncomfortable in writing, drawing or using any of the hardware material provided. Hence, here they verbally gave a description of their current problems in pine needle collection and how the process can be improved. In Murari too, the women were not too comfortable in making a model, but they did manage to make a collage in which they stuck images of tools that might help them in pine needle collection. They then verbally went on to describe ways in which the pine needle collection process can be improved.

The detailed instructions for these activities can be found in Appendix 5.

2.2.3 COOKSTOVE DEMONSTRATIONS

Avani Bioenergy has been trying to introduce cookstoves in villages that work on charcoal produced as a by-product through their pine needle gasification process. They hope to sell these cookstoves and fuel to pine needle collectors, who can buy them from the money they earn from pine needle collection.

Based on the assumption that people would view cooking on charcoal briquette based stoves in a similar way to cooking on a stove working on Torrified biomass, field demonstrations were carried out in villages, small restaurants (*dhabas*) and hotels/resorts. Household meals were cooked in Avani's small stove (1 time loading of 450 g of charcoal briquettes) in the villages of Murari and Chachret. Opinions of the families on the functioning of the fuel and stove in comparison to cooking on firewood were taken.

Cookstove demonstrations with Avani's big stove (1 time loading of 1400 g of charcoal briquettes) were carried out in 2 *dhabas* in the nearby town of Berinag. The morning meal in each of these *dhabas* was prepared and the owners were asked to comment on the fuel, the design of the stove and the suitability of the entire fuel-stove system to cook the different varieties of food items they prepare (some food items need slow and gradual heating and some food items needed fast heating, for example). A Similar demonstration was also carried out in a nearby resort and the opinion of the owner was taken on the applicability of the stove-fuel system for their kitchen.

The conclusions from the cookstove demonstrations are described in the value proposition for domestic end users and small businesses in the next section.

2.3 VALUE PROPOSITIONS TO DIFFERENT END USERS

In this section, all possible end users that could benefit from the Torrified pine needle fuel business are researched. Value propositions in terms of time and money savings, convenience, health benefits, social benefits on the adoption of Torrified fuel by the end user are assessed and based on this study a target market is recommended for the starting phase of the Torrefaction business.

2.3.1 DOMESTIC USERS

2.3.1.1 VILLAGE HOUSEHOLDS

Most families living in the villages use firewood for cooking. Majority of the households, other than the really poor, would also have an LPG connection. However, they would use LPG sparingly, by cooking most of their morning and evening meals on wood and save time and money by using LPG for cooking lunch, as the women are very busy during this time either working in the fields or with other household chores. They would also use LPG to prepare small items such as tea and for boiling water, as this is quick and does not use much of gas.

Current Forest Department Rules

Today, the role of the forest department is to manage and protect the forests, along with the sale of pine timber and resin through contractors. Economic interests dominate, as the sale of timber is a source of revenue generation for the forests. This is the reason, as discussed in chapter 1 that such vast tracts of monoculture of pine forests exist in the area. The upper administration is beginning to admit problems in the forest management system continuing from British times, but corruption is rampant and change is slow due to sluggish bureaucracy. The reserved forests come directly under the forest department.

On paper, no one is allowed to cut any tree in these reserved forests or is allowed to collect forest produce. Only 1 tree per person (for life) is allowed to be cut, mainly to be used for house repair work. However, there has been such a strong tradition of firewood collection, that there is a mutual understanding between the forest department and the villagers. Women are allowed to venture into the forest to collect forest produce such as firewood, leaf-litter and grass for the cattle. However, if caught by the forest guard, cutting down of entire pine trees (or any tree for that matter) involves a strict fine and confiscation of the cutting tools. People are also not allowed to carry out any sort of firewood collection from government land, which belongs to the revenue department (rather than the forest department), however collection happens anyway due to poor implementation of rules and the strong tradition of collection of forest produce.

On personal land, if the owner wishes to cut a tree, he/she has to take approval from the forest department. The forest department grants approval depending on the tree type and its distance from the reserve forest. However, the owner is free to carry out lopping from the tree on his/her land.

Village forests or *Van Panchayat* forests were given to placate the villagers. These forests were created to meet the fuel, fodder and manure needs of the village. No trees are allowed to be cut in these forests as well and women can only cut dried branches of trees or gather fallen down branches. These are managed by elected representatives (president, treasurer and guard) from the village, but are indirectly controlled by the forest department. The *van panchayat* forest has a guard who is paid every 6 months, to keep an eye on uncontrolled cutting of wood and grass. Each family pays 150 rupees every 6 months for the salary of the guard. Meetings are convened occasionally to assess the state of grass growth, leaf litter and wood availability. If any of these are found to be short, then collection of that resource is not allowed till it replenishes again. If there is a tree that has matured, has dried up, or has fallen down due to snowfall, the

village forest council convenes a meeting with the villagers and a mutual agreement is reached regarding distribution of wood. If there is a big occasion in the village (for example, a wedding) then the family has to take permission from the head of the *van panchayat* to cut a tree for it. However, only trees that have dried up or have fallen down are allowed to be cut. It costs roughly 1500 Rs to get a tree cut if labour is included. If other villagers help in cutting the tree, then they only have to bear the charge levied by the *van panchayat*, which is 30 Rs/ft of circumference.

Trees, thus, are not allowed to be cut anywhere: either in the reserve forests or in the village forests. The people themselves are quite conscious that they should not do so. Village forests have stricter patrol so it is very difficult for someone to slip by and cut a tree, but instances of illegal felling of trees is increasing in reserve forests due to poor patrol.

However, though the village forest system encourages sustainable use of forest produce, these forests are not big enough to meet the fuel, grass and leaf litter requirements of the villagers and thus most often than not people have to venture outside their village forests (reserve forests). This involves travelling greater distances (2-3 km) and investing more time (usually 2-3 hours/day, in the months they collect wood). Additionally, not all villages have a forest council and most people use the reserve forests for firewood collection. According to locals, most forest councils are modest to good at being affective; however, they are not big enough to meet the needs of the village.

Firewood Collection

Based on field surveys carried out in 5 villages, interviews with staff at Avani, village heads (*Gram Pradhan*), Village forest council (*Van Panchayat*) heads, forest department officials and other locals, it was found out that methods of firewood collection varied from village to village, depending on their accessibility to forests. There is no proper systemic arrangement through which people can get wood for cooking.

People in these areas have traditionally respected forests and have given them a religious significance. Thus, people are usually afraid of cutting trees. Wood is usually procured by lopping of tree branches by women in the winter months (Nov-Feb) and it is stored for the rest of the year. As far as possible, the women only cut dried branches or gather branches from the forest floor, i.e. lopping of branches that are still 'green' is avoided. The stock of wood is supplemented by occasional wood gathering during other months. There are other villages in which women go 3-4 times a week to collect firewood, travelling 2-3 hours in the process. This wood is mostly for free.

Villages having a forest council have to pay a modest fee for the forest guard as mentioned earlier. Moreover if a tree has to be cut down for a big occasion such as a wedding, the forest council charges a fee of 30 Rs/ft of circumference.

During the winter months a lot of pine trees fall down due to the weight of the snow on them and people manage to get a lot of wood for the next 1-2 years. If the village has a forest council and the tree has fallen within the village forest land, the village forest council organizes the distribution of this wood among interested villagers. The cutting of wood in this case is either done by the men of the house (with help from other friends), or 3-4 labour is employed by paying them 350-400 Rs for the day's cutting giving a total cost of roughly 1500 Rs. If such a tree falls in the reserve forest, people procure the tree on a first cum first serve basis and chop the wood.



FIGURE 17: FIREWOOD AND LEAF LITTER COLLECTION

Cutting of trees is illegal and not appreciated by the locals themselves. However, due to the shift in the nature of interaction of people with the forests, it is increasingly becoming common and people cut large pine trees (in reserve forests) from which they can get 500-600kg of wood/tree, lasting them 3-4 months. Typically labour is employed to get these trees cut, costing again 1500 Rs for a day's worth of cutting. This is easier to do in reserve forests because of lower chances of them being caught due to its larger size and also due to poor forest patrol.

Some villages that are nearer to urban centers do not have good access to forests. Though forests can be close by, they would belong to other villages where people don't allow outsiders to use their wood. In a village close to Avani's campus, people had to go 5-10 km to collect firewood. There are cases where majority of the families in these villages are really poor and cannot afford even subsidized domestic LPG. Buying wood is expensive, costing roughly 4000 Rs for each purchase, done 4 times a year. Wood for a day's worth of cooking can cost upto 50 Rs, which is very expensive for any household. Most people do not buy wood. Moreover, there are no shops in villages or by other villagers who manage to collect wood. These people have no other option but to use kerosene for cooking or travel long distances to collect firewood. The only other option either is to wait for trees to fall down due to snowfall/rain in reserve forests further away or cut trees illegally. People in these villages could be interested in using a Torrified pellets-cookstove system from cooking if it brings monetary benefits w.r.t subsidized domestic LPG and time and effort savings w.r.t procuring firewood (apart from monetary savings ofcourse). However, such villages are few, with most villages having good access to firewood.

With increasing population pressure and deforestation happening due to change in outlook towards the forests, wood might become scarce in the middle Himalayan region in the future. This is mainly due to the control of large tracts of forests by the forest department; the villagers have no longer a sense of ownership and responsibility towards them. Corruption, poor forest patrol is leading to further deforestation. Most villagers though, show a strong attachment towards their village forests (*van panchayat* forests) as it is part of their commons and their responsibility.

Liquefied Petroleum Gas

Based on visits made to LPG gas warehouses in the towns of Berinag and Almora, it was found that majority of the households in rural areas have subsidized Domestic LPG (14.8 kg cylinder) connections. However, people use LPG only sparingly and use predominantly wood for cooking to save costs. Only

the really poor use just wood for cooking. These families that have an LPG connection, will buy a new cylinder every 2-3 months, which is a long time as for a typical family, with a cylinder lasting only 20-30 days on continuous use. The cost of the domestic LPG cylinder currently was 686.50 Rs and it was subsidized by 235 Rs to 451.6 Rs. The managers of the warehouses mentioned that the prices of LPG fluctuate a lot, but are not really showing an increasing trend. The price paid by the consumer is more or less the same, as the subsidy is varied according to the market cost.

However, though LPG distribution exists even to the remotest parts, the supply chain is poor. There is no home delivery of these cylinders to households in villages. Trucks leave from the nearest urban centers (which are at most 70 km away) where the warehouses are located and halts for distribution at a maximum distance of 5 km from a village. This distance is considerable going by the weight of the cylinders. Families sometimes pay labour 300 Rs to haul the cylinder uphill or downhill to their homes. These trucks only visit the villages roughly once a month and hence people cannot have access to more cylinders if needed urgently. People sometimes have to go all the way to the LPG warehouse in the urban town to get their cylinders.

Thus, the last mile supply chain of LPG is very poor and inconvenience is caused to the end users in the villages. Moreover, the owner of the LPG cylinder also complained that right now they are going in losses due to shortage of supply of these cylinders from the plant in the plains (Haldwani). This points to some of the loopholes of the centralized nature of LPG distribution.

<u>Kerosene</u>

Visits to outlets selling kerosene revealed that people do not prefer to use kerosene for cooking due to the odour in the fuel. Hardly anyone uses kerosene for cooking in the villages due to easy access to almost free firewood. Usually the poor, living in villages close to urban areas that do not have easy access to firewood use kerosene. The number of these people is however small in this region. Kerosene is highly subsidized by the government and usually the poor, holding Below Poverty Line (BPL) cards, can claim the subsidy. The subsidized cost of Kerosene is 16 Rs/L and usage of subsidized kerosene upto 3L/month is allowed. In the peri-urban town of Berinag, there are 500 people every month that buy kerosene from the fuel outlet, but this is mostly for lighting lamps at home. With affordable solar lamps and greater electricity access, even kerosene lamps are fading away. With very limited amounts of subsidized kerosene being allowed to be purchased in a month, people buy kerosene from parallel markets in the area at 30 Rs/L.

Cookstove Demonstrations

Avani has designed cookstoves that run on charcoal that is produced as a by-product in the gasification process. These cookstoves were taken to the villages (where people use only wood for cooking and cannot afford subsidized domestic LPG) to give cooking demonstrations, wherein typical food items of the area were prepared. As the demonstrations were going on, the women were asked questions regarding their current methods of cooking and their opinions on the new stove. In the two demonstrations that were carried out in two separate villages, the women mentioned that the time spent in collecting firewood is significant and a lot of hard work. Moreover, they were well aware of the ill effects of cooking with continuous smoke production. They also mentioned of their vessels and walls becoming black due to soot production. They commented that they wouldn't have to keep aspirating the fuel by blowing into it if the used a better fuel and a stove. Since it rains so often, the wood becomes wet (the wood stack is usually kept outside the house) and becomes difficult to light. Looking at the minimal smoke and soot production in the charcoal stove, they immediately took a liking to it and were very enthusiastic to know of the price.



FIGURE 18: COOKING ON AVANI'S CHARCOAL BASED STOVES

Pricing of the fuel is a big factor which will determine their interest in purchasing the stove. There is no fixed monthly income for these families due to no employment opportunities. The only source of income is to provide labour service for local construction projects through a government scheme (MNREGA). The men of the house are able to earn 300 Rs/day through this work. However, usually they get work only for 5-10 days a month. Therefore, the monthly income can vary between 1500-3000 Rs/month, and on rare occasions can go up to 4000 Rs/month. Keeping the income of these households in mind, time savings, health and convenience were secondary to the price of the stove-fuel system for these people. If the entire system works significantly more expensive than their current methods of cooking, they would still prefer to continue with firewood cooking, even though it might involve more time and effort for wood collection. Since these were poorer households, they would not be able to afford the fuel, even if the stove was given for free. A biomass stove for these families will not bring about savings, and will rather be an economic burden. The money earned by these families is better used in other expenditures for food, education of their children etc. For such families, clean and efficient wood based stoves should be encouraged as the fuel is mostly free of cost. The capital cost of these stoves can be met through innovative financing mechanisms through regional rural banks.

Design Session Conclusions

The design session 'Kitchen Design Game' as described in section 2.2.2 revealed interesting conclusions:

- 1. Both teams invested in items that saved time, were practical, were of high utility and were healthy to use. Both teams were very price conscious and refrained from investing in expensive and flashy modern appliances (such as microwave ovens, electric cookstoves, electric toasters etc.) and other decorative items.
- 2. They saw smoke as something very unpleasant and undesirable.
- 3. However, they didn't seem to have a very negative image of the basic three stone stove used for firewood based cooking, indicating that it's usage is something very common and habitual in the region.
- 4. Both teams invested in gas stoves (one LPG and the other biogas) because it is fast and convenient to use and also does not produce smoke. One of the teams invested in a three stone stove as well to save on costs. This is how most rural households in Kumaon do their cooking. This is how most families create a balance between time savings, practicality, utility and health on one hand and expenditure on the other. If a biomass stove as a single system plugs the shortcomings of both, people might be interested in buying it.

5. The women were unfamiliar with a lot of kitchen appliances. One group bought 5 out of the 7 items they needed explanation for and the other bought 0 of the 7 items they were explained for. Thus, familiarity plays a subconscious role. Other parameters such as time, practicality and money play a stronger role in decision making.



FIGURE 19: ITEMS INVESTED BY TEAM B



FIGURE 20: ITEMS INVESTED BY TEAM A

All in all, a Torrified biomass based stove will have potential for a typical Kumaoni rural household if:

- 1. It is competitively cheap compared to LPG, burns cleanly, provides quick and convenient cooking, and is long lasting.
- 2. The company would have to familiarize the women with the product through demonstrations, training and customer support.

Value Proposition

Table 4 shows the expenditure incurred on the three main fuel options for a family of 3-4 people. All the costs associated with different schemes of wood collection and the use of other fuels is described in detail in Appendix 7. Appendix 6 gives the methodology employed to convert usage of one fuel to another.

The final case presented is that of a Torrified fuel, which is sold at 5 Rs/kg. This price is based on the selling price that Avani bio-energy is trying to achieve in order to make their fuel cheap enough for the poorest families in the villages to afford. Based on cookstove demonstrations in villages with these pine needle charcoal briquettes and Avani's charcoal stoves, it was found that a family typically would use around 3.5 kg of pine needle charcoal briquettes in a day to cook 3 meals (based on calculations in Appendix 5 and 6).

As far as costs are concerned, a Torrified fuel cannot compete with free firewood and subsidized domestic LPG.

For families that just use firewood, it is an additional economic burden. The women will always look at this criterion first before judging other parameters such as smoke production, reduction in drudgery, time savings, utility and durability(particularly in lower income groups as seen in cookstove demonstrations). Although, a doorstep supply of Torrified fuel will help women save time and reduce the drudgery associated with collecting firewood, but it will be difficult to equate time savings with savings in money through productive work in the saved time as there are not many options for regular income generating employment.

Fuel	Expenditure (Rs/year)
Wood 1	Nil
Wood 2	300
Wood 3	Nil or 2000
Wood 4	Nil or 2000
Wood 5	Nil or 6860
Wood 6: Wood +LPG	4809
Only LPG	5718
Kerosene	1296
Torrified Fuel @ 5 Rs/kg	4015 (Low estimate)
	17885 (High estimate)
VALUE PROPOSITION	POOR

TABLE 4: YEARLY EXPENDITURE ON THREE MAIN FUEL OPTIONS (FOR A TYPICAL FAMILY OF 3-4 PEOPLE)

TABLE 5: COLLECTION TIME ASSOCIATED WITH VARIOUS WOOD COLLECTION SCHEMES

Daily Wood Collection Time Costs 1 (hr/day)	Daily Wood Collection Time Cost 2 (hr/day)
(periodic firewood collection)	(firewood collection in winter months)
1.50	0.58

Women from economically better off families (that use wood and LPG) are able to give more importance to time, convenience, health and durability (based on results from design session). These families would continue to use LPG for cooking fast items (like tea, boiling water etc.) and lunch as it fulfills their needs better. Currently, though improved biomass cookstoves are not quick, clean and easy to use as compared to an LPG connection (better than traditional firewood stoves though), acquiring an LPG cylinder is an inconvenient process (which can be included in ease of use) due to its poor supply chain. If the price of the Torrified fuel system was cost competitive with LPG and a doorstep supply of fuel is ensured, a potential case for this group of women could be argued to replace cooking of major meals on LPG cylinders. There might be a case for replacing firewood for cooking for such families just on the basis of utility, convenience, health and ease of fuel acquisition (strong supply chain, doorstep delivery). However, it is difficult to go below the current price of 5 Rs/kg if the fuel is produced industrially, thus giving a poor price competitiveness.

Even in villages with most people living below the poverty line and having poor firewood access, the use of a Torrified fuel-cookstove system works out to be too expensive compared to wood, kerosene or LPG usage. Thus, other options need to be explored to meet the needs for an alternative fuel in these villages.

In some cases, going to the forest and working in the fields has become so much part of a woman's identity that it has become a test of a good wife/daughter- in- law within most families[13]. The women feel it is their responsibility to cultivate and go to the forests for its produce. Moreover, collecting firewood can be a very social activity for these women, where they get to meet each other and chat about issues in their villages and households. Thus, it is inaccurate to assume completely that wood collection is a very big burden on the women.

Discussion with staff at various NGOs also revealed that the adoption of improved cookstoves in households has been slow in the region and a lot of endeavors have failed. This seems to corroborate the value propositions mentioned in this report.

Discussions with environmentalists at the NGO Himalprakriti also led to the conclusion that firewood can be a sustainable fuel for the future in villages with dense forests around them. This will help in protecting the forests around as people still have a stake in them for their livelihood. Effort needs to be put in to maintain these forests better through better functioning of *van panchayats*. If modern wood burning stoves with cleaner combustion are provided to these families, this is the best option for people in remote villages and for people who cannot afford to LPG as their primary cooking fuel. Moreover these stoves use significantly lesser wood. Based on cookstove tests done by the organization Aarohi, the ARTI wood stove, reduces wood usage by half.

There is a political economy argument that "Appropriate Technology" is actually needed in urban areas, where energy consumption is much more as compared to rural areas, where the existence is more frugal in nature. Energy consumption patterns in urban areas are unsustainable, and interventions such as a Torrified fuel should focus on such locations. The poor in urban locations cannot afford even subsidized LPG and it can get very difficult to get firewood. There are people, usually the poor, who may not be registered citizens of the state and thus not eligible for any subsidies on fuels. This leads to thievery of wood and coal and many parallel industries thrive on this. There might be a case for an alternative biomass fuel that can fill this gap. Moreover, there is an ethical argument that biomass cookstove adoption should start from the rich in urban and rural areas, as the poor have as much right to use a very good fuel like LPG as the rich.

Thus, Torrified biomass pellets coupled with an improved cookstove do not provide much value to the domestic rural end user and thus should not be pursued as a business case. However, with increasing population pressure, controlled forestry and changing attitudes of people towards forests, wood might become hard to get in the future. If the price of the pellets falls to 2-3 Rs/kg due to scale of the business, then they can be a valuable fuel to the people who use only wood or a combination of wood and LPG for cooking as time savings, convenience and easy acquisition of fuel through doorstep delivery will play a stronger role. However, such a low price for an industrially produced fuel is very difficult to achieve. Additionally, according to the LPG warehouse owner, the demand for LPG is rising in the urban and rural areas of the state, after whose adoption people would not like to shift to a biomass pellet bases system. Thus, the Torrefaction company can have a long term vision as far as domestic cooking in rural households is concerned.

The assumptions and calculations of the above data are presented in Appendix 7.

2.3.1.1 OTHER PERI-URBAN/URBAN RESIDENTS (APPLICATION: ONLY COOKING EXAMINED)

Most households in peri-urban/urban areas in the hill regions of Uttarakhand predominantly use domestic subsidized LPG for cooking. Forests are generally farther away from these urban centers making free wood collection difficult. Additionally, since people here are employed in salaried jobs or are running businesses, they do not have the time to go and collect firewood. They can afford subsidized LPG due to higher incomes. Buying firewood from the market works out more expensive than LPG and hence most people do not buy wood. Additionally, there is no organized market for wood sale. Families that cannot afford to use LPG as their primary fuel, use other methods of wood collection described in Appendix 7 and highlighted in blue here. The poor use the method 'Wood 6' or use kerosene. Table 6 shows the costs associated with various fuel options for domestic use in urban/peri-urban areas.

Wood 1 (Rs/year)	Wood 2 (Rs/year)	Wood 3 (Rs/year)	Wood 4 (Rs/year)	Wood 5 (Rs/year)
8550	Nil or 6000	Nil or 1500	18250	8213
Wood 6 (Rs/year)	LPG consumption (Rs/year)	Kerosene Usage (Rs/year)	Torr. Fuel Usage (Rs/year)	
Mostly free, Nil	5418	1825	4015 (low estimate)	
			17885(hig	h estimate)
VALUE PROPOSITION	POOR (LPG) MEDIUM (WOOD)			

Common practices

Value Proposition

The details regarding the calculations and the assumptions made are shown in Appendix 8. Domestic subsidized LPG works out to be a cheap and convenient option for most middle income households. The supply chain of LPG in these areas, though better than villages, is still weak, with domestic as well as commercial users having to wait 10-15 days to receive the cylinder ordered. The cylinder is not delivered at home but at certain pick up points in the town, where people have to go themselves and get it. If people want LPG cylinders before this time, they have no other option but to buy it through third parties (usually domestic cylinders) at 200-300 Rs greater than the subsidized price or go to the warehouse themselves to get it. However, the supply chain is better than for households in the villages as the warehouses are located close by in the town itself. Thus people do not have to travel long distances in procuring LPG. The value proposition w.r.t LPG might increase if the supply chain of the fuel is excellent, with home delivery, but for this the cost of the fuel has to be at least comparable with that of LPG. Right now, with the range of costs of Torrified pellets shown, it is difficult to convincingly say that it will be cost competitive with LPG. Moreover, the convenience offered by LPG cooking is much greater. Thus the value proposition is poor for Torrified pellets.

For people who use wood for cooking, forests are not close by so wood is hard to get (that's why medium value proposition given w.r.t wood). It can be clearly be seen, that buying wood (Wood 4 and Wood 5) is a very expensive option for domestic use in urban areas. But people put in the effort and hard work to get cheap wood, diminishing the economic value proposition for a Torrified fuel. However, as firewood becomes harder and harder to get in the future (as told by many living in these urban areas), the value proposition to these end users will increase.

Value Proposition

There is group of migrant workers from other states of India such as Bihar living in Urban/Peri-urban hill towns. It was interesting to study their case as we were told that they do not have time to collect firewood and domestic LPG might be too expensive for them to use.

However, this community is doing well financially as compared to an average Kumaoni household as they are able to send 8000-9000 Rs/month as remittances. They are skilled masons, carpenters etc., and they are involved in construction projects in nearby areas. Interviews with them revealed that they stay in groups of 2, 3 and 4 and predominantly use LPG for cooking 3 meals a day, as domestic subsidized gas works out cheap for them. Not all of them are registered citizens of Uttarakhand to be eligible for subsidized LPG. So one person who is a registered citizen buys the gas connection and the subsidy is shared by everyone. Some groups, that do not have any registered citizen in their group could easily get an LPG cylinder sold by third parties (parallel markets) at cost that is 100-200 Rs more than the subsidized cost of the cylinder. These men generally cook three meals a day. Those who stay alone use kerosene for cooking and it costs them 30 Rs/L, which lasts 6 days. Table 7 shows the cost associated with using different fuel to meet the cooking needs of migrant workers. The LPG usage was translated to Torrified pellets usage using assumptions that are mentioned in Appendix 6. As these are estimated values, actual field trials need to be done (as were done with village households) to get more accurate estimates. On average one can gauge that there can be some savings on using a Torrified fuel. However, discussions with them revealed that they were willing to pay a slight additional cost for convenience (due to their busy schedule), but LPG stoves beat any biomass based stoves on that parameter. Additionally, it is difficult to say if modern domestic biomass stoves can be more convenient than kerosene stoves. Thus, the value proposition of a Torrified fuel to migrant workers living in peri urban areas is medium.

Kerosene (Rs/year)	LPG (Rs/year)	Torrefied Fuel (Rs/year)	
1825	2709	556.15 (low	
		estimate)	
		2668.89 (high	
		estimate)	
VALUE			
PROPOSITION	MEDIUM		

TARIE 7.	FIIFI	COSTS	FOR	MIGRANT	WORKERS
TADLE /:	LOFF	00313	LOV	MIGRANI	WORKERS

Appendix 9 gives details regarding the calculations performed for these end users.

Note: As far as heating is concerned people in the villages usually burn the same firewood meant for cooking. There have been instances where people make coal from oak trees themselves and use it for heating in a special coal oven (*sigri*). After cooking in kitchens outside, people bring the burning wood in *sigris* back inside the house to heat it. This is again mostly free, and there seems to be no strong business case for heating in such households. However, better wood furnaces can be provided for more efficient and clean combustion for heating purposes. Awareness needs to be spread in this regard. Electricity is widely available, and higher income households use electric heaters because they are clean, convenient to use and cheap for them.

2.3.2 SMALL BUSINESSES

Based on advice from staff at Avani, it was decided to explore commercial applications in urban areas in the mountains that might require a solid fuel for cooking purposes. This was based on the information that wood is difficult to get near urban areas, as was described in the case of domestic use in the previous section. Additionally, these commercial cooking businesses do not get LPG at subsidized costs and have to pay the full price for a commercial cylinder, which has been the reason for a lot of shops shutting down in the past. Also, as discussed before, the supply chain of LPG is weak. Thus it was felt, that a Torrified pellet-cookstove system might be attractive to such end users and thus the value proposition for them was analyzed. A selling price of 14 Rs/kg was used to evaluate the economic value proposition. However, discussed in the section of market estimation, the fuel will be sold at 15 Rs/kg to these commercial food businesses. The trends in value proposition do not change much by this 1 Re/kg shift in fuel price.

2.3.2.1 SMALL EATING JOINTS (SMALL DHABAS) - DO NOT USE COMMERCIAL LPG

Some eating joints are not able to afford to commercial LPG and hence they either use just kerosene for or wood for cooking.

Use Only Kerosene (Value Proposition-POOR)

These are very small shops that just sell tea and other small snacks. They usually require quick and fast cooking, which might be difficult with the nature of current biomass cookstove technology. Thus, a solid biomass fuel will not be suitable for such end users. Additionally, kerosene is highly subsidized and available at 16 Rs/L, with a cap of 3L of subsidized kerosene allowed per month. Unsubsidized kerosene in the parallel market is available at 30Rs/L. These shops usually buy kerosene at 30 Rs/L, which lasts 5-6 days. A Torrified fuel-cookstove system will not be able to compete economically.

Use Only Wood

These shops usually employ labour to cut wood for them and the shop owners go once a month to the forests to get wood. They typically use 20-30 Kg of wood in a day and spend 4500-5000 Rs/month on wood. They prepare full meals over long times, which suits the nature of current biomass cookstove technology. Additionally, they prepare the food for the entire day in the morning in one go.

A cookstove demonstration was carried out with the owner of the food outlet using Avani's charcoal stove. The entire meal for the day was prepared in the morning. During the demonstrations, questions were asked regarding their current fuel and what they would like to improve. In adoption of a new fuel-cookstove system, they would value the following apart from cost:

- 1. They want a reliable and regular supply of fuel. Doorstep delivery of fuel is a must as they do not like to spend extra time and money on procuring wood.
- 2. The owners do not like to use wood, as it takes time to cook. Wood combustion in their simple clay stove produces smoke, and they can't adjust the flame. As such they want cleaner combustion and convenient cooking. They liked the charcoal stove on this account and they wanted to buy the stoves from Avani if the stove and the fuel was cost competitive.
- 3. They feel a deep sense of responsibility towards the forest. If the stove-fuel system is affordable, they are willing to buy it just because it will protect the forests.



FIGURE 21: COOKSTOVE DEMONSTRATION AT A *DHABA* THAT USES ONLY WOOD FOR COOKING

TABLE 8: FUEL COSTS FOR EATERIES THAT USE ONLY WOOD

Fuel Used	Nature of Cooking	Problems With Current Fuel Usage	Current Cost (Rs/year)	Estimated Cost of Using Torr. Pellets- Cookstove System (Rs/year)	Benefits of Using Torr. Pellets- Cookstove System (Rs/year)
Wood	Full meals over long times	Have to pay for wood, inconvenience in wood procurement (time and effort), smoke, cannot adjust flame, takes time to cook	60000	85750 @ 14 Rs/kg 60000 @ 9.79 Rs/kg	Doorstep delivery of fuel, cleaner combustion, more control of flame, easy to light fuel, reduced cooking time, it will help protect forests
Suitability of Torrified pellets to Nature of Cooking			HIGH		
VALUE PROPOSITION		MED	IUM (Curro	ently)	

Value Proposition

Table 8 shows that a Torrified fuel sold at 14 Rs/kg does not bring about any economic savings for these end users. This is the selling price of the Torrified fuel based on financial calculations done for commercial food outlets in Kumaon. It is assumed that the stove is free and the company only charges for the fuel. Please refer Appendix 10 for details of the calculations done for this case. For the fuel to be cost competitive it needs to be sold at 9.79 Rs/kg or less. However, in all other aspects mentioned in Table 8, the Torrified pellet-cooktove system scores better: convenience, health, time savings, and protection of environment. Though, with the current reactor design it is very difficult to achieve fuel production costs at less than 10 Rs/kg, with improvement in reactor technology and scaling and diversification of the business, the costs can fall down and this will pose a better value proposition to these end users.

2.3.2.2 LARGER EATING JOINTS (LARGER *DHABAS*) - USE COMMERCIAL LPG ALONG WITH OTHER FUELS

These eating joints typically use commercial LPG cylinders as their primary fuel and supplement that with diesel fired stoves for slow and continuous heating of food items. The diesel is bought from the nearest gas station and it works out cheaper than commercial LPG to be used as secondary fuel. Additionally, most of these eating joints will have an oven called *Tandoor*, to make the Indian flat bread or *Rotis* that requires slow heating. The fuel used in these ovens is coal, which is obtained from nearby shops. Different eateries use different mixes of fuels and their expenditure on them varies depending on the scale of the business.

However, interviews with most of these businesses revealed that commercial LPG is really expensive for them to use. Many businesses have shut down because they could not afford the fuel costs. A commercial LPG cylinder is not subsidized and its cost varies between 1200-1800 Rs/cylinder depending on crude oil prices. Some of these businesses also have domestic LPG cylinders that they buy through parallel markets, 200-300 Rs greater than the subsidized price (around 800 Rs.). Some shops also complained of the weak and infrequent of LPG and the limitations imposed of using only 6 cylinders in a month by the local distributor.

A cookstove demonstration using Avani's charcoal based stove and other interviews gave the following conclusions:

- 1. Most shops do not face any inconvenience in using LPG for cooking. It is simple, flexible and easy to use.
- 2. However, cost of commercial LPG cylinders is too high for them to bear. Supply chain of LPG in the town is also poor. The truck reaches the delivery point only once in 15 days. There is no doorstep delivery. Moreover their frequency of LPG use is much higher than the distributor's delivery frequency. Thus, they have to go themselves to the warehouse to get the cylinders.
- 3. A biomass pellet fuel will be best used in combination with LPG. LPG can fulfill the need for quick batches of cooking (tea, fast food etc). A biomass pellet based stove can be used for long, fast and continuous cooking, such as for preparing full meals, sweets or snacks.
- 4. A quick and easy method of reloading the fuel should be provided as these shops are very busy catering to their customers.
- 5. The stove should be modern looking and aspirational in nature. The fuel sold should be branded and publicized well.
- 6. If the stove is to be used indoors for cooking, a chimney should also be provided to vent the gases and some amount of smoke that could be produced initially in starting the flame or during reloading of pellets. Moreover, some applications might require a charcoal fuel that produces

more CO as compared to raw biomass pellets/Torrified pellets/wood on combustion, further underscoring the need for a chimney.

7. If the Torrified pellet-cookstove system is cost competitive, protection of the forest from forest fires is a secondary reason why the people would want to buy the fuel. This shows that they are culturally very attached to the forests around them.

Fuel Type	Current Specific Consumption	Nature of cooking	Current Specific Costs	Curro (Rs	ent Costs s/year)	Torrij cooksto cost (Rs, R	fied fuel- ove system /year) @ 14 Ss/kg
Domestic LPG	6 cylinders/month	Full meals, fried snacks, sweets Nature of cooking : long duration	800 Rs/cyl	57600	=129600	35282 (low estima -te)	169666 (high estimate)
Commercial LPG	4 cylinders/month	continuous cooking, fast cooking in batches	1500 Rs/cyl	72000		Av 10	erage=)2474
Coal for Bread Oven	390 Kg/month	For making breads Nature of cooking: Slow and steady heat provisions	13 Rs/kg	12	21680		
Coal for Small Stove	390 Kg/month	For keeping food warm Nature of cooking: Slow and steady heat provision				A separa fuel ne supp compet	ate charcoal eeds to be lied at a titive price
Diesel + Appropriate Stove	2L/day	For keeping food warm Nature of cooking: Slow and continuous heating	57 Rs/L	3	5568		
Diesel +Appropriate Stove	0.5 L/h	For preparing sweets Nature of cooking: Fast and continuous heating	28.5 Rs/h		-	-	-
Value Proposition			GOO	D			

TABLE 9: FUEL COSTS FOR LARGER EATERIES USING DIFFERENT FUELS FOR DIFFERENT APPLICATIONS



FIGURE 22: A DIESEL STUFF PROVIDING SLOW AND CONTINUOUS HEAT TO KEEP FOOD WARM

Value Proposition

Table 9 shows the fuel expenses for a typical eatery in an urban area (based on interviews in Almora, Berinag and Pithoragarh).

Cost wise, a Torrified pellet system works out considerably cheaper than the commercial and domestic LPG usage for these eating joints. Most of these shops do not save much. One shop mentioned that out of revenue of 65000Rs/month 40000Rs is spent on their shop and home expenses and 25000 Rs is paid to their employees, thus saving none at all. On using these biomass cookstoves they get to save 2300 Rs/month. Moreover, if the fuel is delivered at the doorstep of these businesses, it will provide a better supply chain than LPG. The use of coal also suggests a business case for producing charcoal from pine needles. The current price for coal (13 Rs/kg) is close to the sales price of Torrified pellets (14 Rs/kg). Thus a possible charcoal fuel can be produced at similar or even lower costs, and it is worth looking into in the future. Moreover, the nature of heating adopted in diesel stoves, fast and continuous cooking, suit the combustion characteristics of Torrified pellets, which burn fast like raw biomass pellets. As future work, it will be interesting to note the economic value proposition for Torrified pellets against diesel for cooking, as one also has to go all the way to the gas station to get diesel. Thus, with Torrified pellets showing a strong economic advantage with LPG and the potential for replacing other fuels in these restaurants, this case presents a good value proposition. The benefit to the forests that the use of this fuel will bring will make the acceptance of the fuel easier.

Appendix 11 describes the cost calculations performed for these end users.

2.3.2.3 HOMESTAYS AND SMALL RESORTS (IN RURAL AREAS)

A visit to a nearby homestay brought to light the applicability of a Torrified fuel-pellet system for a variety of applications. For cooking, the homestay uses 2 commercial LPG cylinders in a month, purchased at 2000 Rs/cylinder. They also use two domestic cylinders a month. Since only 12 subsidized domestic cylinders are allowed in year, it was assumed that the other 12 domestic cylinders were bought from parallel markets at a higher cost of 800 Rs/cylinder. Heating is required predominantly to boil water and for space heating in rooms. The homestay has a cash flow of 3200000 Rs/year and operational expenses of 1200000 Rs/year, including salaries of employees. Tables 11 and 12 discuss the economic value proposition of a Torrified fuel system for cooking and heating. The calculations performed are in a similar manner to large eateries mentioned in Appendix 11.

Fuel	Primary Application	Fuel Usage	Cost (Rs/year)	Cost of Torrified Fuel-Stove System (Rs/year)	Value Proposition
Commercial LPG	2 hours of continuous cooking at scheduled times	2 cyl/month @ 2000 Rs/cyl.	48000	8356 (Low estimate) 39995 (High estimate)	GOOD
Domestic LPG	2 hours of continuous cooking at scheduled times	1 cyl/month @ 450 Rs/cyl. 1 cyl/month @800 Rs/cyl.	15000	6245.50(Low estimate) 29891 (High estimate)	GOOD
Firewood	Food prepared for staff in an open kitchen	-	Free	-	POOR

TABLE 10: COSTS ASSOCIATED WITH FUEL USE FOR COOKING AT A SMALL RESORT

TABLE 11: VALUE OF TORRIFIED FUEL FOR HEATING APPLICATIONS IN A SMALL RESORT

Source of Heating	Cost of Usage (Rs/year)	Possibility of Replacement with a Torrified Fuel System	Value Proposition
Solar Water Heaters	Free	NO	
Wood Boilers	Free	YES	
Electric geysers for	-	NO	
heating water in rooms			
Electric Heaters for	-	NO	POOR
space heating			
Future Idea- Indian	Free		
Fireplaces or		YES	
'Bukharis' in rooms			

Value Proposition

As the tables suggest, the biggest economic value proposition is the replacement of LPG usage with a Torrified fuel-cookstove system. The owner also mentioned that cooking gas is a big economic burden for them. As the form of cooking is continuous 2 hour sessions, this suits perfectly with the nature of operation of a biomass pellet cookstove. For short and quick cooking, such as for making tea, LPG is still recommended due to the flexibility it provides in usage.

It was found through calculations (Appendix 17) that the overall business case is not very sensitive to the cost of the stove, and hence a high end stove with good combustion characteristics should be provided to end users. Through cookstove demonstrations and cooking trials done with Avani's charcoal based stove, the owner opined that time taken for cooking and convenience is very important to them, so a cookstove technology would have to meet those needs. This is another reason why a high end stove needs to be used. The owner also mentioned of the poor supply chain of LPG in the area and the fact that they have to travel 25 km to the LPG warehouse to get their cylinders, thus increasing the value proposition if the fuel if doorstep delivery is provided. Again, one has to keep in mind that biomass pellet cookstoves will not be able to replace all LPG usage. It can replace LPG for only those heating styles that suit biomass cookstoves.

The resort also has bar-be-que facilities, where charcoal produced from pine needles will be useful. In the cooking applications which use firewood, a Torrified pellet-cookstove system loses out on cost as the wood is free and is available easily from the nearby forests.

As far as heating is concerned, the value proposition is low in cases of wood boilers and 'Bukharis', as they use wood which is mostly available for free. Solar water heating has essentially free operational costs and hence a biomass based boiler system will not be able to compete with it. Electric geysers and electric space heaters in guest rooms, which are used as the primary source of heating, are luxury appliances which provide quick and flexible room heating, which current biomass heating technologies will be unable to provide. Electricity is widely available and is cheap and based on simple back of the envelope calculations, the regular purchase of a pine needle pellet fuel at 14 Rs/kg will work out more expensive than electric geysers for water boiling (described in the following section).

2.3.2.4 BIG HOTELS AND RESORTS (IN URBAN AREAS)

TABLE 12: VALUE PROPOSITION FOR BIG RESORTS AND HOTELS

Value Proposition for Cooking	GOOD
Value Proposition for water and space heating	POOR

Big hotels and resorts in urban areas do not have access to free firewood. Hence they have to rely on other fuels to meet their cooking and heating needs. As far is cooking is concerned, these hotels predominantly use commercially LPG cylinders for cooking. The owners stated that convenience and ease of use is very important to them. Typically, these bigger hotels make 3-4 visits in a month in their own vehicles to the local LPG warehouse to procure LPG cylinders. The owners stated that LPG is a big expense and if another product which is easy and convenient to use can be supplied at a cheaper cost, they are more than willing to try it. Moreover, they say that the business supplying the biomass pellets would need to work professionally and have a good delivery service. Coal is also used as fuel in bread ovens called *Tandoors*. This coal is bought at 4-5 Rs/kg, but is transported all the way from the city in the plains 100 km away. Typically, it will cost 2000-2500 Rs/month for the transportation of coal. Calculations show that these charcoal briquettes can be cost competitive with coal brought from outside. If charcoal briquettes are

produced locally along with the Torrified pellets and sold at 14 Rs/kg, then with this improved supply chain, the value proposition for replacing coal is high.

The money savings on using a Torrified Fuel pellet-cookstove system is considerably high. If this is coupled with a good supply chain of Torrified pellets and an easy to use stove, the value proposition for cooking is good. Again, one has to keep in mind that biomass pellet cookstoves will not be able to replace all LPG usage. It can replace LPG for only those heating styles that suit biomass cookstoves, i.e. continuous cooking as compared to fast cooking in batches.

Heating and boiling of water is predominantly done using smaller electrical appliances, which are distributed per room. Although options do exist for centralized water boilers and heating systems that run on solid biomass fuels, the manufacturers recommend that such systems work out economical for hotels, hostels, hospitals, recreational clubs and guest houses that use diesel or gas boilers[46]. Thus, these electrical heating appliances are most cost effective as compared to even biomass pellet boiler system. A simple calculation showed that the cost to heat 30L of water (capacity of these geysers) by electric heaters used by these hotels is 5.5 times cheaper than cost of heating 30 L of water using biomass pellets on a pure energy basis.

Calculations for cost competitiveness for cooking and electric heating is given in Appendix 12.

2.3.3 SMALL INDUSTRIES

Small and medium scale industries in the area that might use solid fuels as a source for heating were also examined for their value proposition. The businesses considered were iron smiths, biscuit factories, Avani's biomass gasification plant and dairy processing plants.

2.3.3.1 IRON SMITHS

Iron smiths in this region are generally very poor and work in small shacks on the side of the streets. They sometimes pay for the fuel and sometimes don't. When they don't pay for the fuel, they spend 2-3 hours/day collecting pine tree bark, which they use as a fuel for their work. They use this fuel as it burns really fast and can give a lot of heat in a very short time. They burn the pine bark and blow a lot of air through it in a very crude system to make it burn fast, and then they start doing metal work on that flame. When they pay for the fuel, it costs them 35 Rs/day. They generally get an income of 200 Rs/day.

Fuel	Nature of Application	Cost (Rs/day)	Times invested in collecting fuel (hrs./day)	Applicability of Torrified/charcoal Fuel	Value Proposition
Pine Tree	Fast and hot			YES (Charcoal	POOR
Bark	heating	0 or 35	2-3	Briquettes)	

TABLE 13: FUEL USAGE ASSESSMENT OF IRON SMITHS

Value Proposition

Charcoal briquettes produced can be utilized for this application as traditionally blacksmiths have used coal/coke/charcoal for this purpose[47]. However, most of the times they get their fuels for free and support should be given to them in terms of better equipment to save time and produce more output, rather than selling a fuel which cannot bring any economic benefit.

2.3.3.2 BISCUIT FACTORIES/BAKERIES

There were two kinds of biscuit factories/bakeries interviewed. The first shop was a biscuit factory which used a diesel fired oven with electric control. The owner bought diesel from a gas station 5 km away at 51.9 Rs/L. The cost of the diesel oven was 500000 Rs. Due to frequent electricity outages, they have a diesel generator. However, the owner did not have clear estimates on how much diesel he used every day. Another bakery had an oven that was fired with commercial LPG as a fuel. Their production varies as per demand, but they use 10 LPG commercial cylinders/month. Based on biomass pellet fired oven of Abellon Bioenergy, the cost of using Torrified pellets as a fuel in comparison to the current system is illustrated in Table 15. These ovens are quite modern and are equipped with electronic control systems. For detailed calculations, please refer Appendix 13.

Oven Type	Fuel Cost (Rs/year)	Biomass Oven Usage Cost (Rs./year), including capital cost	Applicability of Torrified fuel	Value Proposition
LPG Fired	180000	136234.38	YES	MEDIUM
Diesel Fired	Owner did not	-	-	-
	know/did not give			

TABLE 14: COST OF FUEL USAGE IN BAKERIES

Note: Since this is a cooking based enterprise the price of Torrified pellets was kept at 14 Rs/kg.

Value Proposition

A biomass fired oven offers very good economic advantage and hence there is a business case here against ovens which are fired with commercial LPG. However, the shop owners themselves are not very clear how much fuel they use and they gave a very rough estimate. Additionally, there is not much data available in literature comparing biomass oven usage with ovens working on other fuels to arrive at the right oven capacity for these shops. Additionally, there are very few suppliers of such ovens in India with limited variations oven capacities to match the needs of different consumers Hence proper field trials with actual biomass ovens need to be conducted to arrive at a conclusion. The temperature in the ovens should be 180-230°C. Additionally, the oven should have provisions to produce in batches and not continuously. This is because most facilities here are small scale and produce in small batches.

2.3.3.3 AVANI BIOENERGY PINE NEEDLE GASIFICATION PLANT

Value Proposition

The most natural application of biomass that is Torrified is in power generation processes such as cofiring in furnace-boiler systems and gasification plants. This is because, Torrified biomass exhibits properties very similar to that of coal and hence can be easily adapted to pre-existing power generation equipment. The gasification plant at Avani Bioenergy presents a good application for a Torrefaction business to pursue because the plant is having severe problems with the pine needles being wet and condensing tars downstream (various blowers, gas engine sometimes) in the plant leading to high maintenance costs and downtimes. Torrefaction can help solve these problems and produce a commodity fuel that will make the plant run more efficiently. The 120 kW rated gasifier generates electricity, which it sells to the grid at 4.89 Rs/kWh. The market proposition of the gasifier for a Torrefaction business is currently low, as the company is still experimenting with the gasifier and is not producing power efficiently to be profitable. The plant would need to essentially run 24 hours a day, for 300 working days in a year close to its rated power of 120 kW to generate a profit (as planned by Avani). Currently the plant is only able to run 48 hours in a week, with an average power rating of 45 kW and is working under a loss as shown in Table 16. The current maintenance costs of the plant are at 7% of the capital costs. The plant currently buys fuel at 1 Re/kg from the pine needle collectors. Since the market and application is different from commercial cooking (different business model), the fuel will be sold at a different price. There might not even be a need to briquette or pelletize the pine needles.

The value proposition for the gasification plant in using Torrified pine needles is due to:

- 1. No loss of pine needles due to rotting
- 2. Reduced downtimes of the plant with less maintenance following reduced tar condensation. Additionally, with lower moisture content in the pine needles, the gasifier will operate more efficiently.
- 3. Achieving power output close to rated power due to the use of a better Torrified fuel.

If with the help of a Torrified product, the plant is able to run even at 90 kW for 24 hours with a reduced maintenance cost of 4% of capital costs, then the business is profitable even if the Torrified biomass is sold at a higher price of 1.9 Rs/kg, making it a suitable partner for a Torrefaction business. If the plant is able to run at higher rates powers, the Torrified biomass can be sold at higher rates to the gasification plant based on its improvement in performance by using a Torrified fuel. The business case for the Torrefaction project might be good once the company is profitable, as it even plans to establish 20 more such plants in the future. However, this is highly speculative in nature. As of now, the company is still experimenting and can be thought of as a long term partner. Table 17 gives potential profits on using a Torrified fuel for gasification, run at 90 kW at 24 hours a day and 200 days in a year, with pine needles sold at 1.5 Rs/kg. The savings mentioned is the difference in profits shown in Table 16 and 17.

It should also be noted that having gasification as an application for Torrified fuel will also enable the use of electricity /waste flue gas generated by the power plant for the Torrefaction process. This would make the Torrefaction independent from the unreliable electricity grid (As described in Chapter 3, the final design of the Torrefaction reactor built in India would run on electricity from the grid based on comparisons with other heating options).

Appendix 14 also gives the cost calculation for this end user and a brief description of possible service systems discussed for a Torrefaction-electricity generation business that can be detailed in the future.

Profit (Rs/year)	Profit (Rs/hr)
-1076680	-449

TABLE 15: CURRENT PROFITS FROM THE 120 KW GASIFIER WITHOUT USING TORRIFIED BIOMASS

Profit (Rs/year)	Profit (Rs/hr.)	Savings (Rs/year)	Applicability of Torrified Pine Needles	Future Value Proposition
				GOOD but
464720	54.55	1541430	GOOD	SPECULATIVE

TABLE 16: POTENTIAL PROFITS FROM THE 120 KW GASIFIER WITH USING TORRIFIED BIOMASS

2.3.3.4 DAIRY PROCESSING PLANTS

A visit to the dairy processing plant of Aanchal dairy for Almora and Bageshwar districts revealed interesting insights. The processing plant produces steam which is used as a heat source to pasteurize milk, make butter and clarified butter (*ghee*). They also burn diesel in large stoves to make two different kinds of sweets (*Rabri and Bal Mithai*). To produce steam, they have two boilers. One boiler runs on pine needle briquettes which they import from a city which is 100 km away in the plains. The other boiler runs on diesel, which they have kept on standby. They buy the briquettes at 6-7 Rs/kg. They import the briquettes all the way in a truck which costs them an additional 1 Re/kg. Thus effectively they pay 7-8 Rs/kg for the fuel. They order the fuel in bulk, and they manage to get 10 tons in 1 load. They use to use 'steam coal' earlier which use to cost them an additional 40,000Rs/month.

TABLE 17: COSTS	ASSOCIATED	WITH FUEL	USAGE IN	DAIRY PLANTS

Fuel	Application	Applicability of Torrified Fuel	Current Cost (Rs/day)	Cost with Locally Produced Torrified fuel Briquettes (Rs/day)	Value Proposition To end user
Pine Needle Briquettes	Boiler	YES (But in briquette form, not pellets)	4800	4200 @ 7 Rs/kg	GOOD but SPECULATIVE
Diesel	Stand by boiler, stoves to make sweets	YES	-	-	GOOD but SPECULATIVE



FIGURE 23: THE PINE NEEDLE BRIQUETTE FED BOILER AT AANCHAL DAIRY

Value Proposition

Since the market and application is different from commercial cooking (different business model and possibly a different reactor/plant), the fuel should not be sold at 14 Rs/kg. A different price has to be evaluated for this application and it definitely needs to needs to be sold at 7 - 8 Rs/kg.

As Table 18 suggests the value proposition of locally produced pine briquettes will bring about good savings to these dairy plants on a daily basis if the extra 1 Re/kg on transportation of the fuel is saved. The owners of the dairy business believe that if the pine needle briquettes are produced locally, they will save money and time. Moreover, the plant operators believe the temperature control in the boilers has become much easier with the use of pine needle briquettes as compared to using 'steam coal'. Moreover, with the use of a Torrified fuel it is possible that the boiler will work more efficiently, possibly reducing fuel consumption as well. This might enable the fuel to be sold at higher prices as well.

It is important to remember that the fuel needs to be provided as briquettes and not pellets.

For calculations performed in Table, refer Appendix 15.

The current boiler uses 600 kg/day of pine needle briquettes. Additionally, there are 10 other such plants in other districts of Uttarakhand. This application thus provides a good business case for the sale of pine briquettes by the Torrefaction company.

Note: It was also mentioned that there are dyeing industries nearby that use coal currently, and would benefit if a solid bio-fuel was supplied at a lower cost.
2.3.4 INSTITUTIONS

Other institutions such as schools, university campuses and military campuses in the area were visited to gauge the need for a Torrified fuel for these end users.

2.3.4.1 GOVERNMENT SCHOOLS (MID-DAY MEAL SCHEMES, MDM)

The Mid-day meal scheme was started by the government of India to provide free lunch to students in all government schools from standard 1-8. The government provides 5.35 Rs/student/day to be spent on fuel, vegetables, pulses and cooking oil. 10% of this amount (0.535 Rs/student/day) is meant to be spent on fuels for cooking. Government schools in this region either use domestic LPG or firewood for cooking, or supplement firewood cooking with domestic LPG. Two schools were visited, where one school used only LPG for cooking and the other school used only firewood for cooking.

Fuel	Amount used	Main problems in usage	Cost (1month= 26 days)	Cost of using Torrified pellet- cookstove system	Benefits of using pine needle pellets- cookstove system for MDM over present fuel usage	Benefits of using present fuel for cooking over pine needle pellets- cookstove system
Domestic LPG	3 cyl./month	Poor supply chain of LPG, infrequent supply of LPG	1800 Rs/month	6125 Rs/month @5 Rs/kg	-Independence from centralized gas distribution-better supply chain -Good example of sustainability for students	Clean combustion, Convenience/ ease of use
Firewood	30 Kg/day	Chopping of wood daily for 10 minutes	910 Rs/month	2730 Rs/month @ 5 Rs/kg	-No chopping of wood in the morning -Cleaner combustion -As money is involved in procurement of wood, there might actually be felling of trees to meet the demand	Firewood easily available, villagers supply and sell.
Applicability of Torrified pellets	YES					
Value Proposition	POOR-MEDIUM					

TABLE 18: VALUE PROPOSITION TO MID- DAY MEALS AT GOVERNMENT SCHOOLS

Value Proposition

Table 19 discusses the value proposition for a Torrified fuel-cookstove system to be used for government schools. For the schools that use domestic LPG for cooking, at present they pay around 600 Rs/domestic cylinder due to the fact that the government has not allotted them bank accounts yet for the subsidy to be transferred. This is going to happen soon, and using domestic LPG will be even cheaper. The LPG supply chain, though, is poor and people have to wait hours on the road for the delivery truck to pass by as it is heading or returning from its delivery point lying within a distance of 5 km. Moreover the truck delivers only once or twice a month and if people need fuel before that, they would have to go all the way till the warehouse which is 5-70 km away, depending on the remoteness of the school. In other areas where firewood is easily available, the schools ask villagers to collect firewood and bring it to them 2-3 times a month. The firewood is not free and is bought from the villagers. In order for the pine needle pellet-cookstove system to fall within 0.535 Rs/student/day, the fuel has to be sold at less than 1.5 Rs/kg, which can be a selling price difficult to achieve for an industrially produced fuel for non-commercial applications. The selling price assumed here, 5 Rs/kg, is somewhat more realistic (but still very difficult to achieve) price of sale for non-commercial end users. This is the same price that Avani is trying to achieve for its charcoal briquette program.

For calculations, refer Appendix 16.



FIGURE 24: KITCHEN OF A SCHOOL FOR MID-DAY MEALS

2.3.4.2 MILITARY CAMPUSES

The campus of the Defence Research and Development Organization was visited in the town of Pithoragarh. The permanent staff that stay here have their own homes where they either use subsidized domestic LPG or electric cooking systems. It is very difficult to make a case for the use of a Torrified pellet-cookstove system here as people can afford domestic LPG and electric cooking, which are the most convenient and clean methods for cooking. Again, as calculations have previously shown, domestic LPG usage works out more economical than a Torrified pellet-cookstove system. The research scholars have their own kitchens with similar facilities provided. There is a small canteen which caters to 7-10 people in a day and provides only tea and lunch. Such a canteen, which use a commercial LPG cylinder for cooking would benefit economically from the use of Torrified cookstove-pellet system. However, the value propositions to the owners of the operators of these canteens is low as they are paid a salary by the institution itself and are not dependent on the savings they might get on using a cheaper (but less convenient) fuel-stove system.

There is a big military campus nearby which has a few canteens for the soldiers, with heavy usage of commercial LPG cylinders. However, the authors could not get the opportunity to interact with anyone inside.

Moreover, both these campuses get their LPG cylinders delivered by the gas agencies at their doorstep every 15 days, and thus there is no gap in the supply chain as well.

2.3.4.3 SCHOOL AND UNIVERSITY DORMITORIES

Value Proposition

Table 20 describes the value proposition of using a Torrified fuel system to meet cooking and heating needs in school and university dormitories. Unlike in commercial restaurants where the owners expressed a big need for a cheaper fuel in comparison to commercial LPG, here they did not do so. However, they do use commercial LPG cylinders which are expensive and non-subsidized domestic cylinders which they procure from parallel markets. They usually pay 1000 Rs per domestic cylinder as compared to the subsidized price of 450 Rs. Moreover, the need for these domestic cylinders by the gas company (for urgent requirements, the owners just go to the market and they get domestic cylinders with relative ease from third parties). Thus, good supply chain by the Torrefaction company and economic advantages do present a good value proposition. They may not be potential lead users in the business, but show can adopt this cooking system once the word spreads about the Torrified fuel and the stove.

Additionally, institutions should not be encouraged to use firewood for cooking and heating applications, because unlike in the villages, the wood procured by them is not under the control of the *van panchayats* and will lead to deforestation in the area. Thus these organizations should be encouraged to use alternatives such as solid bio-fuels.

Application	Fuel/Energy Source Used	Benefit of current system over Torrified fuel system	Benefit of a Torrified fuel system over current system	Value Proposition
	 Commercial LPG cylinders non-subsidized domestic cylinders bought from parallel markets 	 Convenience/ease of use Cleaner combustion 	 Cost advantage/savings Better supply chain of fuel 	GOOD , though users didn't express a major need to shift from gas
Cooking	Firewood	• Free/cheap (as in the case of government schools)	 No need to find and cut wood. Convenience/ease of use/easy lighting of fuel (do not have to deal with wet firewood too) Fuel delivered at doorstep Cleaner combustion Protection of forests 	 MEDIUM Cannot compete with free/cheap firewood Long term prospects as wood becomes harder and harder to get in large quantities due to deforestation

TABLE 19: VALUE PROPOSITION TO SCHOOL AND UNIVERSITY DORMITORIES

				MEDIUM-HIGH
Space heating	 No system in place Students not allowed to use electric heaters due to heavy electricity bills 	-	 Heating for students in a 5 month long winter No use of electricity if small 'Bukharis' or Traditional Indian fireplaces with chimneys are used (Torrified pine needle briquettes need to be used) 	 Big need for heating expressed by students. Cost estimations need to be prepared and economic value propositions to hostel owners and the students need to be assessed. Suitable and safe methods of space heating using solid biomass fuels need to be
				researched.
Water heating	 No system in place No immersion coils or electric boilers allowed 	-	 Water heating for students in 5 month long winter No use of electricity if Torrified pellet fired stoves are used to boil water. 	 MEDIUM-HIGH Big need for water heating expressed by students Cost comparisons with solar water heating need to be made
	Firewood	• Free/cheap (as in the case of government schools)	 No need to find and cut wood. Convenience/ease of use/easy lighting of fuel (do not have to deal with wet firewood too) Fuel delivered at doorstep Protection of forests 	 MEDIUM Cannot compete with free/cheap firewood Smaller business case as requirement is only in winter

2.4 MARKET ESTIMATION

Based on the value propositions carried out for various end users in the previous section, it is clear small businesses that depend on commercial LPG and coal for cooking seem to gain the most from using a solid biomass based fuel. They not only stand to gain from an economic point of view, but also in terms of its easy access. Figure 25 describes the market setup and the end users that receive the largest benefit from the use of the solid biomass fuel have been clubbed under 'starting market'. These end users have also been included in the starting market due to their relatively large market size. 'Possible future markets' includes some end users who show a high need for an alternative but using a Torrified pine needle fuel may not bring any value proposition at this point of time or the value propositions are a bit speculative in nature at the moment. Other end users mentioned in this section also expressed an alternative to meet their cooking/heating needs; however, their value propositions could not be thoroughly researched due to limited information given by the interviewees (for example, biscuit factories/bakeries) or due to limited time available to get more information on their energy use during field work(for example dyeing industry). Space and water heating in school and university dormitories is another area where a high need was expressed, but a thorough study needs to be conducted on various technologies that use solid fuels to meet those needs and compare them with other alternatives.

STARTING MARKET

Replacement of commercial LPG and coal usage in :

-Kitchens in small eateries (dhabas)

-Kitchens in hotels/restaurants

-Kitchens in resorts/homestays in rural areas

-Kitchens in schools (nongovernment), univesity campuses and their dormitories

POSSIBLE FUTURE MARKETS

In decreasing value propositions:

-Dairy Processing Plants

-Gasification Plant

-Replacement of wood in small *dhabas* that use wood for cooking

-Replacement of wood for domestic cooking in peri-urban/urban households

-Domestic cooking in villages with poor wood access and Low LPG affordibility

High need but value propositions need to be assessed in more detail (outside scope of this research):

-Dyeing Industry

-Biscuit Factories/bakeries

-Space and water heating in school and university dormitories

DIFFICULT MARKETS

In decreasing value propositions:

-Domestic cooking in villages to replace wood and LPG use

-Domestic cooking in periurban/urban households to replace LPG use

-Fuel for space and water heating in hotels/resorts

FIGURE 25: MARKET STRATEGY

'Difficult market' includes end users for whom the value proposition is poor at the moment and will remain so in the near future.

Thus, the final initial starting market was focused to cooking in small eateries (*dhabas*) and hotels/restaurants with the competitive market being commercial LPG, domestic LPG used by these businesses bought from parallel markets (at higher costs) and coal use. Since there is a high concentration of these businesses in urban/peri-urban areas, it was decided to focus on the hill town of Almora, also the capital of Almora district.

Based on interviews with the owners of these businesses, the market size is presented in Table 21. Since the business has to start out small, it was decided that the company will try to work for 5% penetration of the market by the end of 1st year of its operation. Each *dhaba* will be given 1 stove meant for continuous cooking along with regular supply of Torrified pellets. They would also be given charcoal briquettes to be used in their oven or *Tandoor*. Similarly, each hotel/restaurant will initially be given 2 stoves along with regular supply of Torrified pellets. Charcoal briquettes will also be provided to be used in a *Tandoor*.

End User*	Number (in Almora town)	Number of Stoves	Number of End Users With 5% Market Penetration	Total Number of Stoves
	50-60	1 Stove/Dhaba	3	
Dhaba	(55 Assumed)			
	46 Hotels	2 Stoves/Hotel or	4	11
Hotel/Restaurant	50 Restaurants	Resturant		

TABLE 20: MARKET SIZE IN ALMORA

* Assume cooking is done 8 hr/day, 350 days in a year

Based on calculations done for value propositions to these commercial eating joints, it was found that a selling price of 17 Rs/kg would be the maximum price at which there will be economic savings for these end users. Due to the small profit margins in the phase of capital cost recovery, it was decided to increase the payback period from an initially decided time of 5 years to 6 years, which would allow the company to get small profits and pay back its capital costs. This model of slow growth is also necessary since the adoption of these cookstoves can take time as they are unfamiliar products. Moreover, majority of the end users are *dhabas* that are informal businesses that may exist for short intervals of time. Thus, during the 1st 6 years the company produces its fuel at 14.33 Rs/kg. It was decided to sell the fuel at 15 Rs/kg, to still have a good economic value proposition for the end users. This is also takes into account the final logistics system selected in the next section. The lifetime of the plant was assumed to be 10 years, due to the use of locally available and cheap material used for the construction of reactor 2 as mentioned in the report of Ryan Helmer. The company will make substantial profits between the 6th year and the 10th year at the tune of around 1600000 Rs/year, if the fuel is sold at 15 Rs/kg while being produced at 10.40 Rs/kg. The road map of plant construction and product introduction is also discussed in the report of Ryan Helmer.

Marketing of the fuel and the stove is very important as far their adoption is concerned. During field work, it was found that cookstove demonstrations are a very good way to do this. The idea is to book an appointment with the restaurant owner and take the cookstove and the fuel for demonstration and testing. Since these restaurants are essential open-door, a lot of other people gather to see what is happening and the word spreads.

The company will provide the stoves for free to these end users and will charge only for the fuel. This decision was arrived at after assessing the impact on profits was found to be marginal if the company was bearing the cost of these stoves. The payback time to the company for each cookstove that costs roughly 15500 Rs was found to be 1.80 years for the initial 1^{st} 6 years of plant capital cost recovery and a small value of 0.17 years between the 6th year and 10th year, which can be assumed as the lifetime of the plant equipment (Appendix 17). However, since these businesses are not very established and shut down periodically, they would have to enter into a contract with the company as a guarantee, wherein they are obliged to buy the fuel for a period of 2 years in order to get a stove free of cost.



FIGURE 26: COMMERCIAL COOKSTOVES SOLD BY ANSA GREEN[48]

Table 21 estimates the yearly demand for a Torrified fuel. For a 5% market penetration, the demand works out to be 363 Tons. To meet this demand, a reactor of a cumulative volume of 21 m³ would be needed (Figure 26). The design of the reactor is based on the concept described in chapter 3 ('Reactor Concept 2'), with heating for Torrefaction provided electrically. The procedure for translation of information from LPG and coal usage to Torrified Fuel usage is based on cooking experiments and demonstrations on Avani's charcoal stoves carried out in India, standard water boiling tests with different fuels carried out during field work in India and literature. This is described in Appendix 6. The calculation procedure for Table 23 is described in Appendix 17.

TABLE 21: YEARLY DEMAND FOR FUE

Total LPG Use* (Ton/year)	Total Charcoal Use [*] (Ton/year)	Equivalent Wood Usage (Ton/year)	Equivalent Torr. Fuel Usage (Ton/year)	Equiva Fuel U 5 % Pena (To)	llent Torr. Isage With Market etration n/year)
529.04	3097.50	3780	2627	131	363
		17125	11902	595	(average)

* Assume cooking is done 8 hr/day, 350 days in a year



FIGURE 27: THE CHOICE OF CUMULATIVE REACTOR VOLUME BASED ON MARKET DEMAND

Cumulative Volume of Reactor (m ³)	Total Number of Reactors Needed	Amount of Torrified Fuel Produced (Kg fuel/year)	Amount of Torrified Fuel Produced (Kg fuel/day)	Fuel Demand By End Users with 5% Market Penetration in Almora Town (Kg fuel pellets/day)	Raw Pine Needle Demand (Kg A.R. pine needles/day)
21	330	375352 (matching demand of 363 Tons)	5213	1072	8055

TABLE 22: DEMAND FOR RAW AND TORRIFIED PINE NEEDLES

To beat the supply chain of LPG and coal, it was decided that the fuel will be delivered at the doorstep of the end users of Almora. To reduce the transportation costs associated with the delivery of the fuel, the factory has to be located close to the town. As such, it is practical for the factory to be located 5 km away from the town market, where one can start having easy access to forests and have access to land.

The entire calculation for market estimation is based on Torrefaction process conditions of 250° C and 15 minutes residence time discussed in section II of chapter 3.

2.5 EVALUATION OF LOGISTICS OPTIONS

The market study and the end user value proposition carried out in the previous section brought to light that for the initial operation of the business, the market to focus on has to be in the commercial cooking area such as for small and big *dhabas*, restaurants, hotels etc. Since these businesses are predominantly concentrated in peri-urban/urban areas in the mountains, it was decided to focus on the market in Almora, which is a district headquarters.

To cater to this urban market, essentially two major logistics systems are possible:

- 1. Integrated Plant: This is essentially 1 big plant that will produce Torrified pellets/briquettes and supply to the end users in the peri-urban area.
- 2. Distributed Plants: These are smaller plants located either in a village or for a cluster of close villages.

Moreover, for all logistics systems, the following is assumed/or are facts:

- 1. Pine needles as collected on foot by women in the villages only in the three months when they fall: April, May and June. Collection of pine needles by foot is the only way as the terrain is steep and the forests are dense.
- 2. Therefore, the process of Torrefaction has to be carried out only in the three months of April, May and June.
- 3. Each pine needle collector is only allowed to deliver 45 kg of pine needles/day.
- 4. The assessment in this report is done on a price paid to the collectors per kg of As Received biomass they collect. However, as it rains a lot, measuring pine needles on a mass basis can lead to their underestimation. Hence, during actual plant operations, the collectors will be paid on a volumetric basis. This translation of costs can be done by knowing the bulk density of As Received pine needles and their 'average' moisture content.
- 5. Since the demand from the market is throughout the year, the process of pelletization will happen continuously through the year. Though pelletization of all the biomass can be finished in those 3 months, the goal of the project also to generate employment throughout the year.
- 6. The plant will have a set of temporary staff and permanent staff. The temporary staff will only be responsible for duties pertaining to pine needle Torrefaction and pine needle collection. The permanent staff will be responsible for generally overlooking work in the plant (technical managers), pelletization, packing of pellets, distribution of pine needles to end users, work as security guards, foremen, cleaning staff etc.
- 7. During pine needle collection season, Torrefaction and pine needle collection will happen for 72 days. That is, 6 days a week for 12 weeks. The plant will be operational 14 hours a day, with each batch of the production process lasting 3.5 hours (based on field experiments carried out on built reactor 2 in India).
- 8. Torrefaction will be carried out as soon as the pine needles are received by the plant on a daily basis to avoid long duration storage of pine needles. This is because the pine needles can be wet and they can start rotting. This is also to avoid large storage costs associated with voluminous pine needles. Moreover, after pelletization to meet that day's demand, the same mass of Torrified pine needles will occupy a significantly lower volume.

The following sections describe the logistics options for collection, storage and distribution for each of the above two systems and suggests the most practical options. The numbers for logistics assessment is based on the operation of the plant in the 1^{st} 5 years, till all the capital costs have yet not been recovered.

2.5.1 INTEGRATED PLANT

Figure 28 gives a general overview of an Integrated plant logistics system. In this system, a single large Torrefaction fuel production facility caters to the fuel needs of a town like Almora. Based on visits to the area and the space available around the markets, the plant will have to be located 5 km away. Thus, there are two options as far as the location of the plant is concerned:

- 1. The plant is located within a dense pine forest (ideal situation).
- 2. The plant does not have dense forests around it. In this situation, in order to reduce the distance travelled by the pine needle collectors due to low pine needle density, the plant can get pine needles collected by villagers who live close to a denser forest (can be easily found within a radius of 10 km). The pine needles collected would then have to be delivered to the plant using motorized transport.



FIGURE 28: CENTRALIZED PLANT COLLECTION, STORAGE AND DISTRIBUTION OVERVIEW

2.5.1.1 BIOMASS COLLECTION OPTIONS

There are essentially three ways in which pine needles can be collected:

- 1. Pine needle collection done only by women collectors belonging to nearby villagers: This is manual, foot collection of pine needles. According to staff at Avani, women are more willing to collect pine needles than men.
- 2. Pure foot collection in combination with a ropeway system to reduce the drudgery associated with pine needle collection.
- 3. Pine needle collection which is a combination of foot collection by village women, followed by transportation of the collected pine needles to the plant which is, say, 10 km away. This method has to be employed if the plant has to be located outside dense forests (due to low pine needle density, non-availability of land in forests etc.)

COLLECTION 1: ONLY FOOT COLLECTION OF PINE NEEDLES

The monoculture of pine forests is so vast that it is not difficult to find dense pine forests after a distance of 5 km from an urban center like Almora. In this collection scheme, the plant is assumed to be located within a dense forest and close to the villages to facilitate collection of pine needles by foot by women staying in the villages. Such a location of the plant will avoid any collection of pine needles using vehicular transport based on experiences of Avani Bioenergy, as according to trials and calculations done by them, it reduces the profits substantially and many prior ventures on pine needle pellet production have suffered due to this reason. This is primarily because of the low bulk density of pine needles, 80-90 Kg/m³ (on average, based on field measurements and literature[49]). Moreover, using vehicles to transport raw biomass will affect the carbon neutrality of the project as well. The entire dynamics first foot collection, followed by loading the truck with the biomass, unloading the biomass in the plant and repeating these events another 2-3 trips to meet the plant's daily demand did not work out for Avani. Apart from the extra costs and extra energy spent on procuring pine needles, the steep roads and their poor quality makes the entire transportation process time consuming.

In this system the pine needle are collected everyday by the women from the surrounding villages during the three months of April, May and June, which is the time when the pine needles fall from the trees. The women collect the pine needles and take it directly to the plant.

The cost of pine needle foot collection by women in the villages surrounding the plant is given by,

Foot Collection
$$\left(\frac{Rs}{Kg \text{ of } A.R.Biomass}\right)$$

= cumulative reactor size $(m_{reactor}^3) * packing density \left(\frac{Kg A.R.biomass}{m_{reactor}^3 * batch}\right)$
* Batch Time⁻¹ $\left(\frac{batch}{hr}\right) * Work hours \left(\frac{hr}{year}\right) * Foot Cost(\frac{Rs}{Kg A.R.Biomass})$

Where,

Cumulative Reactor Size, V_{reactor} is the total aggregated reactor volume, m³

Packing Density is the amount of As Received (A.R) pine needles that could packed into 1 batch of reactor design 2 (refer chapter 3),

Packing Density = 95.9 $\frac{Kg \ A.R.biomass}{m_{reactor}^* batch}$

(Based on experiments conducted on reactor design 2 built in India)

Batch Time =
$$3.5 \frac{hr}{batch}$$

(Based on experiments conducted on reactor design 2 built in India)

Work hours are the number of hours the Torrefaction process will run in a year. It was planned that the Torrefaction will be carried out immediately after collection of pine needles. Hence all the Torrefaction has to be done within the three months that the pine needles fall. Since each batch takes 3.5 hours, a day could accommodate 4 batches. Hence it was assumed that the Torrefaction has to take place 14 hours a day, 6 days a week and 12 weeks a year.

Therefore, Work hours = $14*6*12 = 1008 \frac{hr}{year}$

Foot cost is the money paid to the women pine needle collectors for their service.

Foot Cost = $1.5 \frac{Rs}{Kg A.R.Biomass}$

The costs associated with foot collection are shown in Figure 32. Based on the current market demand for the first year, the foot collection costs are 869877 Rs/year.

Number of Pine Needle Collectors Hired

The number of pine needle collectors is given by the following equation:

$$Pine \ needle \ collectors \ hired = \frac{Raw \ pine \ needle \ demand \ (\frac{Kg \ A. R. Biomass}{day})}{Amount \ delivered \ by \ each \ collector \ (\frac{45 \ Kg \ A. R. Biomass}{day})}{day})$$

For the market estimation done for the first year of operation in section 2.4, the number of pine needle collectors that would be hired for a cumulative reactor size of 21m^3 is 179 (The district of Almora has a population density of 198 people/km², giving a total population of 586). The trend is also illustrated in Figure 29.



FIGURE 29: PINE NEEDLE COLLECTORS HIRED VS CUMULATIVE REACTOR VOLUME

Radius of Collection

It was important to get a relation between the cumulative reactor size (V) and corresponding area (A) (and hence radius of collection, 'r') of pine needle collection around the plant. The following steps illustrate the process,

$$dA_{land}[ha] = dV_{reactor}[m^{3}] * Packing \ density \left[\frac{kg \ A. R. biomass}{m^{3} \ reactor \ * batch}\right] * Batch \ Time^{-1} \left[\frac{batch}{hr}\right] \\ * Work \ Hours \ \left[\frac{hr}{yr}\right] * Biomass \ Production^{-1} \ \left[\frac{ha \ yr}{kg \ raw \ biomass}\right]$$

$$C_{1} = Packing \ density \left[\frac{kg \ A. R. \ biomass}{m^{3} \ reactor * \ batch} \right] * Batch \ Time^{-1} \left[\frac{batch}{hr} \right] * Work \ Hours \left[\frac{hr}{yr} \right]$$

$$* Biomass \ Production^{-1} \left[\frac{ha \ yr}{kg \ raw \ biomass} \right]$$

$$dA_{land}[ha] = C_{1} * dV_{reactor}[m^{3}]$$

$$dA_{land}[ha] = 2\pi r[km] * dr * \left(\frac{100 \ ha}{1 \ km^{2}} \right)$$

'r' is the distance from the plant to the biomass source (pine forest)

$$200\pi r * dr = C_1 * dV_{reactor}[m^3]$$
$$100\pi r^2 = C_1 * V_{reactor}$$

And hence,

$$r\ [km] = \sqrt{\frac{C_1 * V_{reactor}}{100\pi}}$$

After introducing a Fudge Factor =0.5, keeping in mind that not all the area around the plant will be covered with forests, but will have villages, waster land etc.





FIGURE 30: RADIUS OF COLLECTION VS CUMULATIVE REACTOR VOLUME

Figure 30 shows that for the current business case in the first year of operation of the plant, a reactor of 21 m^3 would require a radius of collection of 0.86 km. Hence the area of collection is 2.32 km².



FIGURE 31: LARGE TRACTS OF MONOCULTURE OF CHIR PINE

COLLECTION 2: FOOT COLLECTION + ROPEWAY SYSTEM

This system of pine needle collection is based on the need of "Intermediate Collection Centers" discussed later on in this chapter. The radius of collection calculated earlier is a theoretical estimate. In reality there are mountains and valleys in between and people would have to travel much larger distances over difficult terrain to reach the plant. Hence, a ropeway system that can reduce the distance travelled by the pine needle collectors is necessary. These collection centers will act as a breakpoint, thus reducing the distance these pine needle collectors would have to haul the pine needles. This idea is inspired by the stone mining business in the local area that uses ropeway systems to haul stones over steep heights or long distances.

The pine needle collectors, who were earlier being paid at 1.5 Re/kg, will now have to be paid 1 Re/kg as they wouldn't be travelling all the way to the plant to deliver the pine needles.

Table 24 shows the ropeway estimations based on the number of villages that will be associated with a plant of 21 m^3 cumulative size and dealing with the current market demand of 1072 Kg fuel/day. Calculations for the given table are available in Appendix 18.

Further, it is assumed that each ropeway system would make 30 round trips per day. Additionally, each system can carry a maximum load of 40 kg. Hence, simple calculation gives a need of 7 systems with 3 villages being serviced by one.

The use of a ropeway would also mandate to have more staff in the business, running and manning each of the individual systems. Hence, assuming 2 people are required to operate 1 ropeway, this gives an additional 14 people that need to be employed, adding substantially to the operational costs. An electrically run system will add more to the operational costs in terms of cost of electricity.

Moreover, a ropeway system would involve an additional capital cost for each of the 7 systems. The capital costs will also include 7 more Tarpaulin systems sheets that need to be deployed at each of these collection centers to protect the collected pine needles from rain, wind etc. These capital costs will vary according to whether the ropeway system selected is electrically operated to reduce the effort put in by the operators, or is manually operated by the employees through a simple rope & pulley system.

TABLE 23: NUMBER OF VILLAGES ASSOCIATED WITH THE TORREFACTION PLANT BASED ON CURRENT MARKET DEMAND

Daily A.R.Pine Needle Collection Need (Kg/day)	Maximum collection allowed per collector (Kg/day)	Number of Pine Needle Collectors required	Typical number of pine needle collectors in a village		Number of villages associated with plant
8055	45	179	1	2	15
Load capacity of a cable car (kg)	Number of round trips per cable car per day	Number of cable cars needed	Number of villages per cable car		Length of each ropeway (m)
40	30	7	2.14	or 3	150
Amount of pine needles handled by each collection center in a day (kg/day)	Capital cost of electrically operated ropeway (Rs)	Capital cost of ma operated ropewa	Capital cost of manually Operated ropeway (Rs)		cost of 7 tarpaulin systems (Rs)
1150	600000	300000			74823

COLLECTION 3: FOOT COLLECTION + HIRED TRUCK TRANSPORT (UNDESIRABLE)

As discussed before, in situations where the plant cannot be located within a dense forest, the pine needles that have been collected on foot by the women collectors living close to these dense forests would have to be transported by motorized vehicles to the plant. Owing to the low bulk density of raw pine needles, 85 Kg/m³ on average (75 Kg/m³ when measured, 95 m³ in literature[49]), only lower amounts of pine needles (on a mass basis) can fit inside a truck of given cargo volume. Thus, even a small cumulative reactor volume of $1m^3$ would require a truck cargo storage volume of $5m^3$.

Based on the commonly available truck used to transport large volumes/weights in the local area, the collection costs in this scheme for a reactor volume of 21m³ comes out to be 1155704.79 Rs/year, which is higher than foot collection only. Moreover, for this reactor volume such a truck would have to make 7 round trips between the source of the pine needles and the plant, which is assumed to be 10 km away from this forest. This is impractical as it takes time to load and unload the biomass. Furthermore, road travel in the mountains takes usually more time due to narrow roads and steep slopes. Even if the cargo chamber in this truck is completely filled, it can accommodate only 1.31 tons of raw pine needles, which is well below its capacity of 4.2 tons. A smaller truck chosen would have to make more than 8 trips a day for the current market demand, which is not feasible in a day considering extra time for loading and unloading the biomass. For a reactor size of 21m³, the cost of transporting raw biomass from the forest to the plant works out to be 0.52 Rs/ Kg of As Received biomass, in addition to 1 Re/kg paid to the pine needle collectors for their services. Figure 32 shows the cost associated with this collection scheme.

The calculations and detailed tables for the above collection scheme are illustrated in Appendix 19.

Avani tried this system out and the entire operational dynamics for them did not work out due to the reasons mentioned above. Adopting this system would also reduce the profits when compared to collection done only by foot.



FIGURE 32: COLLECTION COSTS VS CUMULATIVE REACTOR VOLUME

COLLECTION 4: FOOT COLLECTION + HIRED TRUCK TRANSPORT WITH BALING

Based information provided by the staff at Avani, the baling costs amount to 0.64 Rs/kg of As Received pine needles, including the cost of a renting a tractor, labour cost (4 labourers), diesel costs for tractor and baling machine. According to them, the truck could carry 1 ton in each trip, thus making multiple round trips to meet their demand. After baling, the truck could carry 3 tons, thus reducing the number of round trips to 3. This is confirmed by the specification sheet of New Holland baling machines (used by Avani as well), that can bale wheat straw (can be approximated to pine needles) up to 200 kg/m³[50]. Typical large trucks that they use have a cargo volume of 15.43 m³, which can now accommodate 3100 kg of pine needles. Additionally, a similar truck used in collection system 3 would now be able to carry roughly 3 times the weight of raw pine needles as compared to 1.31 tons without baling. This is based on information provided by staff at Avani. As one can see from Figure 32, the costs associated with biomass collection increase if baling is adopted, even though the number of round trips to be made for a reactor size of 21 m³ drops down to 3 from 7.

Moreover, carrying out baling on mountain slopes is a difficult task. Based on their experience with baling, the staff at Avani say that it is also a time consuming process (the baling process itself, coupled with tying the bales) thereby limiting the number of round trips a truck could make even more. Furthermore, the staff at Avani says that bales made out pine needles break easily causing even further delays.

Table 47 in Appendix 20 illustrates the costs associated with Baling vs cumulative reactor volumes.



FIGURE 33: NEW HOLLAND BALING MACHINE USED BY AVANI[51]

2.5.1.2 TRANSPORTATION AND DISTRIBUTION OF TORRIFIED PELLETS

Since the plant is 5 km away from the peri-urban center, the final product cannot be transported on foot to the end users as the distance is too much to haul heavy sacks containing pellets. The distance is also quite considerable to deploy any ropeway system till these markets. Hence motorized vehicular transport seems to be only option for transportation of the final product. There are two ways in which this can be done:

- 1. **Transportation using own vehicle:** The factory has its own vehicle, a typical pick -up truck, which it runs multiple times in a day between the factory and markets.
- 2. **Transportation using a "Shared Taxi" or a "Hired Truck":** "Shared Taxis" are essentially jeeps that ply between different towns that are close by and take multiple people at one time. Thus, the cost to commute using this taxi is substantially low as they are essentially a public mode of transportation.

TRANSPORTATION 1: USING OWN VEHICLE

This case examines the transportation costs, when the plant uses its own vehicle to deliver Torrified pellets to the market in the peri-urban/urban area. The vehicle selected is a pick-up truck of 1 ton capacity, commonly available in India. This is a smaller pick-up truck as opposed to the big trucks hired to transport As Received pine needles. This is possible because after Torrefaction, the pine needle strands become brittle and break easily. Hence a pile of pine needles can be compressed into a given volume much easily. Moreover, pelletization of the biomass will increase the bulk density of the product to around 800 kg/m³[26].

Purchasing such a vehicle will add to the capital costs, the details of which are given below:

Number of vehicle needed = 1

Capital cost of vehicle = 500000 Rs[52]

Weight capacity of vehicle = 1250 kg [53]

Volumetric capacity of vehicle = 2.80 m^3

Based on the weight capacity of the vehicle, the truck will only have to make 1 round trip till a cumulative reactor size of 24 m^3 (market demand of 1225 kg/day, $1.53 \text{m}^3/\text{day}$, weight being the limit) and 2 round trips up beyond that up to a reactor size of 47 m^3 (weight being the limit). The costs associated with vehicular transportation will be made according to the number of trips the truck would have to make depending on the cumulative size of the reactor. Thus,

Fuel Delivery Cost
$$(\frac{Rs}{day})$$

= $(\frac{No. of trips}{day}) * \frac{1}{truck speed} (\frac{hr}{km}) * Cost Rate (\frac{Rs}{hr}) * Distance per trip (\frac{km}{trip})$

Assuming the market to be open 350 days in a year,

Fuel Delivery Cost
$$\left(\frac{Rs}{year}\right)$$
 = Fuel Delivery Cost $\left(\frac{Rs}{day}\right)$ * 350

Where,

$$Cost Rate = Truck speed\left(\frac{km}{hr}\right) * Fuel economy of truck \left(\frac{L}{km}\right) * Local Diesel Cost\left(\frac{Rs}{L}\right)$$

The following assumptions were made,

Truck speed =30 km/hr

Fuel Economy of truck = 0.056 L/km [53]

Local Diesel Cost = 57 Rs/L (rate during field visit)

The delivery cost in Rs/year with respect to cumulative reactor size is given in Appendix 21. For the market demand with 5% market penetration and 21 m³ reactor volume, the truck would make 1 trip in a day and would cost 11172 Rs/year. Unlike in the case of pine needle collection, no extra labour needs to be hired as low volumes of pellet distribution can be handles by a driver employed by the company.

TRANSPORTATION 2: TRANSPORTATION USING RENTED VEHICLES

"Shared" taxis can be cheap and effective ways of transporting the pellets to the market as one can avoid the capital investment made in buying a vehicle for the plant. However, there are certain limitations in using them.

- 1. One can at most carry 50 kg in a trip, with the fuel sacks being hauled on the overhead goods carrier of the vehicle.
- 2. Moreover, the frequency of operation of these shared taxis reduces substantially by 4 pm; therefore, it is a reasonable assumption that only 5 round trips can be made from morning till late afternoon. A shared taxi system with 5 round trips is only possible till a cumulative reactor size of 5 m^3 .

Thus, for larger reactor volumes, the only other option is to hire smaller pick- up trucks to transport the pellets to the market. Typically, these trucks can be hired for a minimum cost of 1200 Rs/day to make multiple trips between two locations, with additional costs for fuel. These are essentially small pick- up trucks with a 1.25 ton weight capacity and 2.80 m³ volumetric capacity, as was used in the case of a factory owned pick-up truck. These trucks would essentially have to travel a distance of 10 or 20 km, depending on if they have to make 1 or 2 round trips. This further depends on Cumulative reactor size, $V_{reactor}(m^3)$.

TABLE 24: VARIOUS METHODS OF HIRED TRANSPORTATION TO DELIVER TORRIFIED FUEL PELLETS TO THE MARKET

Size of Reactor, V _{reactor} , m ³	Mode of Transportation of fuel to city
0-5	Shared Taxi
	(With max. 5 round trips allowed, 50 kg/trip)
6-24	Hired Truck with 1 round trip
24-47	Hired Truck with 2 round trips

Hence for a reactor size varying from 0-47 m³, one can either use a shared taxi till a reactor size of $5m^3$, a hired truck with 1 round trip from $6m^3$ to 24 m³, and a hired truck with 2 rounds trips in a day from $24m^3$ - $47m^3$.

Thus, for the chosen reactor size of 21 m³, to meet a market demand of 1072 Kg Torrified pellets/day, a truck would need to be hired which would make one round trips in a day. This will cost 1248 Rs/day or 436758 Rs/year

Appendix 22 gives more details on the calculations performed to reach the above conclusions. It also gives a table $V_{reactor}$, the daily demand of Torrified fuel pellets based on $V_{reactor}$ and the corresponding mode of transportation needed to fulfill that demand.

2.5.1.3 STORAGE COSTS

Based on experiences with Avani's gasification plant where pine needles used to frequently get wet because of rain, it was realized that storage of raw pine needles and the Torrified product has to be in an enclosed building. There have been reports of thefts of pine needles by villagers and deliberate setting fire of pine needles by miscreants, underscoring the need for a building that can be locked.

The storage required will predominantly be for Torrified product and the final product in pellet form. These will be stored in gunny bags that will be piled on top of each other. The raw pine needles that arrive will be Torrified the same day and hence would require less storage space. The shed will also house the grinding and pellet making machine.

The maximum storage would be needed at the end of the Torrefaction period, that is, at the end of the pine needle collection season (April, May, June).

Thus, the amount of Torrified fuel that needs to be stored at the end of the collection season is,

Fuel Storage
$$\left(\frac{kg}{day}\right) = \left(Fuel Production\left(\frac{kg fuel}{day}\right) - Fuel Delivery\left(\frac{kg fuel}{day}\right)\right) * 72$$

Based on calculations performed in Appendix 23, the storage costs per m^3 of cumulative reactor volume were found out to be 14715 Rs/m³.

Raw pine needles need to be protected from the wind (to avoid entrainment) and hence, need to be covered with a sheet of tarpaulin. Therefore 4 sheets of dimensions 45'x39' were purchased and added to the capital costs of the factory[54].

2.5.1.4 EVALUATION OF VARIOUS LOGISTICS OPTIONS FOR AN INTEGRATED PLANT

Table 26 shows the profits associated with various combinations of collection and delivery schemes. The numbers in parenthesis is the production price of the Torrified pellets. The sales price of the Torrified pellets was fixed at 15 Rs/kg, which was based on the economic value propositions done for restaurant and hotel owners.

All logistics systems that involve renting a vehicle for delivery of the product to the marker give either lower or negative profits. Those systems that involve ropeways also give either low or negative profits in the 1st 6 years of operation of plant during capital cost recovery. Ropeway system employ have significant capital costs and employ additional men, which adds significantly to the operation costs of the business. The option of a ropeway system is not disregarded as they reduce the drudgery associated with pine needle collection. Moreover, after the payback period, the profits associated ropeway systems are bound to increase.

As far as the delivery system is concerned, the plant should invest in its own pick -up truck to deliver the product to the market and not rely on rented transport. The most profitable option is to have collection of pine needles by foot only, in combination with delivering the product to the market in a self-owned pick-up truck. For this system to be successful, the plant has to be located in a dense pine forest, with gentle slopes that make it easier for the collectors to haul the pine needles all the way to the plant. Profits are also realized if the collected biomass is transported to the plant using a hired truck if, for some reason, the plant cannot be located in the forest of interest. However, these profits are significantly lower than the case where collection is done simply on foot. Moreover, the truck will have to make 7 trips day, which is impractical considering time taken to travel 20 km in a round trip, loading and unloading of biomass. The profits decrease if baling is carried out for transportation using a hired truck, and thus should be rejected.

TABLE 25: PROFITS (RS/YEAR) ASSOCIATED WITH VARIOUS COMBINATIONS OF COLLECTION AND DELIVERY SYSTEMS FOR AN INTEGRATED PLANT OF 21M³ DURING 1st 6 YEARS OF OPERATION. THE FUEL PRODUCTION COSTS ARE GIVEN IN PARENTHESIS.

Delivery Schemes Collection Schemes	Self-Owned Pick Up Truck (x 10^5)	Rented Vehicle Hired Pick-Up Truck) (x 10^5)
Foot Collection	9.54(11.5)	6.80 (12.2)
Foot Collection + Manually	1.07 (14.3)	-8.01 (16.7)
Operated Ropeway System		
Foot Collection + Electrically	-5.93 (16.2)	-15.01 (18.6)
Operated Ropeway System		
Foot Collection + Hired Truck	6.55 (12.3)	3.82 (13.0)
Foot Collection + Baling + Hired	0.96 (13.7)	-1.77 (14.4)
Truck		

Possible	Avoidable/Impractical	Rejected

Note: For the systems involving baling, an additional capital cost of Rs 900000 for the baling machine will be involved (based on information provided by staff at Avani).

Pine needle collection can be a very burdensome process. In reality, it is difficult to find gentle slopes all around and there can be valleys and breaks in the mountain slopes. The radial distance for pine needle collection is a theoretical estimate, whereas in reality the collectors would have to move around these obstacles and walk longer distances. Thus to make the process of collection easier, it was decided to have a ropeway system. During the 1st 6 years of company operation, the ropeway would be manually operated to save on operational costs. This is possible for a 150 m long ropeway, as all across the Himalayas, it is common to see such systems to haul goods and even cross rivers. After the 1st 6 years of operation, post capital cost recovery, the ropeway system will be electrically operated giving substantial profits of 16.8 (x 10^5) Rs/year and the fuel will be produced at 10.4 Rs/kg.

The fuel will be delivered at the doorstep of these end users to beat the supply chain if LPG. Finally, it should be mentioned that it might be useful to have a few shops in the market that store and sell the product to other end users who might need them. Moreover, roads get frequently blocked in the Himalayas due to landslides, excessive snowfall etc. Thus, having such shops in the market will act as emergency buffer storage when the vehicle from the plant is not able to deliver the product to the end user.

2.5.2 DISTRIBUTED PLANTS

Distributed plants will be useful in reducing the distance the pine needle collectors would have to travel to collect and deliver the biomass at the plant. However, as was seen in the section for the Integrated plant, the radius of collection including a fudge factor of 0.5 is roughly 1 km (0.97 km to be precise), which is small enough to moot the case for having distributed plants for the market of commercial cooking.



FIGURE 34: OUTLINE OF LOGISTICS FOR A DISTRIBUTED PLANT SYSTEM

Figure 34 gives an outline of collection, distribution and storage for a distributed plant system. In this system, the plants will be located in villages and not in a centralized location close to an urban center. The pellet making process post Torrefaction will be carried out in the villages itself, to reduce the costs associated with product delivery to the market. In addition to a plant, each village will also have a small warehouse to store the raw and Torrified pine needles, along with the pelletized product that is produced. There has to be a small warehouse located in the urban center, close to the market, where the daily supply of the product will be collected and stored and distributed to the end users at their doorstep as per demand/schedule (as unlike in the case of an integrated plant, the plants here are generally located more than 5 km away from the urban center, underscoring the need for a local warehouse). These steps are necessary to beat the supply chain of LPG in the area in order to improve the value proposition of a Torrified fuel beyond economic considerations.

From the outside, it seems having Torrefaction plants in villages catering to urban centers far away will not work out economically due to the increased transportation costs associated with delivery of the product to the market. This is because each village or maybe even a group of villages will have their own delivery costs (regardless of the method adopted), resulting in compounding of delivery costs.

The collection costs and storage costs can be assumed to be distributed over the number of villages contributing to the business, and hence were assumed to be the same (if not higher) as in an Integrated plant. The methods of delivery of the product are similar to what were adopted in the case of an Integrated plant. The only method of pine needle collection possible is through foot collection, as the plants in the villages will be small enough to enable short distance collection pf pine needles. As the demand for the fuel is distributed over villages that can be far way, it was assumed that the vehicles responsible for the delivery of the fuel can make only 1 round trip. Pelletization of the Torrified fuel would also enable the use of smaller trucks, as in the case of an Integrated plant. Similar to the case of an Integrated plant, "shared Taxis" are also considered here. Like earlier, it was assumed that in each trip it was only possible to carry only 50 kg of product in these shared vehicles due to space occupied by other people as well. However, it was found tha if the number of villages, V, is less than 20, then a plant in each village (adding up to 21 m³ cumulatively) would produce more than 50 kg of pellets to be delivered. These would have to be delivered in more than 1 trip. Two trips in a shared taxi for larger distances is difficult as these stop plying after 3pm. Thus, shared taxis do not work out if the number of villages selected is less than 20.

Table 27 underscores the fact that having village scale decentralized plants catering to needs in the urban centers lead to lower profits corresponding to similar logistics combinations in an Integrated system. Moreover, one can see a trend, that as centralization is approached (the number of villages associated, V, is reduced from 20 to 5), the profits increase (or the amount of money being lost decreases). Distributed plants would work out economically if they were catering to the cooking needs of the households locally or if they were catering to Avani's decentralized gasification plants. However, the value propositions for these were found to be poor and speculative respectively.

Thus, the final logistics system adopted is the use of foot collection and manual ropeway for the collection of pine needle and the use of a plant owned pick- up truck for the delivery of fuel to the end users. This is the logistics system for an Integrated plant as discussed in the previous section.

Appendix 24 gives details regarding fuel transportation calculations for distributed plants.

Delivery Schemes Collection Schemes		Self -Owned Pick- Up Truck (x 10^5 Rs) Hired/Rented Truck (x 10^5 Rs)		Shared Taxi (x 10^5 Rs)
	V=20	-11.55	-29.40	-7.36
Foot	V=15	-2.82	-16.21	N.A.
Collection	V=10	1.47	-7.46	N.A.
	V=5	5.75	1.30	N.A.

TABLE 26: PROFITS (RS/YEAR) ASSOCIATED WITH VARIOUS COMBINATIONS OF COLLECTION AN	D
DELIVERY SYSTEMS FOR DISTRIBUTED PLANTS FOR 1^{ST} 6 YEARS OF OPERATION	

2.5.3 PRACTICAL CONSIDERATIONS

On evaluation of various biomass collection options, it was found that a ropeway system, meant to reduce the effort invested by the pine needle collectors should be employed. Through interviews and "design sessions", an attempt was made to understand pine needle collection better and suggest more ways to reduce the effort. The following conclusions were reached through various interviews (pine needle collectors and staff at Avani) and designs sessions carried out with pine needle collectors (Activity-"map making and "improving the pine needle collection process) and the design session on daily life carried out in a village(Activity-"illustrative timeline"):

2.5.3.1 PINE NEEDLE COLLECTION: A SUPPLEMENTAL INCOME GENERATING ACTIVITY

Interviews with staff at Avani gave the information that most of Avani's pine needle collectors were women as they were more willing to collect pine needles than men. Men were not willing to carry the pine needle load on their heads (not considered a man's job). As women till now have been the majority of the pine needle collectors for Avani, interviews and design sessions were conducted with them.

The "illustrative timeline" design session activity brought to light that the women pine needle collectors have a very busy schedule, doing household and field work. The women generally have less free time in the summer months from April to June. During April-early May, the women are very busy harvesting wheat, pulses, barley, mustard and peas. This is followed by planting of rice, *madua* (finger millet), other varieties of dal. This continues till early June, so that they are sowed well before the monsoons. Apart from this they have to do other chores such as bringing leaf litter from the forest, cut grass from the forest for the cattle, gather supplemental firewood (most collection done in winter when women have more time) and do household work. Thus, women that would be responsible for pine needle collection cannot be full time employees of the plant as they have no time to spare. Pine needle collection can only be a supplemental income generating activity for these women. The "illustrative timeline" design session also revealed that a lot of these families have debts which they usually pay in the month of August. Supplemental income generation from pine needle collection will definitely help in this regard.

The pine needle collectors should be selected from poorer households as these families have negligible land to even carry out subsistence agriculture. The main form of income for the family is through labour work either for private projects or for government employment schemes such as MNREGA. These women would not be burdened with working in the fields during pine needle collection season, and hence can spare more time for the same. Moreover, they will be more willing to collect pine needles than women from better off families as they are in more need of an additional source of income. These women are quite motivated to collect pine needles because of the supplementary money they can earn. Visits to villages brought to light that there are some women that work extra hard to collect more pine needles, and manage to deliver 120 kg to Avani's plant in a day. An Interview with one of the pine needle collectors revealed how busy they are and how they multitask their household work with pine needle collection. They leave to collect wood at 8 am and leave the wood collection some safe location along the path. While in the forest, they would collect pine needles and leave it in the plant. They would rest in the plant for 5 minutes and leave for home. On their way back they will collect more wood. They keep the wood at home, have lunch/tea and then leave to get grass for the cows. If they have time in the evenings, they will collect more pine needles and deposit it in the plant the next morning. This was brought to light by the "map making" design session. Thus, it should be kept in mind that these women are also very busy with taking care of the household (their sole responsibility as discussed in the widening of gender roles), and pine needle collection should just be a supplementary income generating activity for them. The women cannot be full time employees of the plant.

However, there are practical constraints in just employing women for pine needle collection. There may not be enough women collectors from these low income households in the region (170 needed). The solution has to be to employ additional men as daily labour to collect pine needles. The ropeway system is also an experiment by Avani to involve men in the pine needle collection process, as the collection of pine needles through the operation of the ropeway system can be recognized by the men as a job that they can do. Moreover, the men would not have to travel long distances carrying pine needles bundles on their heads due to the distance breakdown as a result of the ropeway system. If men are employed, they would be reluctant to work at 1 Re/kg, as they are used to daily wage rates of 350 Rs/day. Thus, in the future, the company can adopt a policy in which it hires as many women pine needle collectors it can and pays them at the rate of 1Re/kg as supplementary income. To fill the remaining gap, men can be paid daily wage rates to collect pine needles. However, the problem with this system faced by Avani was that the workers were just focused on filling hours and not maximizing pine needle collection. As a solution, instead of a 45 kg limit imposed on pine needle collection for women for collecting just once in the morning, the men would have to collect in two shifts as they are being paid for the entire day. They would have to collect 30 kg in the morning and 30 kg in the afternoon to be eligible for the day's pay. This would also help in reducing the pine needle collection burden from the women.

As far as this thesis is concerned, only women pine needle collectors were researched and considered for the business case as they have worked more in the past for pine needle collection and Avani's staff has more information to give about them.

2.5.3.2 TOOLS TO ASSIST PINE NEEDLE COLLECTION

The design session which focused on improving the pine needle collection process brought the following to light:

- a. The women expressed the need for a small, portable rake which they can use to gather pine needles.
- b. The women currently use a big piece of cloth to gather and carry the pine needles. More often than not, these are clothes that belong to the women themselves (such as a *saree*). The pine needles tend to fall out from the sides and cause a lot of inconvenience. Additionally, the needles poking out from the side end up touching the skin and cause rashes/cuts. Thus, the women expressed a need for a flexible container of variable volume and a rope to tie into a bundle to prevent spillage of pine needles. Since it rains so often, it will be useful if the "flexible container" is waterproof. A plastic sheet, supplied with a rope should fulfill the need.
- c. Moreover, the women always prefer to support the load of pine needles on top of their heads and would not like to carry heavy loads on their backs supported on their shoulders or foreheads. Thus baskets or some other kind of back pack will not be very useful.
- d. Since pine needle collection involves dealing with a lot of fine particles and dust, a mask is necessary. The women also wanted gloves to deal with the pine needles.
- e. As the collection is done during the summer months, heat is a big issue. The women wanted provisions to drink water as they were collecting pine needles.
- f. The women create time for pine needle collection in between other work that involves going to the forest for gathering wood, grass and leaf litter. Once the pine needle collection is done, the women might have to go all the way to the village to get a sickle to help them in these tasks. Hence, there should be a provision in which the women can carry a sickle along with the tools needed for pine needle collection.
- g. Keeping in mind the needs mentioned by the women in the above points, it might be useful to develop a "utility belt" to carry a sickle, small rake, water bottle and a rope.



FIGURE 36: A COLLAGE CREATED BY ONE OF THE PINE NEEDLE COLLECTORS TO ILLUSTRATE TOOLS THAT MIGHT BE USEFUL WHILE WORKING



FIGURE 35: ENLISTING OF MAJOR WORK DONE BY KUMAONI WOMEN IN THE MONTHS OF JANUARY, MAY AND AUGUST

2.5.3.3 IMPOSING A LIMIT ON PINE NEEDLE COLLECTION

Collection of wood, grass and leaf litter is usually a group activity, where the women go out together to not only collect produce from the forest, but also make the occasion a social outing. However, pine needle collection is driven by money and whoever manages to collect most pine needles in the area gets the most money. This has created competition among the women, and hence they do not collect the pine needles together and go either alone or with their families (mother in law, children). Usually women end up collecting 30-40 kg of pine needles in a day and if they put in extra effort, they can collect up to 60 kg. To avoid creating this sense of competition, a limit of 45 kg collection/woman should be imposed. The children believe that they can get money from collection as well and end up joining their mothers. This limitation on pine needle collection will also reduce the enthusiasm of children in collection pine needles. Moreover, it should be the responsibility of the plant owners to not pay for the collection done by children.

2.5.3.4 REDUCING DRUDGERY IN PINE NEEDLE COLLECTION – THE NEED FOR A ROPEWAY SYSTEM

Pine needle collection is a job that most women don't enjoy doing. Most women say that they have taken up the job as their families have very few alternative sources of income. The job involves carrying heavy loads over distances in the range of kilometers, usually over steep slopes. Moreover, the heat during the day and the problems in handling the biomass itself (itches, cuts, dust, biomass falling over etc.), makes the process laborious. Staff at Avani says that the women would be comfortable only in carrying the pine needles 500-700m from their village. Furthermore, a radius of 1 km might seem small, but it is quite a fair distance when one has to negotiate through steep slopes and gorges in between. Hence steps should be taken in reducing the effort the pine needle collectors have to make.



FIGURE 37: PINE NEEDLE COLLECTION WITH A ROPEWAY SYSTEM



FIGURE 38: A TYPICAL MANUALLY OPERATED ROPEWAY SYSTEM[55]

Upon interaction with the pine needle collectors during the design session, the idea of an intermediate collection center between the plant and their villages was suggested. The women would have to deposit the pine needles in this center, from which it would be hauled to the plant using a ropeway system. This system will reduce the distance that the women would have to travel or avoid travelling on steep slopes. This collection center can also have a small storage space, where the women can deposit the pine needles as per their convenience. This is important, as there might be times when the women are just too busy the in the fields or the forests. Thus, there might be some days when the women do not collect anything, and other days where they find time to collect more and make up for not collecting on other days. Each ropeway system will have two employees of the plant operating it. One of them will be stationed at the intermediate center and would be responsible to keep an account of daily collection by different women in a log book. The employ will distribute the tools needed for pine needle collection and is also responsible for retrieving them. This employee will also be responsible for paying the women on a per m³ basis, as it rains often and wet pine needles can give an overestimation of weight.

It will be also useful to have provisions for water, tea, juice and seats to rest at this intermediate center. The women usually rest for about 15 minutes after depositing the pine needles at Avani's plant, and hence

such provisions will help them recover faster from the intense pine needle collection process. It will also be useful to have such provisions in the plant as some women who stay in nearby villages can directly deposit the biomass there.

However, the money paid to the pine needle collectors using the ropeway system should be reduced from 1.5 Rs/kg to 1 Re/kg as they are travelling a smaller distance to deposit the pine needles. This is justified as pine needle collection is only a supplemental income generating activity for the women, so that their daily busy routine of managing their households and fields (which is completely their responsibility) is not disturbed.

Hence, one can arrive at a conclusion that even though collection of pine needles by only foot seems to be the cheapest logistical option, it may not be the most practical and convenient way.

Based on the profit values given in section 2.5.2, the strategy should be to adopt a foot collection and manual ropeway collection system for the first 6 years which will give modest profits. Post the payback time, the company should invest in motors to make the ropeways easier to operate. Even with this additional investment and operational cost associated with electricity, the profits show a strong value of 1680000 Rs/year.

2.5.3.5 OTHER ISSUES TO ADDRESS

Based on experiences of Avani establishing its first plant in the village of *Chachret*, it is very important for the plant to be located at the road head. Avani's plant is located downhill, closer to the villages. Any heavy equipment that needed to be brought to the plant had to be dragged manually downhill which was a very difficult task. Access to a road close by will also facilitate easy disbursement of the of the Torrified fuel through motorized transport to the end users in the peri-urban area. Moreover, as discussed earlier, the plant has to be located in a dense pine forest to make foot collection possible and avoid motorized transport of pine needles. The land for the plant should have gentle slopes for easy movement of equipment and personnel.

2.6 FINANCING AND GOVERNMENT SUPPORT

Interviews with local banks (State Bank of India, Uttarakhand Grameen Bank) and government officials (Gram Pradhans or village heads, the District Magistrate of Almora) shed light on possible support on the project in the following ways:

1. Finance Options

Public sector banks such as the State Bank of India have been typically financing "activity" based (rather than "product" based) projects related to agriculture or dairy farming in the area due to the lower investments involved and smaller chances of defaulting. In the hilly regions, the banks are a bit hesitant to finance industry based projects due to high need of obtaining man power and machinery from the plains of the country which raises the capital and operational costs tremendously. This has been the reason for failure of a number of such projects in the past. For loans to be granted for a future pine needle Torrefaction factory, the business has to demonstrate low dependency on the plains of the country for its functioning (if using technology from outside, show practical methods for plant operation and maintenance to avoid downtimes) and a promising market for the product. This will also increase the chances of getting a loan at lower interest rates. The average rate of interest for such loans is 12%. For large industrial projects, there usually is a need for collateral.

Joint Liability Group

This option is meant for a group of people interested in starting a small industrial business together in the area. Typically, 4-8 people in a group have the co-obligation of repaying the loan that was granted to the group. This creates a peer pressure to make everyone pay their part. This option is also suitable if a "franchisee" model of the business is created, wherein a group of 4-8 interested locals are trained to start their own Torrefaction business in the local area and likewise through other entrepreneurs in other areas of the state as well.

Self Help Groups

A self-help group is an informal group (usually formed by women). Women typically pool in money into a common fund by what they have earned through alternative sources of employment. After they have gathered enough money, the bank can link them with their local branch and grant them loans. A SHG can be formed with a group of pine needle collectors in a village, and the money that they earn through the collection can be stored in a common pool used to meet larger expenses for health emergencies, weddings, getting loans to start a small scale business etc. If someone withdraws money from the pool, he/she has to repay with a higher deposit next time. Representatives from the Torrefaction company can be responsible for managing these groups, making monthly visits to the villages to check accounts. A small booklet can be given to the villagers to show their credit/debit history.

<u>Microfinance</u>

These banks also provide microfinance options for smaller loans from 1000-15000 Rs, with an interest rate of 4%. These can be typically used for the purchase of cookstoves by the end users. If the capital costs exceed 15000 Rs, a group of people can apply for a microfinance scheme by taking a loan of 15000 Rs or less each. After paying this first set of installments, the group is eligible for a bigger loan at 12% interest.

2. Subsidies

There are various options from the government on subsidies for small and medium scale industries in rural areas. Typically the project has to be approved by the District Industry Center (DIC) or the Khadi and Village Industries Commission (KVIC) for subsidies to be transferred through public sector banks such as State Bank of India. In an interest subsidy, the entrepreneur will receive half of the annual interest (6%) rate back from the government. This is done by declaring the money to be reimbursed as tax deductible payments on his/her tax reporting. In a capital subsidy, the bank and the entrepreneur invest a certain proportion each of the capital investment. The capital subsidy of 25% would be on the entrepreneur's investment on not on the total investment. These subsidies can be useful in meeting some of the initial capital costs of the project.

The PMEGP (Prime Minister's Employment Generation Program) of the Indian Government aims to generate employment in rural India by setting up of micro-enterprises to help arrest migration to urban areas. This program has a subsidy scheme linked to it as well. The maximum capital cost of the project for the manufacturing sector should be 2500000 Rs to be eligible for the subsidy. The rate of subsidy is 15% in rural areas and 25% in urban areas. The beneficiary is responsible for minimum 10% of the project cost. The balance costs have to be met by term loans through public sector banks.

In order to make biomass cookstoves affordable to end users the government has initiated a financial assistance scheme. Under the Unnat Chulha Abhiyan (UCA), the government subsidizes upto 50% of the cost of domestic cookstoves, with a maximum ceiling of 600 Rs/cookstove. For commercial cookstoves, the government finances, the government finances 50% of the cost, with

a maximum ceiling of 3750 Rs/cookstove. As the Torrefaction company is bearing the cost of the cookstoves, these subsidies might be useful in reducing the economic burden on the company.

However, in order for the company to be financially sustainable, it shouldn't be dependent on subsidies from the government. These subsidies should be secondary options once financial sustainability has been achieved. Moreover, the government prioritizes heavy subsidies on LPG, thus still making it very difficult to compete with.

3. Support of Local Government Institutions

Local government bodies such as the village council or the block/district council do receive money from the central and state governments to carry out small scale infrastructure development projects in villages such as building check dams, water tanks, village walls, toilets etc. These are specifically dedicated for such projects and other government schemes and cannot as such be sanctioned to support industrial projects in the region. Moreover, the money received is small and takes a lot of time to reach these local government bodies due to a lot of paper work and bureaucratic delays. However, after speaking to heads of village councils, enthusiastic support can be expected in terms associating villagers with the project and spreading the word around, which can be helpful in marketing the fuel in the urban centers initially and villages later.

2.7 CONCLUSIONS

The following conclusions can be summarized as discussed in this chapter:

- 1. The value proposition study on various end users gave the results that the best immediate market to pursue is in the area of commercial cooking (commercial LPG). Possible end users are kitchens in small restaurants, *dhabas*, hotels, resorts, private school and their dormitories, university campus and their dormitories.
- 2. The value proposition also brought to light that along with a Torrified product, a charcoal fuel should also be supplied to meet different cooking and heating styles (such as its use in a *tandoor*, replacing coal).
- 3. It was decided that the company will have a 5% market penetration by the end of the first year of its operation. The payback time for the initial capital costs will be kept at 6 years. A model of slow growth needs to employed as the adoption of these cookstoves can take time as they are unfamiliar products. Moreover, majority of the end users are *dhabas* that are informal businesses that may exist for short intervals of time. The lifetime of the plant was kept at a low value of 10 years as it is constructed using simple and cheap materials, with very crude manufacturing techniques.
- 4. The market demand for Torrified fuel w.r.t commercial LPG and coal replacement for a market penetration of 5% is 363 tons/year. 1072 kg/day needs to be delivered as fuel to the end users. This leads to a raw pine needle demand of 8055 kg/day. A cumulative reactor volume of 21 m³ would be able to meet this demand. Based on the fuel production cost and cost savings to the end user, a fuel production cost of 15 Rs/kg was chosen. These calculations were possible because of the Torrefaction process conditions f 250°C and 15 minutes chosen in section II of chapter 3. The Mass Yields and the calorific value of the Torrified fuel were also calculated in section II of chapter 3, which were used to get the above numbers. The geometrical and operational parameters of reactor design 2, described in section I of chapter 3 were also utilized for the above calculation.
- 5. The company will provide free stoves to the end users and only charge for the fuel. However, as a guarantee, the end users have to sign a two year contract with the company.

- 6. An integrated plant, rather than multiple decentralized plants gave the cheapest logistics cost. As the radius of collection for an Integrated plant is small, the case for having smaller decentralized plants is diminished. The final logistics system selected was:
 - a. Collection: Foot collection + ropeway system + intermediate collection centers
 - b. Transportation of product to market: Company owned pick up truck.
 - c. The use of motorized vehicle for the transportation of raw pine needles that have been collected is not advisable as they bring down the profits, cause time delays and would involve impractical number of round trips in a day between the biomass source and the plant.
 - d. Even though other combinations of logistics system were more profitable, this combination was chosen to reduce the burden of pine needle collection while having decent profits.
- 7. Women are more willing to collect pine needles than men and should be the focus as far as collection of pine needles is concerned.
- 8. As women pine needle collectors have the sole responsibility for most household work, field work and forest work, they are very busy and hence cannot be full time employees of the plant. They can contribute only some of their time for pine needle collection and earn supplementary income.
- 9. As 170 collectors are needed to meet the current market demand, there might be a chance that there is a shortfall of women pine needle collectors. Men would have to be employed by paying them a daily wage of 350Rs/day. The day's pay would be for not only collecting pine needles but also participate in other operations of the plant, such as manning the ropeway systems. For the scope of this thesis, all calculations are based on pine needles collected by women.
- 10. Tools to assist in pine needle collection need to be provided. Some tools recommended by the women were: a flexible waterproof sheet for wrapping pine needles, a portable rake, a mask, gloves, provisions for conveniently carrying water bottles. A utility belt can be designed to carry all this equipment. Intermediate collection centers and the plant need to have provisions for refreshments.
- 11. A limit of 45 kg/day was placed on pine needle collection for women to prevent competition between them to earn the maximum money. Pine needle collection, which is carried out with wood collection, is a social activity for the women and it was felt that this should not be disturbed.
- 12. The current market demand of 363 tons/year or 1072 kg/day of fuel results in a plant having 330 reactors. The profits were found to be very sensitive to the number of people employed to run these reactors. As a recommendation, future designs of the reactor should be continuous in nature to reduce the number of people to operate these reactors, reduce the land area needed to establish this plant and produce the fuel at a faster rate to meet the daily demand.

The overview of the business is represented in the System Map and the Business Model Canvas shown in the following two pages.



FIGURE 39: SYSTEM MAP: OVERVIEW OF ENTIRE BUSINESS SYSTEM



FIGURE 40: BUSINESS MODEL CANVAS

CHAPTER 3: TECHNICAL SYSTEM DESIGN

This chapter is divided into two sections. The first section gives a narrative of the Torrefaction reactor design selection. This is followed by a description of the testing of the selected reactor designs that were built in India. This section concludes with the shortcomings with the built reactor designs.

The second section talks about the experimental study of Torrefaction of pine needles carried out in the Process and Energy Lab of TU Delft. Mass and Energy Yields for Torrefaction of pine needles were determined and their impact on business case for a potential Torrefaction factory was evaluated. A final selection of process conditions was made based on thermal degradation trends of lingo-cellulosic constituents of pine needles, the mass and energy yields and their impact on the overall energy efficiency and business case.

SECTION I

3.1 DESCRIPTION OF TORREFACTION REACTOR DESIGN PROCESS AND EVALUATION OF DESIGNS

The Torrefaction reactor concepts were developed through a process of brainstorming, refinement and selection with faculty at TU Delft and staff at Avani. In this thesis, the focus was on the design of one individual reactor and assessing its performance through real time testing, rather than on the design and simulation of the performance of an entire Torrefaction plant. An attempt was made to design a reactor that could be manufactured and maintained using local technical capabilities. As per the information provided by the staff at Avani, the main local manufacturing and repair capabilities are arc welding, basic drilling operations (bench and hand held drilling press), sheet metal cutting and oxyacetylene gas welding/cutting operations. Even milling and lathe operators are hard to find. Moreover, there is minimal automation in the manufacturing process and people carry out these processes through simple hand operations. The cutting of steel/iron rods is carried out using a chiseled metal edge and a hammer, for example. Thus, any serious breakdown of machinery that cannot be repaired locally will cause huge downtimes as the equipment/technicians need to arrive from the plains, affecting the business tremendously. Avani's gasification plat faced similar problems, with a broken down blower taking 1 month to arrive post replacement from the plains of the country. The choice of reactor designs were also chosen based on whether they could be designed, manufactured and tested within the time frame of this project.

3.1.1 DESIGNS REJECTED

Torrefaction reactors differ in several key components. The primary difference in reactors is the heat transfer mechanism, being either direct or indirect[56]. Figure 41 illustrates the different Torrefaction reactor designs based on direct or indirect heating.



FIGURE 41: TORREFACTION REACTOR TYPES[56]

Direct heat Torrefaction reactors use direct contact between the heat transfer medium and the biomass particles to be Torrified. However, for designs that use gas as a heating medium, it should be completely free of oxygen or have limited amounts of it. Typically inert gases such as N_2 or flue gases from other thermochemical processes are used as a heat transfer medium. **Indirect heat Torrefaction** reactors involve a design in which the heating medium/heat source does not contact the biomass. These indirect reactors allow for easier control of the atmosphere inside the reactor, assuring a low oxygen concentration and therefore avoid any combustion during Torrefaction. Moreover, the volatile Torrefaction gases produced are not diluted by any gaseous heating medium[56].

The heat transfer mode can also vary to quite an extent. Some reactors employ a **gas-particle convection** mode as the primary source of heat transfer, convecting hot gases through the reactor that passes through the bed of biomass particles. Other, indirect heaters, use **wall-particle conduction**, where the heat source heats the wall of the reactor vessel, which then passes through to the biomass particles inside it primarily through contact conduction. Furthermore, **particle to particle convective heat transfer** is also employed where the particle bed is well mixed, such as in fluidized bed reactors. In addition, electromagnetic radiation, such as reactors based on **microwave heating** can also be used to raise the temperature of biomass in an inert atmosphere[56].

For a simple Torrefaction reactor design that can use local technical skills and facilities for its construction and operation, it was decided to derive and evaluate a concept based on open source packed bed biochar retort kiln designs, among other simple designs that employ a batch process. Since these reactors also operate under close to oxygen free conditions, it was decided to try and adapt these designs for Torrefaction. Based on testing of these reactors and their quality of construction, recommendations will also be given regarding employing local manufacturing and maintenance capabilities.

It was decided not to consider currently researched Torrefaction reactor designs such as moving bed reactors, entrained flow reactors, multiple hearth furnaces and microwave reactors as it would be very difficult to construct them locally.

Various designs were considered before narrowing down on the final concept.

As far as charcoal retort kilns are concerned, in **directly heated reactors**, the heating medium is essentially flue gas produced in an external combustion chamber by typically burning biomass (predominantly wood) or the gasification of the biomass itself in a packed bed reactor[57]–[60]. This reactor is designed for batch processing, with the bed of particles remaining more or less stationary as the hot gases move around the particles. Fixed bed reactors have the potential to be built out of simple materials and can be manufactured and maintained in the rural context with relatively less difficulty. The concept has been demonstrated for other feed stocks and other remote regions in developing countries [27], [61]. However, the volatile gases will be diluted with the flue gases made to flow through the bed, thus reducing the calorific content of the gas flow exiting the reactor.

An interview with the owner of the Sustainable Green Fuel Enterprise (SGFE) in Cambodia brought to light that they use a Top Load Up Draft Gasifier or TLUD to produce a charcoal fuel which they sell to households and commercial cooking businesses in the area. The design has its roots in gasification based cookstove designs[60]. The design is essentially open source and can be easily made locally. This design has been up-scaled for gasifiers to produce electricity/ charcoal. However, it is a design suitable to carry out gasification of biomass at 800-1000°C and produce syngas as the main product and charcoal as a by-product, with mass yields typically between 22-30%. The higher oxygen concentration involved in the gasification of biomass would make the modification of the design difficult for a Torrefaction process. Moreover, Torrefaction occurs at much lower temperatures than gasification.

Another demonstration of a directly heated packed bed reactor is a design by the Indian Institute of Science for the Nagaland Bamboo Development Agency concerning the Torrefaction of Bamboo. The design is essentially a semi-batch process in which a portion of the syngas stream generated from a gasifier is diverted to a combustion chamber for the generation of flue gases that are passed through multiple fixed packed beds of bamboo for its Torrefaction. A pilot plant has been field tested and a design throughput of 1 ton/day (based on raw bamboo) has been achieved. The design is simple and local technical capabilities can be utilized to build part of the reactor and maintain it. This system is able to retain the oxygen concentration under 3% through the combustion of syngas. Since, in chapter 2 it was discussed that a business case for Torrefaction-gasification business model is speculative at the moment, for the scope of this thesis, there is a need to evaluate an independent stand-alone system that uses other sources of energy for Torrefaction for the current business case of commercial cooking.

For a standalone system, the fuels that can be used for combustion and providing heat for Torrefaction are locally procured firewood, locally procured pine needles, reuse of Torrified pine needles produced in the plant and the possibility of using electricity for heating. However, controlling oxygen concentrations in the flue gas flowing through the bed can get very difficult with the limitations in technology at hand and hence it was decided not use a direct heat transfer medium.

Some other designs that could be simplified and can employ indirect heating were also considered.

The screw shaft reactor, following the name, uses an auger to churn and move the biomass through the reactor to enhance heat transfer to the bulk of the biomass and at the same time moves the biomass along its length. The moving part is the auger and not the drum as in the previous case. The reactor could be horizontal or inclined. The biomass in these reactors is typically heated using a flow of a hot medium inside the hollow wall of the reactor or a hollow auger[56][26]. It was thought that heat could be transferred by placing the Torrefaction chamber over a furnace in which wood/Torrified pine needles or other sources of locally available biomass could be combusted. The pine needles may also be heated by heating the screw itself by circulating hot flue gases produced in a combustion chamber through it. Though this design offers continuous operation, it is a relatively simple design that can be cheaper, with potential to be maintained using local capabilities. However, based on inputs provided by the staff at Avani, manufacturing of equipment such as the auger would depend on industrial units outside the hilly
regions of Uttarakhand. Sealing at the points where the auger enters and leaves the drum was also thought to be difficult, considering local equipment availability and manufacturing capabilities. With limited time available in this project to find solutions to the difficulties posed and then construct the reactor, it was decided to put in more thought for an even simpler batch design that could use more of local technical capabilities and could be finished within the timeframe of this thesis.

The **rotating drum reactor** employs a (usually) cylindrical reactor with a rotational motion driving the circular movement of the biomass particles. The biomass can be directly heated by passing heated inert gases such as nitrogen or flue gases from other thermochemical processes with controlled oxygen contents. However, the rotation of the drum also helps in employing indirect heating, thus allowing wood/pine needles to be combusted in an external chamber without worrying about the levels of oxygen inside the reactor. As the heat is transferred through the wall of the reactor, the particles are mixed in order ensure even heat distribution and a uniform product. The Torrefaction process can be controlled by varying the temperature, rotational velocity, length and angle of the drum. These are essentially continuous reactors but can be adapted to batch designs[26], [56].

This design was considered as there was potential for this reactor to be constructed using simple materials and methods. The source of heat was thought to be a combustion chamber that would use locally available wood, raw pine needles or pine needle briquettes produced by the plant itself. It was thought of that the drum could be rotated manually or by even using animal power by training cattle to move in circles and make the drum rotate through a pulley connection. A brush can also be installed at the top of the drum to knock off any small biomass particles that are stuck to the wall of the drum. Sealing of the drum at the section where the shaft exits the drum was a challenge using locally available materials. Simple lip seals could possibly be used, but it was realized that this design will be difficult to pursue within the time limits of this thesis. Moreover, considering local manufacturing capabilities, a rotating drum makes it a challenge to extract volatile Torrefaction gases (using simple pipes and elbow bends) from the drum. Though this reactor can be built to a large extent in the mountains, again, with limited the limited time frame of this thesis to find solutions to the challenges described, it was decided to put in more thought for an even simpler batch design.

3.1.2 IDEA GENERATION AND SELECTION OF FINAL DESIGN

Based on the drawbacks of the designs considered in the previous discussion, it was decided that a **fixed packed bed reactor with indirect heating** would be chosen as the first base design for construction, testing and subsequent evaluation due to the simplicity of its construction, the possibility of constructing and testing the design within the timeframe of this project and easier control of oxygen levels inside the reactor as compared to directly heated packed bed reactors.

The initial reactor design in this concept was also based on charcoal retort kiln designs. These kilns carry out external combustion of biomass such as wood to heat the biomass indirectly in a packed drum[57]. These designs are open source in nature and can be built very easily using locally available materials. The heat transfer mechanism to the biomass would be wall-particle conduction. Some of these designs also incorporated the recirculation of volatile gases produced on pyrolysis back to the combustion chamber to make use of their calorific value[57]–[59]. The reactor can be built simply with a 200L oil drum, rebar, firebricks and some basic welding operations and gas cutting/mechanical cutting operations. Based on the different designs evaluated, each reactor can be built within 100 Euros. This would also help reduce the capital costs of the business tremendously.





FIGURE 42: PYROLYSIS: AN OIL DRUM PACKED WITH WOOD ABOVE THE COMBUSTION CHAMBER (L), VOLATILE GASES PRODUCING SELFT SUSTAINING ENERGY AFTER SUPPORTING INITIAL COMBUSTION THROUGH AUXILIARY FUEL SUCH AS WOOD (R)[57]

However, these designs are meant to carry out pyrolysis and usually their operation did not involve continuous monitoring and control of temperature. Moreover, the volatile gases produced in the case of pyrolysis have a considerable calorific value (due to higher production of CO due to cellulose breakdown and more importantly, H_2 production) whose combustion can possibly self-sustain subsequent heating of the biomass. This is difficult in the case of Torrefaction due to relatively low heating values of the Torrefaction gases produced. These gases cannot be used for completely self- sustaining a Torrefaction process through its combustion; however they can contribute to the combustion process.

Thus, these designs were adapted for Torrefaction to control the temperature within the bed, and the use of volatile gases produced to provide heat for the reactor was not given much emphasis. Since only 1 reactor and combustion chamber could be built, it was decided that the volatile gases produced will be recirculated through a retort system to the combustion chamber, just to avoid their accumulation in the reactor. Finally, the construction and subsequent testing of the prototype would give insights into the temperature gradients within the reactor due to the indirect nature of heating adopted.

3.1.3 REACTOR 1 DESIGN DEVELOPMENT

The initial design that was thought of was based on a "**shell and tube type" design** in which a number of tubes carrying flue gases pass through the bed of biomass, thus transferring their heat through the walls of these tubes to the biomass (concept scheme given in Figure 43). This would increase the surface area for heat transfer to the biomass (as compared to a single large tube passing through the bed), thus improving the radial heat transfer to the biomass. The flue gases are not recirculated anywhere and are let out to the atmosphere. In an actual plant, they would typically be reutilized, for the drying of pine needles for instance. The Torrefaction gases are recirculated back to the combustion chamber using four 2" diameter steel pipes. A damper system (essentially a mechanically controlled butterfly valve) is used to control the flow of the volatiles to the combustion chamber. However, having multiple tubes in a bed gives rise to complex heat transfer process and hence it was decided that to gain an understanding of the heat transfer from one of the tubes to the biomass, an **annular design** would be constructed in which a single pipe carrying the flue gases from the combustion chamber would transfer heat to the pine needles which would be packed between the single flue gas stack and the wall of a 200 L oil drum.

This was decided as the final design for the first prototype that would be built in India.

Prior to leaving for India, the construction of a similar smaller version of the prototype was practiced in the Netherlands. The process of construction for all the reactors built is described in the report of Ryan Helmer.

The draft for the prototype built in India is represented in Figure 44 and the photograph of the prototype that was built in India is shown in Figures 45-47. Based on information provided by supervisors at Avani upon arrival in India, it was decided to construct the reactor in a town in the plains just before the mountains. This decision was taken as the sheet metal and the steel pipes needed for the reactor were not available in the mountains. It was realized, that, though this reactor could be almost completely manufactured in the mountains, some of the materials like the retort pipes had to be procured from the plains. Major portions of reactor 1 were constructed in the town of Haldwani in the plains, with some minor welding work and sheet metal cutting jobs that were completed in the workshop at Avani's campus.



FIGURE 43: SHELL AND TUBE TYPE TORREFACTION REACTOR CONCEPT S

As one can see from the drawings and the images, the main body of the reactor is essentially a 200L oil drum procured locally and available easily in the mountains as well as in the plains. The combustion chamber is essentially a waste cylindrical oil canister also procured locally. A hole was cut in the bottom of the oil drum of roughly the same diameter as the oil canister. The combustion chamber was then welded to the bottom of the drum. Therefore, there was no possibility of any air leak to the reactor chamber from the connection of the combustion chamber to the drum. For such oil drums, if the lid is removed once it cannot be fixed back again. Hence the lid was gas welded to the drum, making an air tight sealing here as well. The flue gas stack starting from the combustion chamber is essentially a welded

series of the same oil canisters that were used to make the combustion chamber. The reactor also has four doors on its side walls. Two top doors were made to facilitate the input of biomass into the annular region and two bottom doors were made to facilitate easy removal of the Torrified product from the bottom of the reactor. The doors had latches on them to have them locked during the Torrefaction process. Top loading of biomass was desired considered but could not be accomplished as the flue gas stack occupied a significant surface area on the top surface of the reactor.



FIGURE 44: 2D DRAFT OF REACTOR 1(DIMENSIONS IN MM)

Thermocouple Legend

- 1- Top Outer Bed 5- Bottom Outer Bed
- 2- Top Middle Bed 6- Bottom Middle Bed
- 2- Top Inner Bed 7- Bottom Inner Bed
- 4- Top Flue Gas
- 8- Bottom Flue Gas





FIGURE 45: REACTOR 1 COMPLETELY BUILT



FIGURE 47: REACTOR 1 ANNULUS AND FLUE GAS STACK ORIGINATING FROM COMBUSTION CHAMBER (FOR HEAT TRANSFER TO PINE NEEDLES IN THE ANNULUS)



FIGURE 46: REACTOR 1 COMBUSTION CHAMBER

The recirculation pipes for the Torrefaction gases were routed through the bed of the biomass, rather than outside it, to keep the temperatures high enough to avoid condensation of volatiles (especially during reactor shutdown and cooling). As condensed volatiles (tars) can clog pipes that aren't very wide, two inch diameter retort pipes were used. If this worked, it would help in reducing the maintenance associated with cleaning the pipes periodically. Holes were cut at the bottom face of the drum to allow the two retort pipes to go through. The gaps in the holes made were covered by gas welding the retort pipe to the bottom surface of the drum. This would also prevent air leaking into the reactor. The retort pipes enter the combustion chamber through a T-junction, one end of which is open to the atmosphere. It was hoped that this could act as a secondary extra air inlet not only for the combustion of wood, but also possibly aid in the combustion of volatiles entering the chamber. The T-junction and the retort pipe were threaded to provide for a good seal against volatile gas leakage. An opening was cut at the top of the combustion chamber to allow the input of fuel (chopped pieces of wood). Three holes were cut to allow for the insertion of three circular rods which would support a wire mesh on which the fuel wood would rest. Another hole of the same size as the one made to feed wood was cut on the bottom of the combustion chamber. This was done to facilitate easy ash removal. The purpose of this was to also act as a primary air inlet.

Before conducting trials on reactor 1, holes were drilled in the top surface and the bottom surface of the reactor drum for the insertion of thermocouple wires to measure the longitudinal and radial temperature gradients within the reactor. Four holes were drilled in the radial direction. On the top surface, one hole was drilled in the flue gas stack so that the thermocouple could measure the temperature of the flue gases that transfer the heat to the pine needles. The other three holes were drilled in a radially outward direction on the annular top surface of the drum to allow for radial temperature measurements. Thermocouples were then inserted into these four holes to a depth of 15 cm from the top surface of the drum to measure radial temperatures at a lateral cross section. Three holes were drilled in a similar way in the bottom surface of the drum, with the fourth hole for flue gas temperature measurement being drilled in the combustion chamber. The four thermocouples were inserted through these holes to a height of 15 cm from the bottom surface of the drum. The thermocouple, arrangement is depicted in Figure 44. The thermocouples used were K-Type, made of Inconel Alloy 600 made by Labfacility, UK. The wires had an insulated sheath, with a probe diameter of 1.5mm and a probe length of 500mm. The temperature was measured at the tip, with the maximum being at 1100°C. Temperature was recorded every 420 ms through National Instruments High Speed USB Carrier connected live to a LabView user interface on a laptop. Thus along with the recording of data, live temperature readings and profiles could be seen in the different positions the thermocouples were placed.

It was felt that some locations in the reactor were not adequately sealed. There were some gaps due to imperfect manufacturing at the doors built in addition to the holes drilled for the insertion of thermocouples. Since the maximum temperatures in these areas were in the range of $300^{\circ}C - 1000^{\circ}C$, the choice of sealants that could be used were limited. The use of high temperature stove sealants was considered, though it was only available in big cities such as Delhi, quite far away from the field site. Clay sealant was also an option to be used; however, it was not available locally. Therefore it was decided to try wheat dough as a cheap locally available alternative for sealing possible air gaps in the reactor.

3.1.4 EXPERIMENTAL VERIFICATION OF REACTOR 1

Trial Runs

The first two trials of the reactor were essentially dry runs to get used to the operation of the reactor and the right method to input wood to get the required temperatures in the pine needle bed. No pine needles were used in these experiments. Only four thermocouples were used: Bottom Flue Gas, Bottom Middle Bed, Top Flue Gas and Top Middle Bed. No insulation was used for these experiments.

The aim of these experiments was to achieve 250°C at the 'Top Middle Bed' thermocouple and see what the corresponding equilibrium temperature would be at the 'Bottom Middle Bed' thermocouple for an isothermal Torrefaction run of 45 minutes. A mixture of pine wood and furniture wood was used for the same. Raw pine needles were used to start the fire in the combustion chamber.



FIGURE 48: TEMPERATURE PROFILES ACHEIVED FOR 45 MIMUTES DURING 2ND DRY RUN

The first trial run failed to achieve the aimed temperatures. The temperatures in the Top Middle Bed were less than 200°C and the maximum temperature reached in the Bottom Middle Bed was 250°C. It was also observed that the flue gas flow rate was so high that it was entraining all the ash produced in the combustion chamber with it. Higher flow rate of flue gas would also mean that at a particular height of the stack, the flue gases had less time to transfer their heat to the biomass in the annular region. This would lead to a situation in which higher flue gas temperatures would be needed to achieve the same temperature in the biomass bed. This will also lead to greater consumption of wood and hence a greater consumption of energy. It was thus decided that there was need for a mechanism to control the flow of flue gases in the chimney/stack. A damper (essentially a circular steel plate welded to a piece of rebar along its diameter) mechanism was built for this purpose and placed in the chimney.



FIGURE 49: MECHANISM TO CONTROL DAMPER OPENING

It was also decided to make the combustion chamber larger. Thus the height of the combustion chamber was increased by lowering the grate that supported the fuel. Three separate holes were drilled 10 cm from the bottom of the oil canister for three pieces of rebar to pass through. These would be the new supports for the grate. The opening to input wood was also made larger for convenience.

On advice from locals and staff at Avani on how to use the wood to get higher temperatures and control it, the 2^{nd} dry run managed to achieve an average isothermal Torrefaction temperature of 250° C in the Top Middle Bed and 300° C in the Bottom Middle Bed. This gave an average longitudinal temperature drop of 50° C.

It was learnt that the wood needs to be cut in longitudinal sections to expose its fibers to the flames for a faster rate of combustion to achieve higher flame temperatures. Thus temperature could be controlled by alternating between section cut wood and whole pieces which burn slower, giving much lower flame temperatures.

The following conclusions can be drawn on the design of the reactor from the 2nd Trial experiment:

- 1. Precise control of Torrefaction temperatures is a difficult task when wood is used as fuel. Although some level of control was achieved by understanding the combustion rate based on the size of the wood piece being put in and the extent of wood fiber exposure, it was difficult to control within a range of $+5/-5^{\circ}$ C from the aimed Torrefaction temperature within the bed.
- 2. Closing the damper 2/3rds lead to a sudden drop in flue gas flow and a reduction in ash entrainment due to slowing down of combustion. However, no significant temperature changes were observed in the bed. This could be due to the fact that the reduction in temperature of flue gases due to slower combustion was being compensated by their higher retention time in the stack.

3. The increase in height of the combustion chamber allowed for a higher wood feed rate. This enabled the high temperatures that were needed for Torrefaction that were earlier difficult to achieve. A 50°C temperature difference was observed in the bed during isothermal Torrefaction operation of the plant. The bottom sections of the reactor have to witness a temperature of 300°C or greater for significant Torrefaction to happen in pine needles at higher points in the bed (250°C and greater).

Torrefaction Trial Run with Packed Pine Needles

With the modifications made to achieve Torrefaction temperatures within the bed, the first Torrefaction experiment was carried out with pine needles. The aim of this experiment was to test for leaks in the reactor from the annular region. Moreover, two semicircular steel surfaces were cut out of sheet metal and placed on top of the biomass in the annular region. Stones were kept on top of these sheets to compress the biomass down as the Torrefaction process proceeded. It was thought that this would help in reducing the longitudinal temperature gradient within the reactor and improve the packing (and hence thermal conductivity) within the biomass bed due to greater packing density. The gaps in two reactor doors were covered with wheat dough and the gaps in the other two were just covered with aluminum foil to provide a reference for the effectiveness of wheat dough.

TABLE 27: DETAILS O	F FIRST TORREFACTION	EXPERIMENT WITH I	REACTOR 1

Maximum Weight of Packed Pine Needles (kg)	Packing Density (kg/m ³)	Heat Transfer Surface Area to Volume Ratio (S/V), (m ² /m ³)	Amount of Wood Used (kg)
12	49.35	3.97	19.75

Please refer Appendix 25 for the calculations pertaining to S/V ratio.

The following observations and conclusions could be drawn from the experiment:

- 1. This was a test of the effectiveness of the wheat dough sealing. Doors that were sealed with wheat dough showed very minimal steam leakage. The other doors covered with aluminum foil showed heavy steam leakage.
- 2. After the Torrefaction experiment was completed and the reactor was opened, the following observations were made regarding the Torrefaction of pine needles:
 - a. The pine needle bed height fell down by 30% due to weights placed on top of it. However, this did not seem to have any significant benefits as could be seen in the nonuniform product obtained. This is described in detail under the next heading.
 - b. The cooling process in the reactor is a big challenge. The reactor was left for cooling with temperature readings continued to be taken. On the next day, when the doors of the drum were opened, it was found that the biomass has still not cooled down and the pine needles (especially the portions right at the top and right at the bottom) immediately caught fire when they came in contact with air.

Pine Needle Torrefaction Experiments

After the trial run with the pine needles, a series of Torrefaction experiments were carried out to get an insight into the operation of the reactor. A glasswool blanket was prepared by stitching a layer of glasswool between two aluminum sheets. The blanket was prepared keeping in mind the height and diameter of the oil drum. All 8 thermocouples, as shown in Figure 44, were utilized to measure the

respective temperatures. The top annular surface of the drum exposed to the atmosphere was also covered with a layer of rockwool, pressed down by bricks. In order to avoid over charring right at the bottom of the drum, a layer of bricks (5 cm high) was laid on the bottom surface of the annular region. In order to increase the surface area of heat transfer to volume ratio, four fins were cut made out of aluminum. These fins extended from the wall of the flue gas stack to the wall of the drum, being bolted on each surface. Each fin also extended from the bottom surface of the drum to the top surface of the drum. This way it was hoped that it would reduce radial as well as longitudinal temperature gradients. A hinged door was also made to control the air flow through the primary air inlet.

A lot of different insights were gained through additional thermocouples that were used to get temperature readings. The major observations and conclusions from the experiments were as follows:

- 1. A thin ring of biomass around the flue gas stack gets over charred all along the height of the reactor. The thickness of the ring increases towards the bottom of the reactor which is closer to the combustion chamber. The thickness of this ring varies from about 3-5 cm. The temperature in this ring is on average around 350°C as shown by the Bottom and Top Inner Bed thermocouple readings in Figure 50. A layer of pine needles roughly 10 cm thick is completely charred radially at the bottom of the reactor (before the bricks were used). This is because of their proximity to the combustion chamber. Moreover, since the bottom of the drum was not insulated, it possibly acted as a path for heat dissipation, thus heating the biomass resting on top of it as well. This region is represented by colour red in Figure 51. Proximity to the combustion temperatures (Figure 50). This region is just above the over charred bottom region and is 8-9 cm thick and roughly 20 cm high. It is represented by colour brown in Figure 51.
- 2. Apart from the charred ring observed around the flue gas stack and Torrefaction around the Bottom Middle Bed thermocouple, the reactor showed very poor heat penetration in the radially outward direction. Outside the charred ring, there was a region observed approximately 60 cm high and 4-7 cm wide that underwent very mild Torrefaction (under 200°C). This can be seen by the curve for Top Middle Bed, which just managed to around 200°C at the end of the experiment. This region was followed by the outermost ring, roughly 80 cm high and 6-8 cm wide that was hardly dried (just managing to touch 100°C), represented by curves Top Outer Bed and Bottom Outer Bed. These regions are represented by the colours dark green and light green in Figure 51.



FIGURE 50: TEMPERATURES AT DIFFERENT POINTS IN REACTOR 1 DURING TORREFACTION



FIGURE 51: OBSERVED TEMPERATURE GRADIENTS AT THE END OF THE TORREFACTION PROCESS (EXCLUDING COOLING) (NOT TO SCALE)

Note: in Figure 51, the reduction in heat penetration depths along the height of the dark green region is not shown in the diagram as this is just a simplistic representation based on observations. The temperature at the outer wall of the drum exposed to the surroundings was 70°C and the temperature of the insulation sheet was 40°C throughout the height.

- 3. Mass Yields were measured for one of the experiments. The top section (1st 30 cm of reactor height), gave a Mass Yield of 75%, the middle section (next 30 cm) gave a similar Mass Yield of 78.32% and the bottom section (the last 30 cm) gave a mass yield of 63.32%. The overall Mass Yield was 72.17% on an As Received Basis. Such a high Mass Yield on an As Received basis points to the fact the very little Torrefaction has taken place in the majority of pine needles.
- 4. In the previous points it was discussed that the heat penetration depth for this reactor is very poor. As the mass of pine needles to be heated increases radially outward, the heat penetration times also become longer. Drying also significantly affects the heat penetratiom times for for pine needles further away from the heated wall. Even though all the regions in the reactor reach drying temperatures fairly quickly, the portion of pine needles that are radially distant (and hence also contain more mass) from the heated packed bed wall tend to complete the drying process much later than the pine needles just next to the heated wall. This leads to the radially middle and outer regions drying much later as compared to the pine needles closer to the flue stack. This creates a situation in which the inner portions of biomass are already at Torrefaction temperatures, whereas

the radially middle and outer portions are still in the process of drying. The flue gas temperatures had to be kept above 600°C throughout the experiment to enable faster drying of middle and outer regions. This lead to the over charring of pine needles next to the flue stack. If this is done, the middle radial regions will finish drying after 65 minutes and stagnate at temperatures close to 200°C around 95 minutes. The radially outward regions never finish drying even after 160 minutes, which was the time about which the experiment was called off. Raising the flue gas temperature further (800-900°C), does not really alter this behavior much.

- 5. As discussed earlier, controlling the bed temperatures precisely using wood is very difficult. It was also learnt that the damper prepared was not suitable for temperature control. As an additional try, a door was created out of a steel plate for the primary air inlet of the combustion chamber. However, the opening and closing of this hinged door did not bring about any immediate changes to the combustion process, as is absolutely necessary for precise control of temperature within a small range. Thus the temperature could only be controlled by varying the wood feed rate, size of wood pieces fed in, extent of exposed wood fibers in the pieces and removing the wood pieces from the combustion chamber by hand to bring the temperatures down immediately. This is very inconvenient and a major drawback of the design.
- 6. The fins added to the reactor made no significant difference in improving radial heat transfer and the bricks laid at the bottom of the drum helped in preventing the over charring of the pine needles there.
- 7. During the drying phase, steam was seen condensing on the retort pipes. At times, when the moisture content in the biomass was high, there was high steam production and one could see this steam flowing into the combustion chamber through the retort pipes. If the steam production was excess, some of it would also escape through to the surroundings through the other opening of the T-junction.
- 8. The volatile gases and steam produced were seen to be sucked into the combustion chamber through the retort system. However, due to the lag in drying happening in different sections of the reactor, steam was always produced throughout the run and hence the input of the gas to the combustion chamber will not bring any significant calorific benefits. Moreover, after the experiments it was found that the pine needles in the top of the reactor were wet due to the condensation of certain fraction of the volatiles and steam. Since Torrefaction/pyrolysis was only happening in a thin charred ring, the volatile gases produced might have channeled their way through this section to the top without coming in contact with biomass in other regions (and hence condensing there). When the fire in the combustion chamber was extinguished for reactor cooling, the driving force for the volatiles to enter the retort pipe also decreased. The volatiles remained in the top region of the reactor, above the bed, condensing on the top layer when the reactor began to cool. Some portion of the volatiles might have also condensed during operation due to the low temperatures on the top of the reactor. Thus, for this design, the retort system design was flawed.
- 9. Cooling is a big issue with this reactor design. After the fire in the combustion chamber has been put out, the pine needles cannot be taken out immediately as they begin to catch fire on coming in contact with air. As observed in the trial runs, even after 24 hours, the temperatures in some regions of the bed were above 200°C (the bottom most section, the top most section and next to the flue gas stack). It was decided that dumping the pine needles into a tub of water immediately after Torrefaction should be avoided, as it will create another drying step. Also, water usage

should be minimized as the region is water stressed. Various methods were tried, with all of them failing to prevent combustion of pine needles.

- **a.** A long ladle was manufactured to scoop out the pine needles immediately after the experiment and lay them on a wire mesh. The pile of pine needles was then covered with a layer of wet jute sacks for cooling as well as to minimize oxygen entry. Water had to be poured all over the pine needles to prevent a fire.
- **b.** Squared sectioned tubes filled with water were manufactured and inserted into the pine needle bed post Torrefaction; however, they had no significant effects in bringing down temperatures.
- **c.** In the end, the reactor had to be cooled by running water through the flue gas stack and pouring water around the outer wall of the drum after removing the insulation. This gave slow cooling results helped in reducing the bed temperatures.



FIGURE 52: PINE NEEDLES ON FIRE AFTER OPENING DOOR FOR COOLING THE NEXT DAY



FIGURE 53: PINE NEEDLES BEGINNING TO CATCH FIRE



FIGURE 54: ONE CAN SEE THE THIN CHARRED SECTION, FOLLOWED BY THE MILDLY TORREFIED AND JUST DRIED SECTION (NOT TO SCALE)



FIGURE 55: PINE NEEDLES RIGHT AT THE TOP OF THE BED. THE PINE NEEDLES LOOK WET DUE TO THE CONDENSATION OF VOLATILE FRACTIONS



FIGURE 56: REACTOR SETUP WITHOUT INSULATION



FIGURE 57: DOORS SEALED WITH WHEAT DOUGH WORKING WELL



FIGURE 58: THE MODIFICATIONS OF INCLUDING FINS AND A BOTTOM BRICK LAYER



FIGURE 60: INSULATION SHEET PREPARED



FIGURE 59: LOWERING OF COMBUSTION CHAMBER AND INCLUSION OF DOOR FOR PRIMARY AIR INLET

3.1.5 REACTOR 2

Based on the poor performance of reactor 1 to provide a product with fairly uniform levels of Torrefaction, it was decided to construct another similar packed bed reactor with a higher surface area of heat transfer to volume ratio. To make this possible, without compromising much on the simplicity of design, the heat flow direction was essentially inverted. A separate cylindrical chamber of the dimensions of the flue gas stack was constructed. This cylindrical chamber would be placed in the center of a bigger drum. The flue gases from the combustion chamber would flow through the annular region, thus transferring heat radially inward to the biomass. In this way the higher mass of biomass in the outer radii of the packed bed would get heated first (and would be exposed to higher temperatures) leading to more Torrefaction of the pine needles. Moreover, as the volume of the pine needles in the packed bed has decreased, the heat transfer process will have a higher surface area to volume ratio that could possibly give improvements in penetration depths for radial heat transfer. The annular region in the reactor was made considerably smaller as compared to reactor 1 to maximize the surface area contact between the wall of the packed bed cylinder and the hot flue gases. Moreover the height of the chimney was reduced by 30cm to reduce the flow rate of flue gases through the annular region.

The reactor was essentially built out of a sheet of galvanized iron ordered from a town in the plains just before the hills. These sheets were not available locally. However, the reactor was completely built locally using hand molding of the sheets to cylinders, followed by gas welding of different parts. The description of the manufacturing process adopted is described in detail in the report of Ryan Helmer.



FIGURE 61: DIFFERENT COMPONENTS OF REACTOR 2, LEFT TO RIGHT: COMBUSTION CHAMBER OUTER DRUM ASSEMBLY, PACKED BED CYLINDRICAL VESSEL, THE CHIMNEY HOOD. BACKGROUND: THE PERSON WHO MADE THE REACTOR, MR.MOHAMMAD IRFAN.

The simple hand drawings utilized for construction in the local workshop are given in Appendix 26.

FIGURE 63: REACTOR 2 ASSEMBLY



FIGURE 62: THERMOCOUPLE ARRANGEMENT FOR REACTOR 2

(DIMENSIONS IN METRES)

A hinged door was included in the reactor drum wall for easy insertion of thermocouple wires through the outer drum till the packed bed in the lower section of the reactor. The thermocouples were inserted radially through holes made on the walls of the outer drum and the packed bed. Figure 62 shows the thermocouples inserted from the top for the purpose of clear representation. The distance between the combustion chamber and the packed bed was increases by 20cm w.r.t reactor 1 to avoid over charring of pine needles at the base of the drum. A one inch diameter hole was drilled on the lid of the packed bed vessel for the escape of the Torrefaction gases along with the flue gases. The use of fins, damper and retort pipes were avoided as they did not add any benefit to heat transfer, temperature control or calorific contribution to the combustion process respectively. The same glass wool insulation sheet prepared for reactor 1 was used for this reactor as well. Torrefaction experiments with sun dried pine needles were carried out in a similar fashion as with reactor 1. The junction between the chimney cap and the reactor outer drum was sealed using wheat dough. A Torrefaction condition of 270°C and 30 minutes was aimed for the Bottom Outer bed thermocouple. This was done as the temperatures shown by the bottom thermocouples are easier to control than the temperatures shown by the top thermocouples.



FIGURE 64: TEMPERATURE DISTRIBUTION FOR REACTOR 2

The following conclusions can be drawn on the design of reactor 2 based on the experiment conducted:

- 1. The input and removal of biomass was made much easier by the fact that the reactor vessel could be taken out and pine needles could be loaded from the top.
- 2. Reactor 2 showed good cooling rates due to the lower mass of pine needles packed in the bed. Pouring of water on the walls of the drum further helped in improving the cooling rate. The sudden drops in temperature towards the end are due to the removal of the thermocouples from the bed to enable taking out the packed bed vessel for cooling.
- 3. No condensation of the volatiles on the biomass was observed, possibly due to their escape through the hole drilled on the packed bed lid during the operation of the reactor.
- 4. However, again, the reactor still produced a product which was not uniformly Torrified across the volume of the reactor. Overall, one could see from the over charred product obtained that the penetration depth was 2-3 cm more compared to reactor 1 across the height of the reactor, but there were still significant radial temperature gradients. The non -uniform product obtained across different heights in the reactor is shown in Figures 66-68. At the location of the bottom thermocouples, the radially distant (middle and inner points) pine needles w.r.t the hot wall dried faster as compared to reactor 1, but were delayed by 36.56 and 57.78 minutes as compared to the radially outward points close to the wall. As a result, these sections just underwent drying at the end of the experiment. One can expect similar behavior at higher sections in the reactor with even more delayed responses to drying due to longitudinal temperature differences. This is also shown in Figures 66-68, with increase in area of non-Torrified pine needles.
- 5. The inner bed temperature being greater than the outer bed at the height of the bottom thermocouples (Figure 64) can be due to different moisture contents at the two points.
- 6. During the isothermal Torrefaction period, the top section of the reactor showed higher temperatures of 295°C-330°C for the three radial distances. Moreover, the temperatures for these different radial points were fairly close to each other and they rose to these values in roughly the

same time. This suggests an alternate phenomenon occurring in heating the pine needles. This could mostly be due to significant levels of oxygen (probably in the flue gas) entering the reactor bed through the hole drilled for the escape of the volatiles. The conical hood of the chimney could also not be fixed in a stable way on the outer drum. It could also be possible that air leaked in from under the hood.

- 7. The sections of pine needles at the base of the packed bed, below the bottom thermocouples, were completely charred. Thus, raising the packed bed by 20 cm from the combustion chamber did not have an impact.
- 8. Due to a shortened chimney height, ash entrainment was substantially reduced.
- 9. The height of the bed had dropped from 90 cm to 75 cm (15 cm difference) when it was examined after the experiment.

Max. Amount of Pine Needles packed in reactor bed (kg)	Amount of Wood Used in Combustion Chamber (kg)	Packing Density (kg/m³)	Mass Yield (%) (As Received Basis)	Total experiment duration	Heat Transfer Surface Area to Volume Ratio (m²/m³)
6.08	7.65	95.6	61.72 %	4 hour 15 minutes	13.36

TABLE 28: REACTOR 2 PINE NEEDLE PACKING DETAILS AND EXPERIMENT DURATION

The pine needle packing density of reactor 2 is almost double that of reactor 1 (49.35 kg/m³). The heat transfer surface area to volume ratio is also 4 times more (calculation in Appendix 25). This is reflected in more Torrefaction represented by the lower Mass Yield obtained. However, the heat penetration is still not deep enough for the Torrefaction of the entire bulk of the biomass. Based on the nature of non-uniform product produced, one has to conclude that even the design of reactor 2 is not suitable enough for further refinement.

Thus, the poor performance of reactor 1 and reactor 2 leads to the conclusion that the shell and tube reactor design described previously is not a design worth pursuing. However, due to data available on the operation of this reactor based on experiments conducted, it was decided that reactor 2 will be chosen as the design for all calculations pertaining to Torrefaction business parameters. The total experiment duration mentioned in Table 29 starts from the preparation of the reactor and the bed and ends when all the sections of the bed have reached the surrounding temperature. Through practice, each batch can be finished in 3.5 hours, which is a value also assumed to assess the business case for Torrefaction. A residence time of 15 minutes will be chosen in the next section of this chapter for isothermal Torrefaction. Thus, four batches are possible in a day, giving 12 hours to run all the batches. Thus a 14 hour workday was assumed after accounting for 1 hour extra for plant startup and shutdown. Unlike some of the small power generation plants in the region, 24 hour operation of the plant was avoided as the general impression was that the plant workers were being underpaid for the amount of effort they put in. This can lead to higher attrition rates with the workers opting for jobs with similar or higher salaries but with much less work hours in the urban centers, thus failing the project in its initial purpose of providing jobs locally and preventing outmigration.



FIGURE 65: OPERATION OF REACTOR 2



FIGURE 66: TOP MOST PART OF BED WHICH IS ALMOST COMPLETELY CHARRED



FIGURE 67: MIDDLE PORTION OF THE BED



FIGURE 68: TORREFACTION AT THE BOTTOM THERMOCOUPLES. THE BASE OF THIS PILE IS COMPLETELY CHARRED AS IT WAS CLOSEST TO THE COMBUSTION CHAMBER

3.1.6 CONCLUSIONS

On the basis of testing carried out with the indirectly heated packed bed batch design, it can be concluded that the indirectly heated packed bed design tested was flawed and the following points sumarize its operation:

- 1. The radial temperature gradients are too large to carry out Torrefaction of significant portion of pine needles. This leads to product that is either too charred or has just managed to dry or very mildly Torrified (under 200°C). Drying significantly affects the dynamics of operation of the reactor. Even though all the regions in the reactor reach drying temperatures fairly quickly, the portion of pine needles that are radially distant from the heated packed bed wall tend to complete the drying process much later than the pine needles just next to the heated wall. Even increasing flue gas temperatures to around 800-900°C did not have a significant effect on improving the rate of drying.
- 2. Temperature control during the isothermal Torrefaction period is difficult with the use of wood/solid biomass as a fuel for the combustion chamber.
- 3. The use of fins did not lead to any observable improvements in the extent of Torrefaction. The use of bricks helped in preventing overcharring of the pine needles in the base of the reactor.
- 4. The use of a damper helped in preventing ash entrainment, but did not have any observable impact in the temperature of the bed.
- 5. Top loading of the pine needles in reactor 2 was found to be much more convenient than side loading through doors in reactor one. One can compress the biomass more easily by hand, leading to higher packing densities.
- 6. After the experiments it was found that the pine needles in the top of the reactor were wet due to the condensation of certain fraction of the volatiles and steam. Since Torrefaction/pyrolysis was only happening in a thin charred ring, the volatile gases produced might have channeled their way through this section to the top without coming in contact with biomass in other regions (and hence condensing there). When the fire in the combustion chamber was extinguished for reactor cooling, the driving force for the volatiles to enter the retort pipe also decreased. The volatiles remained in the top region of the reactor, above the bed, condensing on the top layer when the reactor began to cool. Some portion of the volatiles might have also condensed during operation due to the low temperatures on the top of the reactor.
- 7. Wheat dough worked fairly well as a sealant and can be a cheap alternative to stove sealants or clay sealants.
- 8. Cooling in the packed packed bed reactor design was a very time consuming process. The method of immediate removal of pine needles from bed and placing wet jute sacks on top of them did not work well. With no gas available to flow through the bed and cool the biomass, the only way to cool the reactors quickly without opening the reactor is to pour water on the outside wall the packed bed drum. However, this method did not show good results for reactor 1. Reactor 2 gave good cooling rates due to the lower mass of pine needles packed in the bed. Pouring of water on the walls of the drum further helped in improving the cooling rate.

Recommendation:

9. The very idea of complete local manufacturing of the reactor should not be pursued in the future. The simple designs pursued, constrained by local manufacturing capabilities, put limitations on the heat transfer and control of temperatue within the bed, giving a poor quality product. To a large extent, future designs have to be built in the plains, where better technical facilities will lead to higher quality construction and open up avenues for more sophisticated reactor designs to be used. However, for the purpose of this project all business calculations are based on the design of reactor 2 as its geometrical and operational parameters were available through testing.

SECTION II

3.2 EXPERIMENTAL STUDY OF PINE NEEDLE TORREFACTION

Torrefaction is defined as slow heating of biomass in an inert environment and temperature range of 200-300°C. It is a partially controlled process of isothermal pyrolysis of biomass occurring in the temperature range of 200-300°C. The treatment results in a solid product which is uniform, with lower moisture content and higher energy density compared to raw biomass. Torrefaction also lowers the O/C ratio and makes the fuel more efficient for applications such as gasification and combustion[20].



FIGURE 69: EFFECT OF PRE-TREATMENT ON LIGNO-CELLULOSIC BIOMASS[20]

3.2.1 Effect of Elevated Temperatures on Different Constituents of Biomass

When biomass is exposed to elevated temperatures, it undergoes thermal degradation which is accompanied by loss of mass. The extent of thermal degradation depends strongly on the temperature and on residence time. The different constituents of biomass behave (degrade) differently when exposed to a particular heating rate. The structural and chemical compositional changes are influenced by a number of factors such as temperature, residence time, heating rate, initial biomass composition etc.

Temperature range: 50-150°C

In this temperature range, the raw biomass typically loses unbound moisture and begins to shrink. The biomass can re-absorb moisture if wetted again. Most of the chemical constituents of biomass remain intact and hence this region is known as the non-reactive drying zone. At higher temperatures within this temperature range (120-150°C), the lignin begins to soften and this makes the densification of biomass much easier as lignin is a natural binder[20].

Temperature range: 150-200°C

This temperature range is called the reactive drying range and the decomposition of biomass begins. The removal of bound water begins at around 160° C, when the formation of CO₂ begins. The structure of the biomass deforms, which cannot be regained even if the biomass is rewetted. De-polymerization of hemicellulose takes place, which results in shortened and condensed polymers with a solid structure. The

carbon and hydrogen bonds break due to thermal degradation, thus releasing lipophilic extractives and compounds[20].

Temperature range: 200-300°C

This temperature regime, called destructive drying, results in the de-volatilization and carbonization of biomass. Here, the cell structure begins to get destroyed as the biomass loses its fibrous nature and becomes brittle.

Due to the breakage of most intermolecular and intra-molecular hydrogen bonds and the C-C and C-O bonds, hydrophilic extractives, carboxylic acids, alcohols, aldehydes, ether, water vapour and gases like CO, CO₂, and CH₄ are formed. In this temperature regime, mass loss predominantly results from the decomposition of hemicellulose and some lignin. The decomposition of hemicellulose starts roughly around 180°C and continues till roughly around 300°C. Xylan based hemicellulose begins to decompose at roughly 250-280°C. The decomposition reactions also lead to the destruction of the hydroxyl groups (OH), which further leads to the increase in the specific heating value of the product. The destruction of the OH group makes the product hydrophobic, thus preventing microbial attacks on stored biomass.

In this temperature range, the predominant gases produced are water vapour, CO_2 , CO, some amount of acetic acid and phenols. The energy values of these compounds are relatively low, leading to significant increase in energy density of the biomass[20].

<u>Temperature range: $> 300^{\circ}C$ </u>

At temperatures greater than 300°C, there is extensive carbonization and de-volatilization of the biomass.

At temperatures lower than 250°C, the mass loss is at a minimum as there is limited decomposition of hemicellulose. At temperatures greater than 250°C, mass loss increases as there is extensive breakdown of hemicellulose coupled with limited breakdown of lignin and cellulose. Lignin decomposition proceeds more slowly and starts at around 200°C[20].

3.2.2 BRIEF OVERVIEW OF PAST EXPERIMENTAL WORK

There are a significant amount of studies quantifying the mass and energy yields of different kinds of biomass, including lingo-cellulosic biomass such as agricultural residues, for Torrefaction under different process conditions[62]. Additionally, research in the past has predominantly focused on examining the mass yields, energy yields and constituent decomposition behavior for woody material predominantly. Less attention has been given to the Torrefaction of other lingo-cellulosic biomass such as agricultural residues, forest residues and grass. Among the studies that have been conducted for Torrefaction of lingocellulosic biomass, Pach et. al[63] studied the effects of Torrefaction temperature and residence time on the product distribution and properties of the product for birch, pine and bagasse. The experiments were conducted in a packed with reactor with the reactor tube being heated by electrical heaters. The reactor was purged with a nitrogen flow of 5 l/h. It was found that during the Torrefaction, the wood (birch and pine) sample gave more solid yield and less tar, water and gas than the agricultural residue sample (bagasse). Sadaka and Negi[64] carried out Torrefaction of rice, wheat straw and cotton-gin waste and found that temperature has a greater effect on the chemical and the thermo-physical properties than the residence time of Torrefaction. These experiments were carried out in a muffle furnace, purged with nitrogen flow. Pimchuai et. al[65] studied the Torrefaction of rice husk, bagasse, peanut husk, water hyacinth and saw dust within a range of Torrefaction temperatures and residence times. A muffle furnace was used to carry out the Torrefaction process. They found that the difference between the mass and energy yields improved for higher Torrefaction temperatures. Their results showed that depending on the

severity of Torrefaction conditions, the Torrified fuel can contain can contain 98% of the original energy content on a mass basis. Mass and Energy yields were reported in the range of 41-78% of the original weight and 55-98% (98% being for water hyacinth) of the original energy content respectively. It was seen that temperature has a stronger impact on the increase in energy density of the Torrified biomass. Deng et al.[66] Torrified rice straw and rape stalk to evaluate the pretreatment of torrefaction for co-gasification. They reported that the heating values of the Torrified rice straw and rape stalk could be increased up to 17% and 15%, respectively, compared to those of the raw materials. The properties of the Torrified agricultural residues were closer to that of coal. Thus, they found that torrefaction was a promising method for biomass to combine with coal co-gasification.

Chen et. al[67] carried out Torrefaction of four different kinds of biomass materials: Bamboo, willow, coconut shell and wood (Ficus Benjamina L.). The Torrefaction and pyrolysis study was carried out in a Thermo-gravimetric analyser (TGA). From the results of TGA and DTG (Differential Thermo-gravimetry), they found that the reactions of hemicellulose and cellulose mainly occurred at the temperatures between 200°C and 400°C. Light Torrefaction carried out at 240°C has a significant effect on the depletion of hemi-cellulose, but its impact on cellulose and lignin was slight. Over 60% of the mass was preserved in light Torrefaction. The mass yields were much lower for severe Torrefaction at 275°C and it was concluded that severe Torrefaction is not recommended to pre-treat biomass to increase its energy density.

3.2.3 RESEARCH SCOPE

The objective of most torrefaction studies in the past have been to quantify mass and energy yields for different kinds for biomass, including herbaceous biomass such as grass and agricultural residues within a range of process conditions[66], [68]–[72]. The effects of the thermo-chemical treatment were studied through changes in certain fuel characteristics such as elemental composition, volatile/fixed carbon ratio, and calorific value of the Torrified product. These studies show that with increasing Torrefaction severities there are greater deviations from the properties of raw biomass such as higher calorific value, lower O/C and H/C ratio and a decrease in volatile yields. The weight loss in Torrefaction and improvement in properties have been attributed to the devolatilization of the hemicellulose fraction (and partial degradation of cellulosic and lignin fractions) of biomass. It has been seen that for biomass types with high hemicellulose contents, the weight loss is also higher (and especially prominent at higher temperatures)[69], [73], indicating that hemicelluloses is the least thermally stable structural constituent of biomass, followed by cellulose and lignin.

Additionally, most of the experiments were carried out in idealized lab scale set ups such as a muffle furnace or a Thermo-gravimetric Analyser. There is a severe gap in research where Torrefaction is carried out in realistic heat and mass transfer regimes to get practical estimates on mass and energy yields. In this study, not only is Torrefaction is carried out in a TGA setup, but also carried out in setups with realistic heat and mass transfer regimes. One of the setups is a direct convectively heated packed bed setup and the other setup which was designed for the project is essentially a sealed cylindrical vessel, which can be packed with the biomass and kept in a muffle furnace for Torrefaction. This would roughly simulate the mode of heat transfer employed in reactor 2, which was radial conduction of heat through the cylindrical walls to the biomass inside the reactor. Ordinary muffle furnace experiments involve Torrefaction of biomass in an open crucible purged with an inert gas flow. There is also hardly any literature available which talks about how Mass and Energy Yields, when applied to an actual Torrefaction reactor design, affecting a real time Torrefaction business.

There are very few scientific studies done evaluating the performance of pine needles as a fuel from an engineering perspective in different thermo-chemical processes. As a result, that there are almost nil

studies that focus on the pre-treatment to improve the quality of pine needles as a fuel. There are some general studies that talk about the potential of using pine needles for gasification and production of charcoal from pyrolysis to be used as cooking fuel, but these are not scientific assessments and are more or less a list of different energy uses of pine needles [24], [25]. There is also a severe gap in information available in terms of pyrolysis of pine needles at lower temperatures, as would be the case in Torrefaction. There are some studies which talk about the kinetics associated with high temperature pine needle pyrolysis combustion and derived hemicellulose[74]. This study derives a kinetic model for dynamic and isothermal pyrolysis of pine needles based on results obtained from thermo-gravimetric testing of pine needles and even finds out the ethanol solubilized hemicellulose, cellulose and lignin fractions. Though the kinetic model for pine needle pyrolysis is useful, it is essentially a theoretical result and the results could be complemented through real time estimation of Mass and Energy Yields in a setup with realistic rather than idealized modes of heat transfer. Moreover, this study focuses on severe pyrolysis rather than Torrefaction. Other studies have predominantly concentrated on ultimate and proximate analyses of raw and severely pyrolysed pine needles and its briquettes, followed by combustion characteristics of both the products[24], [75].

The research done for this project focuses on establishing Mass and Energy Yields for different process conditions of Torrefaction under realistic mode of heat and mass transfer through setups described in the subsequent sections. Real time calorific value of the Torrified product will be obtained through bomb calorimetry experiments. Moreover, the behavior of Mass and Energy Yields with different process conditions will be discussed and connected to the thermal degradation of hemicellulose, cellulose and Lignin through a Differential Thermo-gravimetric Analysis.

Moreover, to make the research even more practical, the Mass and Energy Yields will be applied to the reactor design 2 mentioned in the previous sections and the impact of on business case for a potential Torrefaction business with cooking fuel as the main application will be studied. Finally, a choice will be made on the optimal Torrefaction temperature and residence time for the business, based on the Mass and Energy Yields carried found out and their impact on the business case.

3.2.4 RESEARCH GOAL

The experimental study of Torrefaction of pine needles had a twin purpose. Firstly, it aimed to establish the Mass and Energy yields for different process conditions (temperatures and residence times). This information is necessary as calorific value of the fuel produced can directly affect the daily demand of fuel from the end users. The Mass Yields for different process conditions also has a direct impact on the amount of biomass needed daily to produce a fuel to meet the market demand. Furthermore, this affects the biomass collection and fuel transportation costs, factory operational costs and maintenance costs. The importance of Mass and Energy yields also lies in the fact that it can help in giving reasonable back of the envelope estimations of overall energy efficiency of the Torrefaction process carried out in the final reactor design selected (reactor 2). This is based on the energy expended on the drying and Torrefaction of pine needles and initial energy "contained" in the As Received pine needles as input, and energy "contained" in the final Torrified product as output. This can help make decisions in choosing more efficient means of providing heat for Torrefaction for the chosen reactor design.

The second important goal of this experimental study was to gain insight into the variations of Mass and Energy Yields with different process conditions. Moreover, a thermal degradation study of different constituents of pine needles using a Differential Thermo-gravimetric Analysis (DTGA) will help in postulating the reasons for variations in mass yields with different temperatures and residence times. Comparisons with Torrefaction of different biomass (such as verge grass, as used here) will help in giving a perspective on where pine needles stand as a fuel for thermo-chemical conversion processes.

Finally, based on the impact of the Mass and Energy Yields on the profits of the Torrefaction business, overall energy efficiency of Torrefaction for each batch of a reactor, the final end use of the fuel and suitability of different process conditions to the end use, a final choice will be made on the process conditions for Torrefaction of pine needles (in terms of temperature and residence time).

3.2.5 RESEARCH METHODOLOGY

The pine needle samples were obtained from the pile at Avani's pine needle gasification plant without undergoing any prior cutting, drying or pre-treatment. As the pine needle samples were wet due to frequent evening rains, they were kept for sun drying for 24h at the Avani campus. Twelve kg of sun dried pine needles were posted to the Faculty of Process and Energy, TU Delft, to carry out Torrefaction experiments upon return from the field research in India. The samples were available for testing in the lab in May 2015. Drying of the samples was carried out in ovens kept at 105°C for 24 hours. After six trials, the average moisture content was found out to be 12.87% (As Received, partially dried). The moisture content in the 6 trials is given in Appendix 27. Based on field experience, this should be considerably lower than the moisture content of pine needles typically found on the forest floor. Since the study done is this project is based on direct use of As Received pine needles for Torrefaction, an As Received moisture content of 25% was assumed. For most calculations involving the effect of Torrefaction process conditions on the business case for the factory done in chapter 2, the Mass Yields, Higher Heating Values and Energy Yields were translated to an As Received basis (based on assumed moisture content) from the Dried Basis study of Mass and Energy Yields. Combustion of dried pine needles in a Muffle Furnace gave an average ash content of 11.73% (Dried Basis).

3.2.6 PRODUCTION OF TORRIFIED BIOMASS AND ITS ANALYSES

Torrefaction of the pine needle samples were carried out using a direct convectively heated packed bed Torrefaction experimental setup, a packed bed cylindrical vessel heated in a muffle furnace and a Thermo-gravimetric Analyser setup.

The packed bed Torrefaction setup as shown in Figure 70 consists of a vertically disposed stainless steel (AISI 316) tube with a volume of 0.87 litres. The tube has a diameter of 56 mm and a length of 360 mm. The tube is divided into three equal compartments of 120 mm each, (referred to as the bottom, middle and top) by means of perforated dividers to allow for the flow of convective media. Each compartment is equipped with a thermocouple, positioned midway along the compartment, measuring the temperature in the core of that section. The perforated dividers for these set of experiments were removed and a cylindrical wire mesh "stool" was prepared to rest a 10 cm high thin slice of oven dried pine needles in the bottom section of the reactor. A cylindrical wire mesh "cap" was also prepared to constrain the pine needles resting on the "stool". As a convective packed bed reactor does not simulate the regime of heat transfer in the reactor designs built in India, Torrefaction was carried out for a thin slice of pine needles to reduce the heat transfer regime effects on Torrefaction. Moreover, the data collected through permanent gas sampling of the evolved Torrefaction gases from this thin slice of pine needles would be integrated for the entire reactor 2 chosen in Section I. This is carried out by Ryan Helmer in his modelling of the total permanent gases produced during operation of the reactor 2 chosen in. The thin slice was packed with 10g ±0.4g of oven-dried pine needles. Heat was convectively transferred to the biomass packed inside the tube volume using an electrically heated inert gas (nitrogen) with a total volume of 60 normal litres per minute (Ln·min-1) by means of a mass flow controller. The desired Torrefaction temperature was reached using a ramping rate of approximately 7-8 °C per minute, following which the temperature was maintained for a period referred to as the *Torrefaction time*. For a given set of target Torrefaction temperature and time, the reference input to the controller of the electrical gas heater was the temperature measured in the *bottom* compartment (TIC102). Consequently, the torrefaction temperatures and time stated for an experiment truly represent the conditions only experienced by the *bottom* compartment of the packed bed of biomass. A Thermocouple was also used to measure the temperature of nitrogen gas flow just prior to entering the packed bed reactor (TI201). This setup was used for the torrefaction temperatures of 230°C, 250°C, 270°C and 290°C for a Torrefaction time of 45 minutes. Humidity measurements were also not performed. An experiment was designated in the following manner: temperature-residence time-nitrogen flow rate (60 Ln.min-1). For example, an experiment with a Torrefaction temperature of 250°C and residence time of 45 minutes was written as 250-45-60.



FIGURE 70: SCHEMATIC DIAGRAM OF DIFFERENTIAL SLICE TORREFACTION EXPERIMENTS

The Higher Heating Value (dry basis) of the raw and Torrified pine needles was determined through bomb calorimetry (two trials to check repeatability of results), using a Parr automatic bomb calorimeter. The oven dried pine needle samples and Torrified samples were ground to a particle size of 3-5mm. Then, to ensure controlled combustion, 1 g of the raw biomass and Torrified sample was pelletized in a hydraulic press (20 mm die), with a compression force of 50kN.

The permanent gas sampling was carried out using a gas analysis setup manufactured by Mechatest Sampling Solutions B.V., The Netherlands. The setup allowed the simultaneous determination of CO, CO2, CH_4 and O_2 gases using a combination of near- infrared and paramagnetic detectors. The apparatus included a pump, a rotameter to regulate the flow at a constant rate of 60 Ln h⁻¹, a filtration unit, a gas conditioning system MAK 10 (AGT, Germany) and an online gas analyser X-Stream WEGP (Emerson Process Management GmbH, Germany).

The exhaust gas stream was equipped with a sampling line which was used for extracting the torrefaction gases and condensable volatiles for analysis. The maximum flow through the sampling line was controlled by a needle valve, with another needle valve on the main exhaust line acting as a damper to

ensure adequate back pressure. The sampling line consisted of impinger bottles connected in series to condense the 'liquid volatile' fractions of the torrefaction gases (such as acetic acid, formic acid, and methanol). The impinger bottles, each containing 20ml of demineralized water, were immersed in an icebath, for direct cooling and condensation of the condensable gases. It was empirically determined through previous experiments in the faculty that a train of two such bottles of 250 mL volume was adequate for condensing the majority of the volatiles. This was necessary to do to avoid condensation of these volatile gases in the permanent gas sampling setup. To avoid any pre-condensation of volatiles, the main exhaust line from the reactor as well as the sampling line leading up to the first impinger bottle was electrically traced to a temperature of 200°C. After removal of the condensable volatile fractions, the gas was ready to pass through the online analyser for detecting the concentrations of the non-condensable components including CO, CO_2 , CH_4 and O_2 . The gas analysis study is discussed in the report of Ryan Helmer.

Condensable volatiles measurement was not performed in this setup due to significantly low concentrations of products seen (insufficient to be well detected) through the UV and RI spectroscopy in a High Performance Liquid Chromatography setup at the chemical-physical laboratory at TU Delft. This bench scale reactor only allowed for a small portion of the Torrefaction gas flow to be extracted, due to limitations of flow rate through the gas analyzer (50-60 L/hr). For greater concentration of condensable volatile gases to be detected it was important that greater mass of the biomass sample was used for Torrefaction, however this was not possible as only a thin slice of pine needles had to be tested.

In order to verify the Mass Yields obtained through the packed bed experimental setup, another set of Torrefaction experiments was performed for the same process conditions (230-45, 250-45, 270-45, and 290-45) in a muffle furnace with a biomass heating rate of $5-7^{\circ}$ C/min. A sealed cylindrical container was used to pack 10g of powdered pine needles. This was done to avoid entrainment of pine needle particles with inert gas flow in the muffle furnace and to avoid combustion of pine needles due to limitations in sealing capabilities in the muffle furnace. Thus, the predominant mode of heat transfer from the muffle furnace to the biomass is conduction through the wall of the sealed container and the biomass within. This experiment also gave a closer simulation of the conduction regime of heat transfer employed in the two reactors built and tested in India. Two thermocouples measured instantaneous temperatures inside the bed as well as outside the bed (within the muffle furnace chamber). This experiment however, was mainly carried out for the cumulative sampling of condensable volatiles, which was unsuccessful in the packed bed setup. With this setup one could sample greater concentration of volatiles released from the small biomass sample of 10g. The sealed vessel was purged with a small flow of N2, to drive the volatiles produced to impinger bottles downstream for condensing them. The sampling of condensable volatiles and permanent gases, the data analysis and subsequent modelling of Torrefaction gases produced for reactor design 2 is extensively discussed in the thesis report of Ryan Helmer. As far as this study is concerned, this experiment was only used as confirmation of Mass Yield results obtained from the packed bed experiments. The muffle furnace Torrefaction experimental setup is illustrated in Figure 71.



FIGURE 71: TORREFACTION WITH RADIAL CONDUCTIVE HEAT TRANSFER

The mass and energy yields obtained till now were only for a residence time of 45 minutes. Due to practical reasons, experiments for residence times of 15 minutes and 30 minutes could not be carried out in the packed bed Torrefaction setup. Torrefaction experiments were carried out in a Thermo-gravimetric Analyser for 230-45, 250-45, 270-45 and 290-45 (heating rate 10°C/minute). The Mass Yield variation as a function of temperature and time was obtained from the TGA data logger and this gave the Mass Yields for residence times of 15 minutes and 30 minutes for the four Torrefaction temperatures. Energy Yields for these residence times was obtained by using the equation Mass Yield-Energy Yield equation obtained earlier. The heating rates employed in the three experiments are fairly close to each other (5-10°C/min) and should not have any significant impact on the results.

Note: Average Mass Yields for a 45 minutes residence times obtained through the three experiments was used to get the relation between Energy Yield and Mass Yield. The method of average calculation is mentioned in section 3.2.7.

Hence based on the Mass Yields and Higher Heating values for the Torrified pine needles (230-45, 250-45, 270-45, 290-45), the Energy Yields were also found out for these process conditions using the equation:

$Energy Yield = Mass Yield * \frac{HHV of Torrified pine needles}{HHV of dried pine needles}$

Based on the Mass and Energy Yields thus obtained, a curve of Energy Yield vs Mass Yield was plotted giving an equation for the curve whose slope which is characteristic of the biomass, in this case pine needles. This equation gave a correlation between Energy Yields and Mass Yields. This correlation was used to calculate the Energy Yields for Torrefaction at residence times of 15 minutes and 30 minutes based on Mass Yields obtained from the TGA study.

In order to get some understanding of the thermal degradation of different constituents of pine needles as a function of temperature, a Differential Thermo-gravimetric Analysis (DTGA) was carried out for pine needles. Dried pine needles were dried (ramped at 20°C/min and isothermal for 5 minutes at 120°C) and pyrolysed in the TGA setup upto 600°C (heating rate 10°C/min) to help postulate the evolution of different compounds (Hemicellulose, cellulose and Lignin) during Torrefaction temperatures and even

beyond. DTGA for Torrified pine needles was carried out by first Torrifying the pine needles up to the desired temperature and a residence time of 45 minutes, cooling the pine needles to a temperature of 100° C and then ramping the temperature at 10° C/min till 600° C to carry out pyrolysis for the DTGA analysis. The Torrefaction Mass Yields obtained from these experiments helped to cross check with the Mass Yields obtained from previous TGA and packed bed Torrefaction experiments.

The Thermo-gravimetric Analyses were carried out using a TA instruments thermos balance (model SDT-Q600). Approximately 10 mg of dried and powdered pine needle samples were used in each case.

3.2.7 MASS AND ENERGY YIELDS

Figure 72 illustrates the temperature profile for the Torrefaction of thin slice of 10g pine needles in the convectively heated packed bed Torrefaction test rig. One can see three distinct regions in the Torrefaction process. The first region or the "Temperature ramp" region includes the drying of pine needles of the residual moisture left in it, followed by a temperature rise up till the desired Torrefaction temperature, which in this case is 290°C (on an average). The temperature is controlled at 290°C by varying the duty cycles of the electric heater between 0 and 1. This is followed by an isothermal region in which the biomass is kept at a constant Torrefaction temperature of 290°C for 45 minutes. The final stage is the cooling stage, wherein the electric heating and the inert gas flow through the bed is turned off for the cooling of the Torrified biomass. Thus, the temperatures can be controlled quite precisely using this experimental setup, having the potential to give accurate results of Mass Yields for different process conditions.



FIGURE 72: DIRECT CONVECTIVE HEATING TEMPERATURE PROFILE (290°C AND 45 MINUTES) IN A PACKED BED EXPERIMENTAL SETUP, HEATING RATE 7-8°C/MIN

Figure 73 shows the Torrefaction carried out through a conductive mode of heat transfer in a muffle furnace at the Faculty of Process and Energy, TU Delft. Since there was no way of instantaneously controlling the heating (apart from the programming the ramping rate), the temperature inside the furnace (and hence inside the packed bed) was controlled by opening and closing the doors of the furnace (marginally) periodically. This does not pose any serious danger as the biomass is not exposed to the heat, being sealed inside the cylindrical packed bed. As can be seen, the temperature profile is very similar to

torrefaction carried out in the convective packed bed setup, with fairly accurate temperature control. The sudden drop in the muffle furnace temperature is due to the fact that the furnace doors were opened for cooling.



FIGURE 73: TEMPERATURE PROFILE FOR RADIAL CONDUCTIVE HEATING CARRIED OUT IN A MUFFLE FURNACE (290°C, 45 MINUTES), HEATING RATE 5-7°C/MIN

Figure 74 shows the temperature profile for Torrefaction carried out in a TGA. Similar to previous Torrefaction experiments, the ramping region is followed by an isothermal Torrefaction region.



FIGURE 74: MASS YIELDS FOR TORREFACTION OBTAINED AS A FUNCTION OF TIME (TGA EXPERIMENTS), HEATING RATE 10°C/MIN

Immediately after Torrefaction, the gas flow was switched to air from nitrogen and the temperature was raise to 600°C to combust the biomass. This helps in cleaning the crucible for the next set of experiments and also gives a rough estimation of ash content in the sample.

Table 30 illustrates the Mass Yields obtained from Torrefaction using these three methods. As discussed previously, these Mass Yields are only for a residence time of 45 minutes.

Temperature (°C)	Convective Heating Packed Bed Setup		Packed Bed Vessel in Muffle Furnace		Torrefaction in TGA		Selected Mass Yields	
230	88.5%	232.8	85.5%	229.7	88.4%	233.0	88.5%	232.9
		46.2		45.1		45.0		45.6
250	80.8%	252.5	92.3%	249.4	82.6%	249.2	81.7%	250.9
		46.0		46.7		45.0		45.5
270	75%							
	(Average	271.3	71.2%	270.1	76.0%	273.1	75.5%	272.2
	of 2	44.1		43.4		45.0		44.6
	repeats)							
290	71.2%	290.5	65.5%	287.9	66.8%	292.6	66.2%	290.3
		45.6		48.7		45.0		46.9

TABLE 29: MASS YIELDS (DRY BASIS) OBTAINED FOR A RESIDENCE TIME OF 45 MINUTES USING THREE DIFFERENT METHODS

The Mass Yields obtained through the three different methods are fairly close apart from the case of 270°C in the muffle furnace experiment, which is an anomalous reading and can be attributed to an experimental error. The slight lower Mass Yields in the muffle furnace can be attributed to better packing and hence thermal conductivity of the bed due to the use of powdered pine needles. Next to the Mass Yields the actual average temperatures (°C) during the isothermal Torrefaction and the actual residence times are also given. The code used to process the Torrefaction data for the convectively heated packed bed setup is shown in Appendix 28. For a residence time of 45 minutes, the final selected Mass Yields are the average of the two closet values, with their average temperatures and residence times also shown in Table 30.

The biomass Torrified in the convective packed bed experiments were then tested for their Higher Heating Value using bomb calorimetry. Two trials were conducted for repeatability and the values were found to be within an error of 1-1.03%, thus being very close to each other. The final HHV values are the average of the two tests conducted.

TABLE 30: AVERAGE HIGHER HEATING VALUES USING	BIOMASS TORRIFIED IN CONVECTIVE PACKED BED
EXPERIM	ENTS

Experiment	lst run, MJ/kg	2nd run, MJ/kg	Average, MJ/kg
Dried Pine Needles	20.12	20.12	20.1
230-45	20.88	20.91	20.9
250-45	21.58	21.43	21.5
270-45	22.26	22.03	22.2
290-45	22.82	22.77	22.8

The Mass Yields and HHV values obtained from the Torrefaction experiments carried out in the convective packed bed setup and bomb calorimetry were used to calculate the Energy Yields for these experiments. Figure 75 illustrates the Energy Yield vs Mass Yield curve discussed in the methodology section. The slope of the curve is 0.7529 which is characteristic of the biomass being used; in this case it being pine needles. The final equation obtained based on curve fitting is also shown in the graph. This is the equation that was used to calculate the Energy Yields for other residence times 15 minutes and 45 minutes based on the Mass Yields obtained from TGA Torrefaction experiments.



FIGURE 75: ENERGY YIELD VARYING W.R.T MASS YIELD (TORRIFIED PINE NEEDLES)

Figure 76 shows a similar curve for Torrified grass based on experiments performed by the author during July-October 2014. One can see that verge grass has a steeper slope of 0.7915, showing greater sensitivity to Energy Yield reduction with reduction in Mass Yield. This can be indicative of the fact that verge grass as a fuel has a higher volatile hemicellulose and cellulose content which it loses early as compared to pine needles during the range of process conditions studied (230-290°C, 15-45 minutes). This is also evident in the Differential Thermograms for pine needles and grass, represented by Figures 79 and 83 respectively further ahead in the chapter. For a residence time of 45 minutes, one can see the hemicellulose peak almost vanishing for a sample Torrified at 230°C in the case of verge grass. For pine needles one can see the hemicellulose peak vanishing for samples Torrified at a much higher temperature of 270°C. Similarly, for a 45 minutes residence time, the peak for cellulose degradation falls significantly earlier at around 270°C for verge grass as opposed to 290°C for pine needles.



FIGURE 76: ENERGY YIELD AS A FUNCTION OF MASS YIELDS (TORRIFIED GRASS)

Table 32 shows the overview of results obtained for Mass Yields, HHV values and Energy Yields for different temperatures and residence times. For 45 minutes residence time, the average Mass Yields (average of best readings of 2 out of 3 experiments) as calculated before are used. Similarly, the average HHV values were utilized for the case of 45 minutes residence time. The numbers in the brackets indicate the actual average isothermal Torrefaction temperature and residence times. The extreme values for Mass Yields obtained through experiments for 45 minutes residence time are also shown.

Torrefaction Temperature (°C)	Torrefaction Time (min)	Mass Yield (M.Y., %), Dry Basis		HHV, MJ/kg, Dry Basis	Yield (E.Y., %), Dry Basis
	15	91.1 (2	29.2)	20.9	94.7
230	30	89.4 (2	29.2)	21.0	93.4
	45 (45.6)	88.5 (232.9)	85.5 88.5	21.1	92.6
	15	86.3 (2	49.1)	21.2	91.0
250	30	84.0 (2	49.1)	21.4	89.3
	45 (45.5)	81.7 (250.9)	80.8 82.6	21.6	87.5
	15	80.7 (269.2)		21.7	86.8
270	30	77.8 (2	(69.2)	21.9	84.6
	45 (44.6)	75.5 (272.2)	71.2 76	22.1	82.9
	15	72.8 (289.1)		22.3	80.9
290	30	69.2 (289.1)		22.7	78.2
Dried Din	45 (46.9)	66.2 (290.3)	65.5 71.2	23.0	75.9

TABLE 31: FINAL MA	ASS AND ENE	RGY YIELDS FO	R TORREFACT	TION OF PINE	NEEDLES UND	ER DIFFERENT
	TEMPERAT	URE AND RES	IDENCE TIME I	REGIMES, DRY	7 BASIS	



FIGURE 77: GRADUAL CHANGES IN COLOUR POST TORREFACTION FROM 230-290°C, LEFT TO RIGHT (45 MINUTES)

3.2.7.1 DIFFERENTIAL THERMOGRAVIMETRIC ANALYSIS OF DRIED AND TORRIFIED PINE NEEDLES

Figure 78 shows the weight % (Mass Yields) versus temperature. As described before in the research methodology, the pine needles first underwent Torrefaction in the TGA setup for different temperatures ranging from 230-290°C and for residence times of 45 minutes. This was followed by cooling of the biomass to 100°C and then continuous ramping of temperature in inert conditions to 600°C. A sample of dried pine needles were directly pyrolysed till 600 °C to provide a reference to evaluate the pyrolysis curves obtained for Torrified samples. From the curve of dried pine needles, one can see that the moisture content in the oven dried sample was 2-3%. Moreover the curves coincide in the pyrolysis after the Torrefaction temperatures, as the weight loss for all the cases here is over the non-devolatilized dried pine needles were Torrified in another setup and samples were meant to undergo pyrolysis in a TGA, then though the slope of the weight % curves would be the same throughout, they would be offset from each other after the Torrefaction temperature is crossed (approximately as the residence time also plays a role) because for each of them the weight % will be based on the different reduced masses of the sample post Torrefaction.

Figure 79 shows the Differential Thermo-gram of the pine needles undergoing pyrolysis up to a temperature of 600°C after isothermal Torrefaction in the TGA setup. The primary objective of a differential Thermo-gravimetric Analysis is to study the thermal degradation of a fuel. Differential Thermograms give an indication of the change in thermal stability of biopolymers (extractives, hemicellulose, cellulose and lignin) as a consequence of Torrefaction. A qualitative understanding of the effect of temperature on hemicellulose, cellulose and lignin degradation can be gained for non-Torrified and Torrified biomass. The x-axis represents temperature and the y-axis represents the % of the total weight lost (over the initial weight of non-Torrified biomass) per degree increase in temperature


FIGURE 78: TORREFACTION FOLLOWED BY PYROLYTIC HEATING UP TILL 600°C

In the figure shown here one can essentially see two peaks. The first broad peak predominantly represents the degradation of hemicellulose (high rate of hemicellulose loss). Since other biomasses have shown to represent another peak for some thermally unstable extractives before predominant hemicellulose degradation, it might be the case here that the peaks for the two biopolymers are merged. The rate of hemicellulose loss peaks at around 330°C. The second peak is associated with the high rate of decompositions of cellulose, and this for pine needles occurs at around 350°C. The slope of the curve representing degradation of cellulose starts to become steep at around 320°C and this would be the last temperature at which a major portion of the cellulose content will be stable. The peaks for hemicellulose fall in height from dried pine needles up to 250-45, after which these peaks disappear for 270-45 and 290-45. This represents the loss of a major portion of hemicellulose (and possibly thermally unstable extractives) in Torrefaction conditions of 270-45 and 290-45. There is hardly any decline in the cellulose peaks from dried pine needles till 270-45, signifying marginal cellulose decomposition for these process conditions. However, there is significant cellulose decomposition for a process condition of 290-45. Thus significant cellulose degradation has not begun for temperatures lower than 290°C. The lignin tail for all the curves remain the same signifying insignificant lignin loss throughout the Torrefaction process.



FIGURE 79: DIFFERENTIAL THERMOGRAM OF TORRIFIED PINE NEEDLES (RESIDENCE TIME 45 MINUTES)

As far as the degradation of hemicellulose is concerned, the major decomposition seems to happen between dried pine needles and 230-45 (hemicellulose and possibly extractives), with significant and roughly similar quantities decomposition of hemicellulose happening between 230-250 and 250-270.

3.2.7.2 DISCUSSION ON MASS YIELDS FOR PINE NEEDLE TORREFACTION

The Mass Yields show a clear trend in which they decrease with temperature and residence times. The change in temperature seems to have a stronger effect on the mass yields as compared to a change in residence time for the same temperature. For example, the change in Mass Yields from 91.1% to 86.3 % (5.3 % change) due to change in temperature from 230°C to 250°C at a residence time of 15 minutes is observably more than the change in Mass Yields from 91.1% to 88.4% (3.0% change) at the temperature of 230°C between residence times of 15 minutes and 45 minutes. This was visible in Figure 74 as well, where one can see that as soon as the isothermal period begins, there is point of inflection in the weight % curve, with the slope of the curve beginning to even out. Furthermore, one can generally see a trend that the effect of residence times on the Mass Yield for the same Torrefaction temperature increases with the increase in Torrefaction temperature. For example, the % change in Mass Yields between the residence times of 15 minutes and 45 minutes varies from 3.0%, 5.4%, 6.4% and 9.2% for temperatures of 230°C, 250°C, 270°C and 290°C respectively. This can be seen from the general widening of the curves in Figure 80. Higher temperatures seem to activate higher rates of hemicellulose decomposition (between 230 and 290°C), having a greater impact on the Mass Yields during isothermal period (i.e. different residence times), as the rate of hemicellulose loss activated at the particular temperature would not slow down immediately when that temperature is kept constant.



FIGURE 80: MASS YIELDS FOR DIFFERENT TORREFACTION TEMPERATURES AND RESIDENCE TIMES

The change in Mass Yields increases in the order 5.3%, 6.5%, 9.7% as the temperature is changed from 230-250°C, 250-270°C and 270-290°C respectively at a residence time of 15 minutes. This overall increase can be attributed to increased rate of devolatilization of hemicellulose fractions with limited devolatilization rates for a temperature of 230°C and heavy devolatilization rates of hemicellulose at around 270°C. Post 270°C, the rate of increase of hemicellulose decomposition begins to slow down. The steep reduction in Mass Yields for all three residence times at 290°C is due to the coupled decomposition of hemicellulose and cellulose, with predominantly strong cellulose decomposition in the case of 290-45.The comparable change in Mass Yields between 230-250°C and 250-270°C can be attributed to coupled devolatilization of extractives with some quantities of hemicellulose in the range of 230-250°C and the higher rate of hemicellulose decomposition at 250-270°C but without any devolatilization of extractives.

The upward deviation in the Mass Yield curve at 270-45 signifies a reduction in rate of mass loss. This is probably due to the fact that majority of the hemicellulose is devolatilized in the first 30 minutes, leaving behind lower quantities for further decomposition in the next 15 minutes, leading to lower rates of devolatilization. Beyond 270°C, the cellulose decomposition begins to increase, leading to widening of the curves again. This is probably the reason that the %change in Mass Yields between the residence times of 15 and 45 minutes is roughly the same at 250°C and 270°C respectively. This is also the reason for reduction in difference in Mass Yields between 250-45 and 270-45. From Figure 80, we can see that this phenomenon is not visible between residence times of 15 minutes.

3.2.7.3 DISCUSSION ON HIGHER HEATING VALUES, HHV (MJ/KG, DRIED BASIS)

In general, the HHV values show an increasing trend with higher Torrefaction temperatures and residence times as the biomass loses more of its components contributing less to the calorific value of the fuel. The HHV value for dried pine needles is 20.12 MJ/kg. The HHV values for Torrified pine needles vary from 20.90 MJ/kg (230-15) to 23.07 MJ/kg (290-45), showing an increase by 3.87% to 14.66% respectively. As was seen with Mass Yields, a change in temperature seems to have a stronger effect on the HHV as compared to a change in the residence time for the same temperature. For example, a change in temperature from 270-290°C at 15 minutes residence time brings about a 3.18% change in HHV values, whereas a change in residence times from 15 minutes to 45 minutes at a temperature of 270°C brings about a change of 2.03% in HHV values. The change in HHV increases in the order 1.53%, 2.02%, 3.18%

as the temperature is changed from 230-250°C, 250-270°C and 270-290°C respectively at a residence time of 15 minutes. Similarly, one can see a trend that the effect of residence time on the HHV for the same Torrefaction temperature increases with increase in Torrefaction temperature. For example, the % change in Mass Yields between the residence times of 15 minutes and 45 minutes varies from 0.86%, 1.65%, 2.03% and 3.13% for temperatures of 230°C, 250°C, 270°C and 290°C respectively. This can be seen from the general widening of the curves in Figure 81.



FIGURE 81: HIGHER HEATING VALUES FOR THE TORREFACTION OF PINE NEEDLES

Again, due to reasons explained in the section on Mass Yields, there is a downward bump for the point 270-45, leading to reduced changes in HHV values from 250-45 to 270-45 and between 270-45 and 270-30, 45.

3.2.7.4 DISCUSSION ON ENERGY YIELDS

The Energy Yield of a Torrified product is strongly influenced by the Mass Yields and in this case, it exhibits the same trends shown the by the Mass Yields as well. The Energy Yields for Torrefaction of pine needles are illustrated in Figure 82. The Energy Yields post Torrefaction for dried pine needles vary from a value of 94.65 at mild Torrefaction condition of 230-15 to a value of 75.86 at a severe Torrefaction condition of 290-45.



FIGURE 82: ENERGY YIELDS FOR TORREFACTION OF DRIED PINE NEEDLES

3.2.8 COMPARISON OF TORREFACTION OF PINE NEEDLES WITH VERGE GRASS

Torrefaction		Mass Yield,			Torrified Pine	Energy Yield,	Energy Yield,
Temperature	Torrefaction	Grass, M.Y.,	Mass Yield Pine	Torrified Grass HHV	Needles HHV,	Grass, E.Y.,	Pine Needles,
(oC)	Time (min)	(%)	Needles, M.Y. (%)	(MJ/kg.TorrFuel)	(MJ/kg.TorrFuel),	(%)	E.Y., (%)
]	Dried Verge G	rass and Pine N	Veedles	17.5	20.1		
230.0	15.0	82.0	91.1	18.7	20.9	87.9	94.7
	45.0	72.0	88.4	18.5	21.1	76.1	92.6
250.0	15.0	79.0	86.3	18.9	21.2	85.6	91.0
	45.0	72.0	81.7	19.5	21.6	80.5	87.5
270.0	15.0	69.0	80.7	20.0	21.7	79.0	86.8
	45.0	69.0	75.5	20.4	22.1	80.7	82.9
290.0	15.0	57.0	72.8	21.3	22.3	69.4	80.9
	45.0	52.0	66.2	21.7	23.1	64.6	75.9

TABLE 32: COMPARISON OF MASS YIELD, HHV AND ENERGY YIELD (DRY BASIS, SIMILAR ASH CONTENTS)

Table 33 gives an overview of the differences in Mass Yields, HHV values and Energy Yields for Torrefaction of Verge Grass and Pine Needles. This comparison is between a residence time of 15 minutes and 45 minutes.

In the case of pine needles, the Mass Yields predominantly tend to diverge and then converge between residence times for different Torrefaction temperatures. However, this does not happen in the case of verge grass and one sees a big difference in Mass Yields between residence times initially, with the difference narrowing down almost to zero as one approaches 270°C. This difference in Mass Yields for grass, then tend to increase again post 270°C. The reason for this can be explained by the DTGA curve for dried and Torrified grass (Figure 83) for different temperatures and a residence time of 45 minutes. On comparison with the DTGA curve for dried pine needles, one can immediately see a difference that the DTGA curve for grass has three distinct peaks. The extractives and hemicellulose peaks are distinct and not merged as in the case of pine needles. Moreover the peak for hemicellulose decomposition (at around 270°C) and the onset of decomposition of major portions of cellulose happens much earlier for grass than for pine needles.

The peak for cellulose decomposition also occurs around 20°C before for grass than for pine needles. The merging of Mass Yields between different residence times till 270°C (Figure 84) is probably due to the fact that this is the transition temperature at which a major portion of hemicellulose has already decomposed and could be the last temperature at which a major portion of cellulose is stable. As the temperatures rises from 230 to 270°C, the hemicellulose content available for decomposition for higher residence times keeps reducing, with practically no hemicellulose left for decomposition at 250-45 and 270-45, as is evident from the DTGA curves. This merging of Mass Yields in the case of pine needles for different temperatures will be observed around 330°C. Moreover one can see that the rate of extractives and hemicellulose decomposition rise very sharply in the case of grass than in the case of pine needles, where there is a more gradual rise in hemicellulose decomposition.



FIGURE 83: DIFFERENTIAL THERMOGRAM OF TORRIFIED VERGE GRASS (45 MINUTES)[76]

One can also see from the DTGA curves that for residence time of 45 minutes, there is minimal hemicellulose content left in grass after 230°C. It was observed that this temperature was 270°C in the case of pine needles. The decline in cellulose peaks for grass happen at 270-45, whereas in the case of pine needles significant decline in cellulose peaks happen were observed at 290-45. These results may point to the conclusion that pine needles might have lower volatile matter content (that contributes less to the energy content of the fuel) within its hemicellulose structure than verge grass as seen by the lower and delayed rates of hemicellulose decomposition, and thus being more "woody" in nature as compared to verge grass and even maybe even other agricultural residues. Moreover, the Thermogram for dried pine needles shows a lower cellulose peak than height for dried grass, signifying lower amounts of volatile matter in the cellulose structure of pine needles.



FIGURE 84: MERGING AND DIVERSION OF MASS YIELDS FOR VERGE GRASS[77]

The early major decomposition of hemicellulose for grass and its marginal decomposition of cellulose between 230 and 250°C (significant cellulose decomposition starts post 270°C), leads to very similar

Mass Yields for these two temperatures. Post 250°C, the effect of temperature on the Mass Yields of grass is much stronger than on the Mass Yields of pine needles, due to a combination of smaller hemicellulose decomposition and increased rates of cellulose decomposition. This is unlike in pine needles where there is a much sharper difference in Mass Yields between 230 and 250°C due to a delayed and more spread out decomposition of hemicellulose. These trends are reflected in the HHV and Energy Yields as well.

As far as the HHV values are concerned, pine needles seem to have a higher HHV value (20.12 MJ/kg) compared to grass (17.46 MJ/kg). The amelioration in HHV values w.r.t dried samples seem to be higher for grass than pine needles. Moreover, with increase in temperature post 250°C the amelioration in HHV values in the case of Verge Grass is much stronger as is in the case of pine needles.

Parameter	Pine Needles	Verge Grass[77]
Moisture Content	20-25% (A.R. Basis)	72% (A.R. Basis)
Ash%	11.73% (Dried Basis)	10% (Dried Basis)

20.68% (Dried Basis)

FC%

TABLE 33: FIXED CARBON, MOISTURE AND ASH CONTENT FOR DRIED AND AS RECEIVED PINE NEEDLES AND VERGE GRASS

Table 34 shows that pine needles have a slightly higher Fixed Carbon content than Verge Grass. The Fixed Carbon content for pine needles was found out from finding the weight % of Fixed Carbon + Ash at the end of the pyrolysis stage (carried out in the TGA setup) at 600°C for dried pine needles. Then the Ash% found out from combustion carried out in a muffle furnace was subtracted from this value to give the Fixed Carbon % for dried pine needles. Adjustments were made for the moisture content to give Fixed Carbon content for pine needles on an As Received Basis. The Fixed Carbon % for Verge Grass was found out in a similar way through experiments carried out in the Process and Energy Faculty of TU Delft during July-October 2014 for the System Integration Project 2. One can also see that on an As Received Basis, Verge Grass has significantly high moisture content than Pine Needles, thus making the drying stage in the Torrefaction process more energy intensive.

Table 35 shows the Fixed Carbon content on a Dry Basis for Pine Needles and Verge Grass under different Torrefaction regimes. The Ash content in each of the Torrified pine needle samples was found out by adjusting the original ash content in the dried sample with the Mass Yields obtained post Torrefaction. The (Fixed Carbon+ Ash) % for pine needles was found out by running the Torrified samples (also done in the TGA) through a pyrolysis regime and measuring the weight% at the end of the pyrolysis regime at 600°C. This Fixed Carbon + Ash) % is over the initial weight of the dried biomass sample. Knowing the Mass Yields for that particular Torrefaction temperature, adjustments were made to give the (Fixed Carbon + Ash) % over the fractional mass of the pine needle sample post Torrefaction. The Ash% for that Torrefaction condition was subtracted to the Fixed Carbon % for that particular Torrefaction temperature. The Fixed Carbon and Ash % for grass were found out through earlier experiments conducted during July-October 2014 at the Process and Energy Faculty at TU Delft for the System Integration Project 2.

One can clearly see from Table 35 that there is a stronger amelioration in Fixed Carbon % in the case of verge grass as compared to pine needles, however there is a corresponding sharper rise in Ash% as well with increase in Torrefaction temperatures. This increase in Ash% and Fixed Carbon % with increase in temperature is expected though, owing to their greater mass fractions due to devolatilization of other compounds (Ash and Fixed Carbon amounts are unaffected by Torrefaction and Pyrolysis)

18.7% (Dried Basis)

		P	ine Needles	Verge Grass			
Torrefaction Temperature (°C)		Actual Temperature (°C)	Ash (%) Dry Basis	Fixed Carbon (FC, %) Dry Basis	Actual Temperat ure (°C)	Ash (%) Dry Basis	Fixed Carbon (FC, %) Dry Basis
230	45	232.9	13.3	23.8	231.3	13.3	25.1
250	45	250.9	14.4	26.3	252.2	13.0	26.7
270	45	272.2	15.3	25.6	270.9	16.8	30.1
290	45	290.3	17.7	31.2	291.2	19.5	38.8

TABLE 34: FIXED CARBON AND ASH % FOR TORRIFIED GRASS AND PINE NEEDLES ON A DRIED BASIS

On the basis ash samples of Verge Grass and Pine Needles sent to the X-ray Diffraction facility at TU Delft, grass was found to have SiO_2 in the highest concentration (37.85% weight %) among other constituents, whereas pine needles had CaO (45.40 weight %). The fraction of other constituents for both the fuels is shown in Appendix 29. Typically, elements such as calcium and magnesium increase the ash melting temperature, whereas elements such as silica, potassium and sodium decrease it. Thus tendency for slagging and fouling in heat transfer equipment will be more in the case of grass than pine needles. Herbaceous biomasses generally tend to exhibit low ash melting temperatures whereas woody biomasses tend to exhibit high ash melting temperatures[78].

On the basis of the above discussion and on account of higher Mass Yields and Energy Yields observed for different process conditions between 230-290°C, pine needles are a better fuel as compared Verge Grass. However, due to significant changes in the bio-chemical structure of grass as compared to pine needles in the Torrefaction regime, there will be more amelioration of fuel properties in the case of grass. Thus, one can also argue that Torrefaction is more beneficial for grass than to pine needles, which is relatively a better fuel. Lower temperatures would be needed to bring about baseline (hemicellulose decomposition) significant improvements in the fuel properties of grass (230-250°C), whereas for pine needles higher temperatures would be needed for major hemicellulose decomposition (270-290°C).

From the DTGA curves for Torrified grass, one can see that lignin decomposition is limited, slow and gradual within these process conditions. Consequently one can see the fraction of lignin in the biomass increasing at higher Torrefaction temperatures. This is not visible in the DTGA for pine needles as in these experiments the rate of weight loss is measured over the original weight of the dried biomass sample, rather than the fractional weight of the Torrified biomass sample. However, the phenomenon will hold for pine needles as well.

Note: During Torrefaction experiments in the convective heating based packed bed setup, there was frequent clogging the sampling pipe with a highly viscous black liquid which was evolved between 130-200°C. This liquid solidified into beads on cooling. This liquid could be certain waxes that are evolved in this temperature range and could have an impact on plant design as might add to the clogging caused by tars that begin to evolve at higher Torrefaction temperatures. Lesser quantities of these waxes were seen in the case of Verge Grass.

It is established that pine needles is a good fuel in itself, but Torrefaction is still justified to bring about uniform thermo-chemical properties within the bulk of the fuel as it was observed that the pine needles in Avani's gasification plant varied so much in moisture content within one bulk itself. Drying only could be a solution, however, since drying is the most energy intensive step, extra energy spent beyond drying to improve fuel properties can be justified. Moreover, drying does not prevent biomass from reabsorbing moisture and start rotting.

3.2.9 OVERALL ENERGY EFFICIENCY OF TORREFACTION REACTOR DESIGN 2

Appendix 30 gives the overall energy efficiency for the 2^{nd} reactor design chosen, with comparisons done with wood as a source for heating vs electricity. The calculations are based on a Torrefaction temperature of 250°C and a residence time of 15 minutes.

The overall energy efficiency is based on the equation,

η

Energy contained output Torrified Pine Needles

Energy Contained in input As Received Pine Needles + Energy to provide heat for Torrefaction

If wood is combusted to produce heat for Torrefaction, the efficiency works out to be 40.5% as opposed to 85% if electricity is used. Thus, it was decided that electrical heating of individual reactors (for reactor 2 design) will be carried out using electric trace wires (as a low cost option) provided by companies such as Isotherm India. The cost of the heating tracer is 310 Rs/m and can heat up to 290°C. The power consumption of the tracer is 40 W/m. With 10 windings of a heating tape on 1 reactor, the estimated length of a heating tape per reactor was found to be 9.42m, giving a capital cost of 2920 Rs/reactor which is to be recovered over a period of 6 years. The energy input costs take into account drying of As received pine needles. The details regarding the capital costs and the operational costs associated with these heaters are talked about in the paper of Ryan Helmer.

Heating Cost Comparison of Different Fuels/Electricity That Can Provide Heat for Torrefaction

(Only For Reactor 2 design, only operation costs considered)

Wood is not an option to be used as there no large source of firewood available apart from the option of cutting trees. Moreover, it was concluded in chapter 2 that the business case with the gasification plant is currently speculative in nature and hence should not be pursued currently. This currently leaves out the possibility of using waste heat streams from the gasifier. As discussed in the 'Designs Rejected' part of section I of this chapter, the plant is actually located in the middle of the pine forest, and hence has to be a stand-alone system.

Using electricity for heating through heat tracers

Electricity energy input for Torrefaction = 6.49MJ = 1.82 kWh/batch/reactor (refer Table 55, Appendix 30)

Commercial price of electricity = 5 Rs/kWh (field visits gave 4.7 Rs/kWh)

Cost of using electricity = 9.086 Rs/batch/reactor

The capital cost for these tapes is low as well, at 2920 Rs/reactor.

Using Torrified and briquetted pine needles for heating

Based on the information provided in Table 54 in Appendix 30, 7.65 kg of wood is used per batch of reactor 2. The Higher Heating Value of Torrified pine needle is 21.22 MJ/kg. The Higher Heating Value of As Received wood as taken to be 15 MJ/kg[79]. It was assumed that the same combustion chamber design could be used for the combustion of pine needles briquettes.

Amount of Torrified pine needles needed to carry out Torrefaction = (15/21.22)*7.65 = 5.40 kg/batch/reactor

The reactor produces 3.95 kg/batch/reactor of Torrified pine needles. Thus, for the operation of each batch of a reactor, more pine needles will be used in heating the reactor than actually producing the fuel.

Using LPG for heating

Gross Heating Value of LPG = 11920 kcal/kg = 49.87 MJ/kg[80]

Assuming that the combustion happens so efficiently the same energy is utilized for heating as electricity, that is 6.5 MJ (therefore underestimating costs),

Amount of LPG utilized to heat 1 batch of a reactor = 6.50/49.87 kg/batch/reactor = 0.13 kg/batch/reactor

Average cost of a 19 kg commercial cylinder = 1500 Rs (Found out through field research)

Cost of heating 1 batch of a reactor with LPG = (1500/19)*0.13 = 10.26 Rs/batch/reactor

The capital costs associated with a separated LPG burner would also add to the above costs.

Using Diesel for heating

Gross Heating Value of Diesel = 44.8 MJ/kg[81]

Assuming that the combustion happens so efficiently, that as much energy is utilized for heating as electricity(therefore underestimating costs).

Thus, amount of diesel utilized to heat 1 batch of reactor = 6.5/44.8 kg/batch/reactor = 0.15 kg/batch/reactor

Density of diesel fuel = 0.75 kg/L[82]

Liters of diesel utilized to heat 1 batch of reactor = 0.20 L/batch/reactor

Cost of Diesel fuel in Almora during field visit = 57 Rs/L

Cost of heating 1 batch of reactor with diesel = 11.4 Rs/batch/reactor

The capital costs associated with a separated diesel burner would also add to the above costs

Procuring extra pine needles

Assuming extra pine needles are procured through foot collection only at 1 Re/kg.

Assume they are sun dried to a moisture content of 10%.

HHV of sun dried pine needles = 20.12* (1-0.10) MJ/kg = 18.1 MJ/kg

For reactor 2, amount of wood used for Torrefaction = 7.65 kg (Table 54, Appendix 30)

Assuming the usage of the same combustion of reactor 2 for pine needles,

Therefore, amount of pine needles used for heating = (15/18.1)*7.65 g/batch/reactor = 6.34 kg/batch/reactor

Cost of pine needles needed for heating = 6.34 Rs/batch/reactor

Even though using raw pine needles seems to work out the cheapest, it should not be used for heating for the following reasons:

- 1. Currently reactor 2 can Torrifiy 6.1 kg of pine needles in one batch. Using another 6.34 kg of pine needles for its heating would double the amount of pine needle collectors needed per day from 170 to 340 collectors. Finding these many pine needle collectors is very difficult and the process of hauling the pine needles from a large radial distance is a very labour intensive task considering the terrain of the region. More ropeway systems would also be needed adding significantly to the capital and operational costs of the project.
- 2. Based on raw pine needles for combustion in reactor 2, it was seen that they burn very fast, delivering their energy in a very short time. However, through temperature readings it was observed that it need not lead to higher flue gas temperatures in comparison to burning wood. Thus, as a result more pine needles would be needed for Torrefaction and 6 kg/batch/reactor is an underestimation. Moreover, due to their fast burning, controlling temperatures within the reactor can get very difficult.

Thus, the use of electricity through heat tracers seems to be reasonable to provide heat for Torrefaction. One can ask that if one is using electricity for Torrefaction, why not just sell electric cookstoves for cooking. As far as heating through tracers adopted for reactor 2 is concerned, as mentioned in chapter 2, the use of electricity for heating still produces a fuel which gives significant savings to the end user on a yearly basis and good profits to the Torrefaction company as well. Additionally, during field visits to a lot of these restaurants and *dhabas* and to other cookstove conferences in the region, it was realized that a flame is really important for nature of cooking done in these areas. Apart from the higher cost w.r.t LPG, this is one of the reasons why electric cookstove adoption has been poor in India.

It is to be noted however, that these conclusions might only be valid for the reactor design 2 that was tested in India. Separate evaluations need to be done for other reactor designs in the future.

3.2.10 FINAL CHOICE OF TORREFACTION TEMPERATURE AND RESIDENCE TIME

These calculations have been done for the final chosen business system in which collection is done by foot, through the assistance of a ropeway. Transportation is done by a small pickup owned by the plant truck of 1 ton capacity. The profits shown will be for after the capital costs have been recovered, that is 5 years.

Table 36 shows the overall energy efficiency for different process conditions if an electric heating system is adopted. Similar to the trend observed in the case of Mass Yields, the drop in efficiency is more sensitive to the Torrefaction temperature than to the residence times. Moreover, the effect of residence times on the drop in efficiency increases with increasing Torrefaction temperatures. The efficiency is dropping with increase in severity of process conditions due to the drop in Energy Yields. If this factor was also included, then a larger drop in energy efficiency will be observed for different process conditions.

Residence Time	15 minutes	30 minutes	45 minutes
Temperature			
230°C	88%	87%	87%
250°C	85%	83%	82%
270°C	81%	79%	77%
290°C	76%	73%	71%

TABLE 35: OVERALL ENERGY EFFICIENCY OF A REACTOR FOR DIFFERENT PROCESS CONDITIONS

Table 37 shows the change in profits with change in Torrefaction process conditions. Again one can see a clear decline in profits with increase in severity of process conditions with similar trends as observed in the case of efficiency. The profits are strongly related to the change in fuel demand from the market and this has direct repercussions on the sizing of the reactor. This can be explained as follows:

As the calorific value of the fuel increased, the amount of fuel needed to meet the market demand decreased. However, the reduction in Mass Yields had a greater impact on the business, giving greater cumulative reactor volumes for higher torrefaction temperatures and residence times. A bigger reactor would essentially lead to a greater demand for raw, As Received biomass. This had a direct bearing on the pine needle collection costs, with greater number of pine needle collectors and ropeway systems needed. Transportation costs for the fuel to the market remained the same, as for all situations, the chosen truck of 1 Ton weight capacity had to make two round trips between the factory and the market. As far as the operational costs are concerned, the briquetting costs reduced due to the lesser amount of pellets to be produced for the market. Moreover, this reduction in briquetting costs was mostly due to reduction in costs associated with using the binder than electricity costs. The electricity costs associated with running the ropeway systems increased along with the electricity costs for running the heating tapes (as the number of reactors to be heated has increased). Overall, with a bigger plant, the maintenance costs increased.

Now based on the DTGA results obtained, one can see that there is no significant Torrefaction in the case of 230-45 as much of hemicellulose is still left to be degraded. In order to improve the quality of the fuel and derive benefits from the Torrefaction process in terms of longevity of storage, the process condition adopted has to be 270-45, because as per the DTGA study done 270-45 has marginal hemicellulose content left. However, since it was established that pine needles is already "woody" in nature and a good fuel in general, there might not be a case for amelioration of properties up till 270°C. This might give penalties in terms of more energy used for smaller improvements in fuel quality as compared to other biomasses. Using even higher process conditions in the 290 series would produce a much better fuel, which would be significantly more energy dense because of the onset of devolatilization of cellulose, but this will bring about a steep reduction in profits and the overall energy efficiency w.r.t the 270 series. A process condition of 250-45 will be an optimized choice, with significant (but not complete) decomposition of hemicellulose content coupled with good profits and overall energy efficiencies. However, based on the fact that the residence times are having a smaller effect on the Mass Yields, Energy Yields, Overall Efficiency and Profits as compared to change in temperature, a change in residence time 45 minutes to 15 minutes is justified. This will lead to slightly lesser hemicellulose decomposition but will be comparable to the case of 45 minutes residence time. Moreover, as per experiments conducted with reactor design 2, a change in residence time does not really affect the number of Torrefaction batches that can happen in a day (due to long cooling times observed for the reactor design), reducing the significance of the parameter as far the operation of the plant is concerned. However, since a change in residence time from 45 minutes to 15 minutes will increase the profits of the business by 37% and will also lead to an increase in overall efficiency of the Torrefaction process, it was decided to select a process condition of 250° C and 15 minutes.

Residence Time	15 m	inutes	30 minutes 45 minutes			inutes
Temperature	Profit (10^6 Rs/vear)	Factory Parameters	Profit (10^6 Rs/vear)	Factory Parameters	Profit (10^6 Rs/vear)	Factory Parameters
230°C	1.47	368 20 314 2 7	1.37	366 20 314 2 7	1.32	364 20 314 2 7
250°C	1.28	362 21 330 2 7	1.16	359 21 330 2 7	1.07	356 22 346 2 7
270°C	1.01	355 22 346 2 7	0.84	351 22 346 2 7	0.74	348 23 362 2 8
290°C	0.58	344 23 362 2 8	0.37	338 24 377 2 8	0.19	333 25 393 2 8

TABLE 36: CHANGE IN PROFITS WITH CHANGE IN PROCESS CONDITIONS

TABLE 37: LEGEND FOR TABLE 37

Factory Parameter (in order as in table)	Unit
Amount of Torrified fuel produced	Ton. Fuel/year
Cumulative reactor volume	m^3
Total number of reactors	number
Number of round trips made of factory truck to	number
deliver fuel	
Number of ropeway systems	number

3.2.11 DTGA AND BOMB CALORIMETRY ASSESSMENT OF SAMPLES AFTER TESTING IN REACTOR 2

The testing of the two reactors built in India has been described in detail in Section I. Some sections of Pine needles tested in reactor 2 were sampled and were tested for their Differential Thermograms and Higher Heating Values at the Faculty of Process and Energy to get some insight into the Torrefaction, if any. Pine needles tested in reactor 1 could not be sampled because they were beginning to combust post Torrefaction when they were taken out due to the slow cooling process within the reactor. The samples taken were:

1. An observable charred sample taken from the bottom of reactor 2.

- 2. An observable uncharred portion taken from the section along the middle height of reactor 2.
- 3. A mix of charred an uncharred portions taken from a section between the bottom and middle heights of reactor 2.



FIGURE 85: DTGA STUDY OF PINE NEEDLE SAMPLES TESTED IN REACTOR 2

The first two samples were studied for their differential Thermograms and all three samples were tested for their Higher Heating Values. From the Thermogram one can see that the Observable charred portions were indeed charred with complete hemicellulose decomposition and severe cellulose decomposition. This is also reflected in the high HHV value of 23.83 MJ/kg. Since this segment of biomass was closest to the combustion chamber, the section was charred throughout radially. The observably uncharred portion of pine needles was taken from the radial inward sections (between the outward charred portions and the centre of the section), thus it due to high radial temperature gradients from the outside to the inside, it would have witnessed lower temperatures. However, surprisingly, one can see some amount of hemicellulose degradation. The low HHV value for this section is probably due to the moisture content in the sample, as it was not dried and tested As Received (to give a more realistic estimate of the product obtained from the reactor) in the TGA and bomb calorimeter. This was done to get actual HHV values post Torrefaction in reactor 2. The third sample which is a mix of charred and uncharred portions shows a substantially high HHV value of 21.47 MJ/kg. Thus, with the radial temperature gradient, though not desirable in terms uniform torrefaction throughout a radial section, one can still get a "mixed" product of substantially higher calorific value.

TABLE 38:	HIGHER	HEATING	VALUES (OF SAM	PLES	TAKEN	FROM	DIFFERENT	POSI	FIONS	IN RI	EACTOR	POST
					TORR	REFACT	ON						

Sample Name	Higher Heating Value (MJ/kg)
Observed charred ring at reactor 2 bottom	23.83
Observed uncharred ring at a cross section in the	
middle height of reactor 2	19.02
Mix of observed charred and uncharred portions	
between at a cross section between the bottom and	21.47
middle of reactor 2	

3.2.12 CONCLUSIONS

It can be concluded from the Mass Yields, Energy Yields and the DTGA study carried out that pine needles by themselves are a better fuel than verge grass, undergoing lesser amelioration of fuel properties (in terms of delayed and lower levels of degradation of volatile fraction of hemicellulose and cellulose) through Torrefaction than verge grass. However, Torrefaction of pine needles is still justified as they are found very wet and prone to rot. Long term storage of pine needles for year- long sale of a fuel further underscores the need for Torrefaction.

Based on Mass Yields, Energy Yields, profits and overall energy efficiency an isothermal Torrefaction temperature of 250°C and a residence time of 15 minutes were chosen as the process conditions. It was also concluded that for the design of reactor 2 (which is essentially a stand-alone system), electrical heating using heat tracers can be adopted to provide heat for Torrefaction. The use of electricity using this system not only provides better overall energy efficiency, it also leads to lower costs of heating for Torrefaction in comparison to using LPG and diesel. The use of wood was rejected due to ecological reasons and the use of raw pine needles for heating was rejected due to logistical constraints and the problems associated with their very high rates of combustion.

Recommendation:

Pine needles in a bulk can vary in moisture content to a significant extent (as was seen in Avani's pile). This can affect the uniformity of Torrefaction, as was seen in the experiments conducted as well. Thus, pre-drying of pine needles before Torrefaction is important. Moreover, the moisture content in pine needles on an As Received basis is high due to frequent evening rains. Thus, using electricity for drying can cost a lot of energy and leading to higher operational costs. Thermal drying of pine needles using green houses with the relative humidity being controlled by solar PV powered fans should be the way forward. Such systems have been demonstrated to dry food grain in large quantities (to around 10% moisture) in numerous countries[83]. These green houses are very simple to construct using poly-sheets, and can be made at very low capital costs. However, this is an idea for future investigation.

Even though it was found that electricity can be used (through heat tracers) to carry out Torrefaction in this reactor design and yet produce a product that is cheap enough to bring about savings to end users, this may or may not be true for other designs. Thus, a thorough evaluation of potential fuels/other heating sources for various future Torrefaction reactor designs need to be carried out, being a separate study in itself.

Field research in the Kumaon region of Uttarakhand and testing of Torrified pine needles in the Process and Energy Lab at TU Delft has helped in providing foundational information on the feasibility of Torrefaction as a business in the region.

It was concluded through the general context study done in chapter 1 that the major needs of the area are sustained income and employment generation to enable people to live in their home villages and prevent outmigration. Keeping in mind the terrain of the region, innovation in farming related businesses, handicrafts production and weaving businesses is necessary, as in remote regions such as Pithoragarh district, people still have those skill sets in them. Other options include cultivation of medicinal plants, which grow in plenty in the region, and their sale as raw materials for medicines. These options will not only generate employment, but also help in conserving the forests (as has been done for centuries) as these businesses will be heavily dependent on them. Moreover, it will help revive what was once seen as the identity of the region. Small scale industries can also play a supportive role in providing employment to people in the region (agro-forestry, dairy farming etc.) and the environment, as both of these are a big part of Kumaon's cultural identity. Another major need is on the environment front: To prevent forest fires due to the burning of pine needles in *chir* pine monocultures. The establishment of a biomass Torrefaction factory can provide sustained income and employment to the locals, while utilizing the harmful pine needle waste generated in the pine forests.

As the first step in establishing the business case for the Torrefaction factory, pine needles were tested for their Mass Yields and calorific value for different isothermal Torrefaction temperatures and residence times in the Process and Energy Lab of TU Delft. A process condition of 250°C and 15 minutes was chosen based on Mass Yields, Energy Yields, DTGA study, overall energy efficiency of a reactor and the impact of choosing the process condition on the profits of the business for different end users. These studies also revealed that pine needles are a good fuel by itself when compared to grass, being more "woody" in nature. They undergo lesser amelioration of fuel properties (in terms of delayed and lower levels of degradation of volatile fraction of hemicellulose and cellulose) through Torrefaction than verge grass. However, Torrefaction of pine needles is still justified as they are found very wet and prone to rot. Long term storage of pine needles for year- long sale of a fuel further underscores the need for Torrefaction.

Two different indirectly heated packed bed reactor designs were constructed in India and tested for their performance through attempted Torrefaction of pine needles. An attempt was made to make the designs simple enough for local manufacturing and maintenance. However, both designs showed poor radial heat penetration to the pine needles, leading to the production of a product which was either over charred or just dried/hardly Torrified. Fins constructed to improve radial heat transfer did not give any significant improvements. Nevertheless, reactor 2 showed better heat transfer characteristics (though similar trends) than reactor 1, and thus its geometrical and operational parameters were used to calculate the value proposition for different users and the overall business case for Torrefaction.

Field visits to different end users brought to light different fuel usage patterns for cooking and heating needs. Based on a variety of parameters such as economic, convenience in cooking, convenience in fuel acquisition, health reasons and impacts on the forests of the region, it was decided that commercial kitchens that use coal and commercial LPG for cooking will benefit the most from the use of a Torrified fuel. The market demand for Torrified fuel w.r.t commercial LPG and coal replacement, for a market penetration of 5%, was found out to be 363 tons/year. 1072 kg/day needs to be delivered as fuel to the end users. This leads to a raw pine needle demand of 8055 kg/day. A cumulative reactor volume of 21 m³

would be able to meet this demand. Based on the fuel production cost and cost savings to the end user, a a selling price of 15 Rs/kg was chosen. The company will provide free stoves to the end users and only charge for the fuel. However, as a guarantee, the end users have to sign a two year contract with the company. This was based on the calculation which showed that the payback time for a typical commercial stove is small: 1.8 years for the initial 6 years of operation and 0.17 years for operation between the 6^{th} year and 10^{th} year.

It was decided that the company will have a 5% market penetration by the end of the first year of its operation. The payback time for the initial capital costs will be kept at 6 years. A model of slow growth needs to be employed as the adoption of these cookstoves can take time because they are unfamiliar products. Moreover, majority of the end users are small eating joints or *dhabas* that are informal businesses that may exist for short intervals of time. The lifetime of the plant was kept at a low value of 10 years as it was constructed using simple and cheap materials, with crude manufacturing techniques.

An integrated plant, rather than multiple decentralized plants gave the cheapest logistics cost. As the radius of collection for an Integrated plant is small, the case for having smaller decentralized plants is diminished. Even though other logistics systems were more profitable, it was decided that collection of pine needles will be a combination of foot collection and a ropeway system (at intermediate collection centers). This system was chosen to reduce the effort in pine needle collection. The transportation of pellets to the market through a company owned pick-up truck, rather than hiring transportation services, worked out to be the most cost effective option. The use of motorized vehicle for the transportation of raw pine needles that have been collected is not advisable as they bring down the profits, cause time delays and would involve impractical number of round trips in a day between the biomass source and the plant due to the low bulk density of pine needles (85 kg/m^3).

It was found that women are more willing to collect pine needles than men and should be the focus as far as collection of pine needles is concerned. However, as women pine needle collectors have the sole responsibility for most household work, field work and forest work, they are very busy and hence cannot be full time employees of the plant. They can contribute only some of their time for pine needle collection and earn supplementary income. Furthermore, as 170 collectors are needed to meet the current market demand, there might be a chance that there is a shortfall of women pine needle collectors. Men would have to be employed by paying them a daily wage of 350Rs/day. The day's pay would be for not only collecting pine needles but also participate in other operations of the plant, such as manning the ropeway systems. Tools to assist in pine needle collection also need to be provided. Some tools recommended by the women were: a flexible waterproof sheet for wrapping pine needles, a portable rake, a mask, gloves, provisions for conveniently carrying water bottles. A utility belt can be designed to carry all this equipment. Based on complaints by the women on how tiring the collection process can be, the intermediate collection centers and the plant need to have provisions for taking rest and refreshments. A limit of 45 kg/day was placed on pine needle collection for women to prevent competition between them to earn maximum money. Pine needle collection, which is carried out along with wood collection, is a social activity for the women and it was felt that this should not be disturbed.

Overall, the business gave marginal profits in the first 6 years (107000 Rs/year) and strong profits after 6 years (1680000 Rs/year), underscoring the business potential for this concept. Although further research is needed to develop the technology before realization of the project, this novel method of simultaneous development of the technology and business system with contextual consideration has produced a promising foundation of a business with much potential.

Future Work

The business case and value proposition for the use of a potential Torrified fuel has been fairly well established. However, the reactor designs tested failed to give a uniformly Torrified product. In some regions of the bed, no Torrefaction could be achieved. Thus, future work in this project has to concentrate on evaluating new reactor designs. The current market demand of 1072 kg of Torrified pellets per day (or 8055 kg of A.R. pine needles per day) underscores the need for a continuous system rather than a batch system. Even though it was found that electricity can be used (through heat tracers) to carry out Torrefaction in this reactor design and yet produce a product that is cheap enough to bring about savings to end users, this may or may not be true for other designs. Thus, a thorough evaluation of potential fuels/other heating sources for various Torrefaction reactor designs need to be carried out, being a separate study in itself. However, wood should not be considered as a fuel at all for ecological reasons.

Moreover, the very idea of building a reactor completely locally in the mountains should not be pursued as it can only lead to the construction of very simple designs, which as in this case, lead to limitations in heat transfer, adequate sealing and consequently the production of a uniformly Torrified product. More sophisticated designs need to be pursued to achieve better extents of Torrefaction and achieve a more uniformly Torrified product. To a large extent, these plants would essentially have to be built in the plains of the country. Future work should also look into how these reactor designs can be possibly maintained in the mountains to prevent long downtimes. Graduates from local Industrial Training Institutes (ITIs) could be trained and then hired for the operation and maintenance of the reactor (s).

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APPENDIX 1: TASK DIVISION

Technology Design

Both students will contribute to the design of the Torrefaction reactor technology through some common and some distinct contributions.

Common Contribution

- Literature research on Torrefaction principles and important process parameters for reactor design
- Evaluation of different Torrefaction reactor design options

<u>Distinct</u>

Vidyut Mohan

- Description of design process and final selection of design
- Idea sketches of initial designs and CAD drawings of the chosen design
- Testing of the chosen design and the evaluation of its performance
- Selection of process parameters such as Torrefaction temperatures and residence times based on Mass and Energy Yields obtained from experiments on a packed bed setup with direct convective heating, Thermo-gravimetric Analyser, muffle furnace and bomb calorimetry experiments. This decision will be based on the sensitivity of these process parameters on the Torrefaction business case.
- Thermal degradation study of raw and Torrified pine needles using Differential Thermo-Gravimetric Analysis (TGA). This would provide further insights into the behavior of Mass Yields and thus would help in making a more informed decision on the Torrefaction temperature and residence time.

Ryan Helmer

- Description of construction methods used in the final chosen design
- Chemical reactor modelling of the chosen design to predict temperature gradients
- Kinetics modelling of volatile and permanent gas evolution during Torrefaction of pine needles
- Description of the mass and energy balance of the entire process.

Business System Design

Both students will contribute to the design of the Torrefaction reactor technology through some common and some distinct contributions.

Common Contribution

- Description of culture theory and its impact on intercultural management of businesses based on literature research
- Description of the major socio-economic context of the Kumaon region and Uttarakhand state
- Market overview of possible stakeholders customers/end uses of a Torrified product through desk and field research
- Research o major sources for the supply of pine needles and other biomass for biomass Torrefaction
- Service system idea generation and research on possible business models

<u>Distinct</u>

Vidyut Mohan

- Torrefaction fuel market study
- Torrefaction business stakeholder analysis though value propositions to different stakeholders in the service system
- Logistics (biomass collection, storage and product distribution) system design
- Service system design procedure and final selection of service system

Ryan Helmer

- Design of Torrefaction factory business structure
- Design of optimal operations and maintenance procedures of the Torrefaction plant
- Financial Analysis of the Torrefaction Business
- Life Cycle Impact Assessment (LCIA) of the Torrefaction Plant

APPENDIX 2: KUMAON OUT-MIGRATION STATISTICS



FIGURE 86: REASOND FOR OUTMIGRATION

Occupation	Average monthly remittance (in Indian Rupees)
Armed forces	3,333
Managerial job	3,333
Chef/cook	2,667
Waiter	1,693
Other	1,219
Driver	1,208
Clerical job	1,024
Daily wage labourer	833
Mechanic	667
Teacher	NA

¹ Figures do not include migrants who are not sending remittances; international migrants were excluded.

FIGURE 87: REMITTANCES BY MIGRANTS

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APPENDIX 3: HOUSEHOLD EMPLOYMENT OPTIONS IN RURAL AND URBAN UTTARAKHAND

Uttarakhand				
Items	Rural			
Self Employed Non-Agri	15%			
Agri Labour	9%			
Other Labour	8%			
Self Employed Agri	53%			
Other	15%			

Household employment (Rural)

FIGURE 88: HOUSEHOLD EMPLOYMENT OPTIONS IN RURAL UTTARAKHAND[14]

Household employment (Urban) Uttarakhand				
Items	Urban			
Self-Employed	39%			
Regular Wage/Sallary Earning	43%			
Casual Labour	5%			
Other	13%			

FIGURE 89: HOUSEHOLD EMPLOYMENT OPTIONS IN URBAN UTTARAKHAND[14]

APPENDIX 4: "SCIENTIFIC FORESTRY: ITS IMPACT ON KUMAONI LIVELIHOODS

The coniferous forests of the middle Himalayas were in terms of extent and ready access the most commercially valuable in the country. Shortage of timber for the railways urged the colonial state to start taking control over these forests and use the wood of chir pine and deodar for commercial timber production. The *chir* pine was found to have other uses in terms of a resin extract (raw material in paints and varbishes) and the possibility of antiseptic treatment of its wood for railway sleepers[9]. The forest department constituted by the state started to exercise control over certain blocks of forests, which belonged to the communities living in those areas. Large tracts of forests were usurped by the state without any legal settlement of rights. Thus "scientific" and formal management of forests came into being in the forests of Uttarakhand in the form of silviculture, to selectively grow and protect those trees that maximized commercial timber production and revenue. The policy of the state was oriented towards the conflicting objectives of maximizing timber production and taming peasant protests. In Uttarakhand the aim was to convert the mixed forests of oaks and conifers to pure coniferous forests due to its commercial value. What followed was the felling and girdling of non-coniferous trees (such as oaks and rhododendrons) to make way for a monoculture of coniferous forests. In the mixed forests of pine and oak, the larger oaks were removed before the pine tree fellings in order for better regeneration of new pine trees. Grass would be cleared around oak trees to allow further growth of pine trees in these mixed forests[9]. This was met by stiff protests by the locals, who would disobey these new rules and continue with their traditional forest use practices. Most protests were peaceful though, the heart of them being the Chipko (means hugging in Hindi) movement led predominantly by women in Uttarakhand as they were by that time solely responsible for cultivation and livestock rearing.

Over the years, based on the recommendation provided by foresty expert R.S.Troupe, total ban on customary agrarian practices were rejected as impractical due to strong resistance faced by the forest department by the peasants. New policies were developed to enable sustained reproduction of favoured species of trees while minimizing the threat to state monopoly through peasant protests. This was managed through skilful manipulation of customary agrarian practices of forest use[9]. The forest laws exemplified a very diplomatic balance between state control for commercial interests and pleasing the peasants.

Three important practices of traditional forest practices were manipulated by the forest department[9]: Grazing and grass cutting, lopping and burning of the forest floor. It was found that grazing was actually beneficial to the growth of chir pine and deodar trees and hence the forest department believed that this would help divert grazing away from the areas closed for reproduction to other forest areas where increased grazing would actually benefit 'other' tree growth. Thus, regulated grazing was allowed as a favour and not as a right. Loping was restricted to only those trees that did not give timber or to trees which were shortly to be felled. Loping was allowed on other non-coniferous trees such as oak (banih), which coupled to their felling by the forest department, created a monoculture of coniferous trees in the middle Himalayan region of India and in particular, a monoculture of *chir* pine in the Kumaon region. Due to inaccessibly of coniferous trees for firewood, the villagers had to lope other tree species, thereby reducing their number substantially. It was a traditional practice in the villages of Kumaon to set fire to the pine needles that would fall on the forest floor during the month of April, May and June. The pine needles hinder the growth of other grasses and shrubs that act as fodder for the cattle and also make the forest floor very slipper for the cattle to stand. The coniferous trees, particularly the *chir* pine were fairly resistant to fire but continuous reproduction in the areas of commercial logging operations rendered the young growth particularly vulnerable to fire. Attempts at completely banning this practice of burning pine needle forest floors was followed by strong resistance by the local population, who resorted to

incendiarism, by setting fire to *chir* forests belong to the forest department. The forest department came up with a solution of deliberately setting fire to certain tracts of forests. The areas under regeneration were divided in to blocks, and separated from the rest of the forest by "fire lines" of width upto 100 feet. These "fire line" were cleared of all trees and were set on fire in winter or spring, to make it grazing worthy before the onset of summer. The villagers were also allowed to burn the rest of the open *chir* pine forest (though still under control and supervision of the forest department) for grazing purposes. This was, thus, a middle path that the forest department could adopt to prevent incendiarism and keep the village population happy by allowing certain tracts of forests to be burned.

Local communities were involved in forest management in 1931, following many years of intense agitation and protest by the locals. Again, the forest department resorted to manipulative techniques of minimizing protests. The forests were divided into 3 categories. Class 1 forests were those which contain trees of little or no commercial value. Class II forests contain commercially valuable species (such as *chir* pine, *deodar, sal, kail*) for the forest department. Class II forests were controlled by the forest department and class I forests are under the civil administration. The class I forests were further divided into Civil, *Soyam* and *Van Panchayat* forests[84]. Through the *van panchayat* forests, or the local village forest, the government made limited tracts of forests available to the villagers. However, these forests were also declared 'reserved' and were indirectly controlled by the forest department. These village forests being completely controlled by the villagers implemented in a very piecemeal fashion. These van panchayat forests were small in extent and a village could never meet its complete firewood and grass needs from these forests.

Commercial forestry struck at the very root of peasant society. The assertion of state monopoly ran contrary to traditional forest management practices. These practices, once, represented community action towards production and unity between man and nature. Colonial forest law recognized only individual rights of the user, initiated the fragmentation of the community and the erosion of social bonds, hastened by the commercialization and the capitalist penetration in later years[9]. The resources and the produce of the forests no longer belonged to the villagers, but were now appropriated by the state. The alienation from the forests sometimes developed a lack of interests among communities to protect the forests that is no longer vested in them. In Eastern Kumaon, villagers lost interest in cultivation due to large tracts of adjacent forests being reserved as the entire subsistence of the farmers was threatened by the loss of control over the forests. With lesser broad leaf trees such as Oak around, it became increasingly difficult to find vegetation to make quality materials for their fields.

This practice of Silviculture and manipulation of customary forestry practices has remained unchanged to date, and in remote areas such as the Pithoragarh district of Uttarakhand, one can feel the uneasy equilibrium between the forest department and the village communities.

Current Forest Department Rules

Today, the role of the forest department is to manage and protect the forests, along with the sale of pine timber and resin through contractors. Economic interests dominate, as the sale of timber is a source of revenue generation for the forests. This is the reason, as discussed in chapter 1 that such vast tracts of monoculture of pine forests exist in the area. The upper administration is beginning to admit problems in the forest management system continuing from British times, but corruption is rampant and change is slow due to sluggish bureaucracy. The reserved forests or is allowed to collect forest produce. Only 1 tree per person (for life) is allowed to be cut, mainly to be used for house repair work. However, there has been such a strong tradition of firewood collection among the women, that there is a mutual understanding between the forest department and the villagers. Women are allowed to venture into the

forest to collect forest produce such as firewood, leaf-litter and grass for the cattle. However, if caught by the forest guard, cutting down of entire pine trees (or any tree for that matter) involves a strict fine and confiscation of the cutting tools.. People are also not allowed to carry out any sort of firewood collection from government land, which belongs to the revenue department (rather than the forest department), however collection happens anyway due to poor implementation of rules and the strong tradition of collection of forest produce.

On personal land, if the owner wishes to cut a tree, he/she has to take approval from the forest department. The forest department grants approval depending on the tree type and its distance from the reserve forest. However, the owner is free to carry out lopping from the tree on his/her land

According to a forest officer that was interviewed, Village forests or Van Panchayat forests were given to placate the villagers. These forests were created to meet the fuel, fodder and manure needs of the village. No trees are allowed to be cut in these forests as well and women can only cut dried branches of trees or gather fallen down branches. These are managed by elected representatives (president, treasurer and guard) from the village, but are indirectly controlled by the forest department. The van panchayat forest has a guard who is paid every 6 months, to keep an eye on uncontrolled cutting of wood and grass. Each family pays 150 rupees every 6 months for the salary of the guard. Meetings are convened occasionally to assess the state of grass growth, leaf litter and wood availability. If any of these are found to be short, then collection of that resource is not allowed till it replenishes again. If there is a tree that has matured, has dried up, or has fallen down due to snowfall, the village forest council convenes a meeting with the villagers and a mutual agreement is reached regarding distribution of wood. If there is a big occasion in the village (for example, a wedding) then the family has to take permission from the head of the van panchayat to cut a tree for it. However, only trees that have dried up or have fallen down are allowed to be cut. It costs roughly 1500 Rs to get a tree cut if labour is included. If other villagers help in cutting the tree, then they only have to bear the charge levied by the van panchayat, which is 30 Rs/ft of circumference.

Trees, thus, are not allowed to be cut anywhere: either in the reserve forests or in the village forests. The people, in general, are quite conscious that they should not do so. Village forests have stricter patrol so it is very difficult for someone to slip by and cut a tree, but instances of illegal felling of trees are increasing in reserve forests due to poor patrol.

However, though the village forest system encourages sustainable use of forest produce, these forests are not big enough to meet the fuel, grass and leaf litter requirements of the villagers and thus most often than not people have to venture outside their village forests (reserve forests). This involves travelling greater distances (2-3 km) and investing more time (usually 2-3 hours/day, in the months they collect wood). Additionally, not all villages have a forest council and most people use the reserve forests for firewood collection. According to locals, these forest councils manage the village forests fairly well; however, they are not big enough to meet the needs of the village.

APPENDIX 5: DESIGN SESSION INSTRUCTIONS

Introduction to the Generative Design Sessions

For this project, we are employing methods developed and used in the Industrial Design Engineering faculty at the TU Delft. These methods are called Generative Design (or Context Mapping) and are outlined in the recently published book Convivial Toolbox.

The general idea of this method is to use activities and discussions to gain insights into the values and preferences of a target group of people, usually potential users of a product or system. These activities are typically hands-on, and enable the people to reflect on their daily lives and past experiences, and enable them to help design an ideal future situation. Overall, it helps in the expression of their values and preferences that they might otherwise have difficulty putting into words.

Thus, drawing on the resources of Convivial Toolbox and Crossing Culture Chasms, we have developed these 3 sequences of activities, or 3 Design Sessions, for each of the following topic areas: Pine Needle Collection (Logistics of Biomass Procurement), Domestic Cooking, and Business Structure. The instructions below are meant to be used in facilitating the sessions.

Design Sessions Instructions

Collection Session

Activity 1- Map making

In this activity, I want each of you to draw a map of the journey of carrying the pine needles. Think about the important points in process of carrying the pine needles to the plant. What do you do while taking the pine needles? What places do you pass by? In the map, include the places on the mountains where you find and collect the pine needles, the path you walk while carrying them, and the place you leave them. Also include other important points, like the road, the houses, the gasifier plant, or any other places that you think are important. Also, draw the path you walk, and mark the places you come to and the things you do along the way, giving them numbers in order (1, 2, 3, etc.). Feel free to draw these points on the map or the images to represent them. Use any of the materials provided. At the end, we will gather together as a group and all of us will explain the maps we have made. (Note: Emphasize that we know very little about the process, and we want to know even the simple things that they think are obvious)

Now, I want each of you to explain the maps you have made. Explain the points on the map, and most importantly, explain the journey. What are the places you come to? What do you do along the way? Who wants to go first? (Note: for the first activity, ask for volunteers. For later activities, pick out people who haven't spoken much.)

Next, I want you to think of your past experiences in collecting pine needles. Take five minutes, and think about the following. What are 1 or 2 bad memories you have about moving pine needles? (Frustrating moments, tiring experiences, lonely moments, etc.). Also, what are 1 or 2 good memories you have? (Rewarding moments, fun experiences, etc.) After 5 minutes, we will come together as a group and share these memories. Feel free to act or draw the memories if you want.

Activity 2 – Improving Pine Needle Collection Process

For this last activity, we will split into two groups (Note: we can just quickly divide them into two groups after the instructions). We want you to create the ideal or perfect way to take the pine needles to the plant.

Group 1 will design a tool or device to use to take the pine needles. It can be anything, from something you carry in your hand or on your head, or something that two people use together, or something with an engine or battery, or a machine that you operate. Use the materials provided to build a small model of what it would be like. Think creatively!

Group 2 will design a process to take the pine needles. Think of several things: what is a better way for the pine needles to move? How will you move them? What people will be needed in the process? How many people? What tools or machines will be needed? How is this better than the current process?

After designing these, we will come together afterwards and explain our designs to the whole group, explaining what it is, how it works, and how it is better than the current system.

Daily Life and Cooking Session

Activity 1 - Illustrative Timeline

In this activity, I want you to make a timeline of the things you do in a day in January, starting with waking up, and ending with going to sleep. Put down whatever activities you think are important, and illustrate them. You can draw them, or use the images to represent them. At the end, you will explain your timelines. However, I want you to make three timelines - one for a normal day in January, but also one for a day in May, and one for a day in August. Thus, in total you will make three timelines. (If there are things that they will put on all three timelines, they don't have to illustrate these on all three timelines, but can just illustrate them on one timeline (i.e. January), but on the other they should at least make a note of the activity, if not illustrate it)

Now, we are going to explain the timelines we have made. Talk about the following: what is the activity? How do you do it? Why do you do it? How long does it take?

Activity 2 - Kitchen Design Game

For this activity, we are going to have a design game. You will be divided into 3 teams. (Quickly group them into teams after the instructions). Each team will have the task of designing the ideal dream kitchen. Each team will be given a "credit card" with a limit of 10,000 Rupees, and you cannot use more money than that. There will also be a store with different things to purchase for your kitchen. First, take a look at the options in the store, then discuss with your team the design of the kitchen. Then, draw the kitchen on the poster, arranging things how you want within the kitchen, and choosing which items you want to place in the kitchen. Illustrate it as you want, and place the images of the purchased items within in. At the end, you will explain the kitchen.

Now, let's explain the kitchens. Talk about the following things: What items are in your kitchen? Why did you choose those items? How did you arrange things in the kitchen? Why did you arrange them that way? What are the most important things for your team in the kitchen?

TABLE 39: KITCHEN ITEM PRICE LIST

Kitchen Item	Cost (Rs)
Cooking Appliances	
Gas Stove	3500
Charcoal Stove	2500
3 Stone Stove	1000
Kerosene Stove	3000
Electric Stove	5000
Wood oven	3000
Electric oven - large	6000
Electric oven - small	2500
Gas oven	5000
Charcoal oven	3500
Biogas based cooking system (stove and digester)	3000
Microwave oven	8500
Electric Toaster/Grill	1500
Cooking Utensils	
Pressure cooker	200
Kadhai	100
Tawa	100
Electric rice cooker	400
Pateela	150
Microwave containers	500
Frving pan	300
Eating Utensils	
Ceramic plates+ bowls + cups	500
Steel plates+ bowls +cups	200
Plastic plates+ bowls +cups	250
Glass plates+ bowls +cups	350
Clay plates+ bowls +cups	150
Steel spoons and forks	75
Plastic spoons and forks	60
Decoration/Utility	
Tiles for decoration	800
Chimney/Hood	500
Exhaust fan (hood not included)	800
Refrigerator	1500
Manual grinder (mortar and pestle)	75
Electric Mixer/Blender	800
Storage	
Modular Kitchen Drawers	1000
Basic Wood Cabinets	800
Simple Racks for keeping crockery and cutlery	500
Simple Rack for keeping freshly washed vessels	500
Simple Racks for spices dal rice wheat and vegetables	500
Drums for dry storage	200

Activity 3 - Collaging Cooking (could not do this activity due to time constraints)

Next, we are going to make a collage, or a collection of pictures, to represent our experiences in cooking. Take a few minutes to think of 3-5 memorable moments you have experienced in cooking in your life. These can be when you were a child, a teenager, a student, or even yesterday. Think of at least 1 good memory (such as the first time you cooked something or a special meal that you helped prepare), and at least 1 bad memory (maybe a frustrating day where the meal did not work out right). Then, after thinking of these, illustrate these on the paper, either drawing them or using the images provided. Afterwards, we will discuss them.

Now, let's get together and discuss our memories. Each person chooses 1 good memory and 1 bad memory, and we will share those to the group. Talk about the following: What happened? How was cooking involved? How did you feel? Why was it good or bad?

Business Structure Session

Introduction:

These activities are about the people you interact with often, in daily life and at work, either now or in the past. To be clear, this information is just for us to understand preferences and norms, and no details of what you say will be reported back to Avani or our professors. This is just for our own understanding.

Activity 1 - Daily Life Collage

To start, I want you to make a collage of the people you interact with often, on a daily or weekly basis. Place yourself at the center of the paper, and show the other people around you. You can draw them, or use the pictures given to represent them. Also, draw a line between the image of yourself and each person, and describe your relationship with them in 5 words or less. As you do the activity, think about the following questions: Who is the person? How do you know them? How do you interact with them (what do you talk about, where do you talk with them)? What is your relationship like with them? Are they the same gender as you? Are they the same caste as you? After making the collages, we will discuss them.

Now, let's discuss the collages. I want each person to choose two people who aren't from your family to discuss, and answer the following questions: Who is the person? How do you know them? How do you interact with them (what do you talk about, where do you talk with them)? What is your relationship like with them? Are they the same gender as you? Are they the same caste as you?

Activity 2 and 3- Coworker Collage and Experience Discussion

For the next activity, I want you to make another collage, similar to the first one. In this one, again you will draw yourself at the center of the paper, and show other people around you, but now I want you to focus on coworkers. Think of all the people that you interact with at your work (whether frequently or not), and draw them and use the images to represent them. Again, draw a line on the paper from yourself and the person, and use 5 words or less to describe your relationship with them. Afterwards, we will talk about your interactions with these persons.

Now, let's come back together to discuss the collages. I want each person to choose 2 people to discuss, and answer the following questions: Who is the person? How do you know them? How do you interact with them (what do you talk about, where do you talk with them)? What is your relationship like with them? Are they the same gender as you? Are they the same caste as you?

As we are thinking about work experiences, I also want to talk about past work experiences. Now, this time, I don't want you to use specific names of people, and I don't want you to think only about your current job, but also other working experiences you have had. If you haven't had another job, that's fine too, but we don't need to know who exactly you are talking about.

So take a few minutes and think about a 2-3 memories you have had about interacting with a supervisor or employer at your work. Include both good memories (such as an encouragement given, acknowledgment of hard work, etc.) and bad memories (a frustrating situation, an ignorant supervisor, etc.). Afterwards we will discuss them.

Now, I want to discuss your experiences. For each experience, think about the following: What happened? What did each person say? How did you treat each other? How did you feel during and after the interaction?

Activity 4

In the last activity, I want you to work as a group to resolve the following scenarios. We have written these imaginary situations that you may encounter in the workplace, and we want you to discuss what could be the best way to solve the situation. After 10 minutes, you will present your proposed solution, and then we will move onto the next one. Feel free to act out your proposed solution, illustrate it on the chart paper, or use bullet points to explain it. When presenting, discuss why you think the proposed solution is the best.

Scenarios

For all of the following scenarios, you will be put in the position of an employee, manager, or owner of a restaurant or hotel. The restaurant is a medium sized establishment with about 10 employees. The restaurant makes a variety of dishes, maybe sweets, maybe snacks like samosas, and full meals or *thalis*. So imagine yourself in the following work situations. You will have about 10 minutes to discuss each scenario.

Scenario 1 (Approachability, Taking responsibility): You are managing the restaurant for one week, as the owner has left on holiday, and thus the restaurant is in your care. One evening, several men walk in, sit down, and order *thalis*. After a few minutes, they order a bottle of whiskey. You tell them that the restaurant does not serve alcohol, but they demand nonetheless, and begin to yell, until you give in, and decide to go to the nearby shop. You bring back a bottle of whiskey, which they proceed to drink within a few minutes. They quickly become drunk, and make comments at people walking by on the street. One of them gets into a fight with a taxi driver, breaking a table in the restaurant. Within minutes, the police arrive, and take the drunk men away. You regret ever buying the bottle of whiskey. Should you tell your boss when he returns?

Scenario 2 (Independence in decision making): Again, you are managing the restaurant for one week, as the owner is on holiday for a week for Holi. He purchased 2 full cylinders of LPG for the restaurant before leaving, which is usually enough for 1 week. However, the first day after he left, the restaurant had a large surge of customers unexpectedly, and made a lot of money. However, after that day, you have finished one entire cylinder, and are almost done with the second. You need to purchase more in order keep the restaurant open, but you have never made any large purchases for the restaurant, nothing above 1000 Rs. You have called your boss 10 times already, but he has turned his phone off, and is not answering. You can use restaurant's money to make the purchase, but your employer has never let you purchase the LPG cylinders in the past. Do you purchase them? Or close the restaurant until the owner returns?
Scenario 3 (Motivation): You are the owner of the restaurant now. You notice that your restaurant has been declining for the past 6 months, and it is predominantly due to the lack of enthusiasm and effort by your employees. They seem to be very tired, and they don't seem to care much about their work. Thus, you have noticed that the quality of food and service is declining, and you are having few customers than before. You need to improve things quickly if you want to keep your restaurant alive, and you know that the quality of the work of your employees is the problem. What do you do?

Scenario 4 (Approachability, power distance): You are working one evening as a server, and a nice, very old couple comes in. They have been travelling all day, and they are very tired and hungry. They order two *thalis* with tea, which you go to prepare quickly. After they have been waiting 15 minutes, you are finishing the *thalis*, and are about to take them to the couple, when the owner of the restaurant walks in with two of his mates. He sees the *thalis* that are almost ready, and tells you to give them to his two friends, instead of the old couple who have been waiting patiently, and are very tired. What do you do? What do you say to your boss? How do you feel?

Scenario 5 (Gender, for men): You are an employee of the restaurant. One morning, you show up to work, and the owner does not arrive, but rather, a woman you have never seen before walks in and says that she is now managing things. She informs you that the owner had an emergency family situation to take care of, and will be gone for two weeks, and he has left her in charge of the restaurant until he comes back. She says that it will be her personal mission to make the restaurant 10 times cleaner than it is now, and that everyone will have to work hard to make sure that happens before the owner comes back. How would you react? What would you think? What would feel?

Scenario 5 (Gender, for women): You are an employee of a weaving center. One morning, you show up to work, and the woman in charge does not arrive, but rather, a man you have never seen before walks in and says that he is now managing things. He informs you that the manager had an emergency family situation to take care of, and will be gone for two weeks, and she has left him in charge of the weaving center until she comes back. He says that it will be his personal mission to make the center twice as efficient as it is now, with no one wasting time while at work, and they everyone will have to work hard to make sure that happens before the owner comes back. How would you react? What would you think? What would feel?

APPENDIX 6: FUEL CONVERSION METHOD

An estimate was needed of how much Torrified fuel would be required to replace a given amount of LPG, thus a ratio of mass of Torrified fuel per mass of LPG was calculated. Ideally, this could be done by testing Torrified fuel and comparing it to LPG. However, this was not possible, due to not having Torrified fuel there. Moreover, the translation of fuel use from one to another can vary significantly as was found out through the study of different literature and fuel usage trials conducted in Uttarakhand. Thus, comparisons were made between LPG, wood, and charcoal to establish a range of values for translation one type of fuel use to another.

First, literature was found comparing different sorts of fuels and cookstoves, applying standardized tests to compare them. In one paper[85], a water boiling test was used to compare wood, charcoal, kerosene, and butane on various stoves. The amount of fuel consumed was given, and this was used to get fuel conversion ratios. See the table below.

Consumption in Standard Water Test (kg fuel)							
Wood (3-stone stove)	Wood (Bottom Air Fan Stove)						
1.9	0.609						
Charcoal Stove 1	Charcoal Stove 2	Ratio (kg fuel/kg wood)	Ratio (kg fuel/kg wood)				
0.8	0.55	0.3552631579	1.108374384				
Kerosene Stove 1	Kerosene Stove 2	Ratio (kg fuel/kg wood)					
2.9	4.2	1.868421053					
Butane Stove 1	Butane Stove 2	Ratio (kg fuel/kg wood)	Ratio (kg fuel/kg wood)				
0.4	0.25	0.1710526316	0.5336617406				
			For the business case (using Bottom Air Stove for wood)				
kg Charcoal/kg LPG	kg Charcoal/kg Wood	kg Wood/kg LPG	kg Charcoal/kg Wood	kg Wood/kg LPG			
2.08	0.36	5.846153846	1.11	1.873846154			

TABLE 40: FUEL CONSUMPTION COMPARISON BASED ON STANDARD WATER TEST FROM LITERATURE

Similarly, another paper made comparisons with a standard water test, and the same method was applied to achieve fuel ratios [86].

TABLE 41. FIIEL	CONVERSION	RATIOS USIN	G OTHER	STANDARD	WATER	ΤΕΥΤΥ Ε	ROM L	ITERAT	'HR F
TADLE 41. FUEL	CONVERSION	KA1105 0510	G OTHER	STANDARD	WATER	I LOID F	KOM L	TIERAI	UKE

Consumption in Standard Water Test (kg fuel)							
Wood (3 stone)	Wood (Mud/sawdust)	Average					
1.253	0.754	1.0035					
Mali Charcoal	Charcoal Jiko	Charcoal w/ skirt	Ratio (kg fuel/kg wood)				
0.655	0.613	0.657	0.5121042831				
Propane (LPG)			Ratio (kg fuel/kg wood)				
0.14			0.1117318436				
Kerosene (unpressurized)			Ratio (kg fuel/kg wood)				
0.223			0.1779728651				
kg Charcoal/kg LPG	kg Charcoal/kg Wood	kg Wood/kg LPG					
4.58	0.51	8.95					

Similarly, a study on First Energy Oorja stoves gave similar data:

TABLE 42: FU	IEL USAGE	COMPARISON	FROM	OTHER	LITERA	TURE
	First Ener	rgy Oorja Stu	ıdy			

First Energy Oorja	Study	
kg Pellets/meal		kg/month
	1	60
kg LPG/meal		kg/month
	0.5	30
kg Wood/meal		kg/month
	5	300
Kg Wood/Kg LPG		10

Interviews with locals, and measuring amounts of wood, gave an indication on wood usage per meal. See table below.

TABLE	43. FUEL	USAGE	COMPARISON	THROUGH	INTERVIEWS	WITH	LOCALS
IADLE	45. FUEL	USAGE	COMPARISON	Inkoudii		VV I I I I	LOCALS

Fuel Use from Interviews (kg wood/meal)	
	Murari Interview 1 -
5 (chosen)	inferred
6.5	Murari Interview 2
4	Chachreth Demo
Fuel use of charcoal based on cooking tests and demonstrations using Avani's	
stove (kg charcoal/meal)	
1.25	
Kg charcoal/kg wood	0.25

Thus, around 5 kg of wood per meal was assumed.

Lastly, the authors performed their own tests at Avani, cooking a standard quantity of rice (approx 1 kg) in the same pot, on charcoal, wood, and LPG. The results and fuel ratios are given below:

Wood								
Wood Count (kg)	Rice (kg)	Time (min)	Fuel-Food Ratio (kg fuel/kg food)					
1.5	1.2	61	1.25					
	Charcoal							
Charcoal (kg)	Rice (kg)	Time (min)	Fuel-Food Ratio (kg fuel/kg food)					
0.625	1.125	30 min	0.56					
	LPG							
Gas Count (kg)	Rice (kg)	Time (min)	Fuel-Food Ratio (kg fuel/kg food)					
0.3	1.2	27	0.25					
kg Charcoal/kg LPG	kg Charcoal/kg Wood	kg Wood/kg LPG						
2.22	0.44	5						

TABLE 44: FUEL USE CONVERSION USING RICE COOKING TESTS

Thus, the minimum and maximum fuel usage ratios are as follows:

 $\left(\frac{Kg \ charcoal}{kg \ wood}\right)^1 = 1.11$, if a highly efficient wood burning stove is used

 $\left(\frac{Kg \ charcoal}{kg \ wood}\right)^2 = 0.25$, if a simple and inefficient three stone stove is used

 $\left(\frac{Kg \ wood}{kg \ LPG}\right)^1 = 1.87$, if a highly efficient wood burning stove is used

 $\left(\frac{Kg \ wood}{kg \ LPG}\right)^2 = 8.95$, if a simple and inefficient three stone stove is used

 $\left(\frac{Kg \ Torr.Fuel}{kg \ wood}\right)^1 = 0.70$, based on calorific value of wood and Torr. pellets

Wood was chosen instead of charcoal to further convert to Torr. fuel, as in interviews with experts from Philips, Torr. fuel appears to burn more like raw biomass than charcoal, having a higher oxygen and hydrogen content. Thus, LPG usage was first converted into equivalent wood usage, and then into equivalent Torr. fuel usage.

Wood was converted into Torr. fuel by mere ratio of calorific value. In the tests at the Process and Energy Laboratory TU Delft, the Torrified pine needles have a calorific value of 21.22 MJ/kg at selected process conditions of 250°C and 15 minutes residence times. In literature, pine wood is reported to have a calorific value of 14.7 MJ/kg [87]. Thus, in terms of energy equivalence, 0.70 kg of Torr. Fuel equates to 1 kg of wood. This ratio, in combination with the LPG/wood ratios above, was used to estimate a range of equivalent Torr. fuel consumption, given a defined LPG consumption (such as a *dhaba* owner gives in an interview).

APPENDIX 7: ECONOMIC VALUE PROPOSITION FOR COOKING IN RURAL HOUSEHOLDS

In this calculation, it is assumed that the stove is sold for free and the company only charges for the fuel.

Typical household size assumed = 3-4 members

Wood 1: Lopping of trees and branches in reserve forests

In this scenario, the costs associated with firewood collection are nil.

Wood 2: Cost of wood collection (lopping) if a village has a local forest council

Collection is carried out by lopping of branches and gathering of branches on the forest floor.

Based on interaction with the van panchayat head of Bhandari village,

Salary of the guard for the upkeep of the forests = 150Rs/6 months/family

Money spent by a family in the collection of firewood = 300 Rs/year

Wood 3: Cost of wood collection from fallen down trees due to heavy snowfall

If labour is employed to chop the wood,

Number of people employed as labour to chop wood = 3-4

Wage to each labourer = 350 Rs/day

Number of days taken to chop wood = 1

Number of years the collected firewood will last is 1-2 years (1 year assumed)

Labour cost= 1500-2000 Rs/year

If such fallen down trees are located in the reserve forests, people manage to get by without taking permission and paying a fee. This is because forest patrol is poor and people manage to slip past gaurds The only costs involved are the costs associated with using labour to chop the wood. If these trees are located in the *van panchayat* forest, then the forest council calls interested people and distribution of the wood is organized collectively. This would also involve just a labour cost, and not any extra fee.

All in all, whatever the scenario the costs associated in procuring wood through this way is 1500-2000 Rs/year.

Firewood cost = 2000 Rs/year (higher value assumed as a limiting case)

There have been other instances in villages where labour is employed for lopping of branches, and not whole trees. In this system as well, the costs amount to 2000 Rs/year.

However, it is important to keep in mind that most often than not this wood can be cut without employing labour and families can help each other out. Then the cost associated with getting the wood will be minimal.

Wood 4: Cost of wood collection with actual chopping down of dried Trees/Cutting of dried trees for weddings

The costs associated with labour are similar to Wood 2.

If the wood collected lasts 1-2 year (1 year assumed for maximum costs), then the firewood costs are same as Wood 2 if dried trees are cut in the reserve forest. If the dried tree is cut from the reserve forest there is usually no fee involved as forest patrol is poor and people manage to slip by the guards (If a dried tree needs to be cut, permission from the forest department has to be taken and would involve a fee/tax as well). However, even if the guards spot them, they allow cutting of dried trees and branches as this is something that has been practiced for a long time (based on information provided by forest officer). This is also the typical duration (1-2 years) for which the wood will last if it is cut for big occasions like weddings. There is substantial amount of wood left after the weddings that can last 1-2 years. Dried trees can also be used for such occasions.

Dried trees can also be cut in the *van panchayat* forest after taking permission and paying a fee of 30 Rs/ft of circumference. The usual circumference for a pine tree is 10 feet. Considering the fee for the forest guard of the village forest, the firewood costs in this system is,

Firewood costs = 2000+300+300 = 2600 Rs/year (also assuming the wood lasts 1 year)

If dried trees are being cut by the forest department themselves, then interested people from nearby areas are called and wood distribution is organized. The procurement of wood in this case would involve a fee/tax to the forest department and labour costs for chopping the wood.

However, it is important to keep in mind that most often than not this wood can be cut without employing labour and families can help each other out. Then the cost associated with getting the wood will be minimal

Wood 5: Illegal cutting of trees

Green trees are not allowed to be cut, either by the forest department or the people. The people are generally very protective of the forests and would not cut green trees. This is particularly true for the case of their village forests as it belongs to them and they have a stake in it. People are aware that they only need to cut dried trees or branches or pick up fallen down pieces of wood. Cutting of dried trees and branches is managed in the village forests by the village council and hence some control is exercised to maintain the forest. However, these forests are not able to meet the needs of the people and hence they have to venture in to reserve forests to get dried trees and branches. Even though collection of any sort of forest produce is not allowed in the reserve forests, the forests department officials allow it as it is such a strong tradition among the locals. Cutting of green trees, however, is a big offence and if caught can involve fines and confiscation of tools. However, instances of illegal cutting of green trees are increasing and people manage to slip by guards due to poor patrol.

If the wood from chopping a full collected lasts 3-4 months (3.5 months assumed), through any of the methods mentioned in this section (based on interviews), number of times trees have to be cut is 12/3.5=3.43

Firewood costs = 2000*3.43 = 6860 Rs/year (assuming wood lasts 3-4 months)

However, it is important to keep in mind that most often than not this wood can be cut without employing labour and families can help each other out. Then the cost associated with getting the wood will be minimal.

Use of 1 LPG cylinder = 2 months

Wood 1 firewood costs =300 Rs/year

Money paid to labour to haul LPG cylinder to the village (uphill or downhill) = 300Rs/cylinder

Subsidized cost of 1 LPG cylinder = 451.50 Rs/cylinder (based on price stated by local distributer during field visit)

Therefore total LPG cost = (451.50*6) + (300*6) = 4509 Rs/year

Total cost = 4809 Rs/year

Only LPG usage

Number of cylinders used per month = 1

Cost of 1 subsidized cylinder = 451.50 Rs

Cost = 5418 + 300 = 5718 Rs/year

Where 300 Rs is the cost associated with labour used to bring the cylinder to homes.

<u>Kerosene</u>

Cost of subsidized kerosene at ration shops = 16 Rs/L

Number of days of cooking with 1 Litre = 6 days

Number of subsidized litres of kerosene allowed in a month = 3 L

Non –subsidized cost of kerosene = 30 Rs/L (non-subsidized price or from parallel markets)

litres of non-subsidized kerosene used in remaining days = 2 L

Total cost = 16*3+30*2 = 108 Rs/month or 1296 Rs/year

Torrified fuel

Calorific value of torrfied pine needles @ 250°C and 15 minutes residence time = 21.22 MJ/kg (dry basis)

Calorific value of As Received wood = 14.7 MJ/kg [79]

Based on cooking trials done on Avani's charcoal cookstoves,

Amount of charcoal required to cook a meal for 3-4 people = 3.5 kg

Now, based on the study carried out in Appendix 6,

$$(\frac{Kg \ charcoal}{kg \ wood})^{1} = 1.11$$
$$(\frac{Kg \ charcoal}{kg \ wood})^{2} = 0.25$$

$$(\frac{Kg \ Torr. Fuel}{kg \ wood})^1 = \ 0.70$$

Low estimate of Torr. Fuel consumption = (3.5/1.11)*0.70 = 2.21 Kg/day High estimate of Torr. Fuel consumption = (3.5/0.25)*0.70 = 9.8 kg/day Assuming, the Torr. Fuel is sold at a minimal price of 5 Rs/kg, Low estimate of Torr. Fuel costs = 2.2*5*365 = 4015 Rs/year

High estimate of Torr. Fuel costs = 9.8*5*365 = 17885 Rs/year

Time Consumed in firewood collection

Based on interaction with women in two different villages, there are two ways in which wood is collected:

- 1. All the wood is collected in one go in the 3-4 winter months
- 2. Wood is collected periodically

Wood is collected every day in winter months

Time taken for collection (hr/occasion) = 2

Monthly rate (occasions/month) =30

Collection months (months/year) = 3.5

Annual time cost (hr/year) = 2*30*3.5 = 210

Daily time cost (hr/day) = 210/365 = 0.58

Wood collected periodically

Time taken for collection (hr/occasion) = 3

Weekly rate (occasions/week) = 3.5 (on average)

Daily time cost (hr/day) = 3*3.5/7 = 1.5

APPENDIX 8: VALUE PROPOSITION FOR OTHER PERI URBAN/URBAN RESIDENTS

In this calculation it is assumed that the stove is sold for free and the company only charges for the fuel.

Wood Consumption 1: Estimate based on average wood consumption in rural Uttarakhand

Wood consumption for an average rural Uttarakhand household = 258 kg wood/month[14]

Amount of wood procured from 1 tree = 500-600 Kg/tree (550 assumed) (from field interviews)

Number of trees required = (260*12)/550 = 5.7 trees/year

Costs associated with chopping wood from 1 tree =1500 Rs/tree (labour cost in chopping wood)

Cost associated with acquiring wood = 8550 Rs/year

However, it is important to keep in mind that most often than not this wood can be cut without employing labour and families can help each other out. Then the cost associated with getting the wood will be minimal.

Wood Consumption 2: Felling of trees that have dried up /Illegal felling of trees

Based on information gathered from a number of interviews,

Number of times a year a dried tree is cut = 3-4 trees/year

Costs associated with chopping wood from 1 tree = 1500 Rs/tree (Fee to forest department and labour cost in chopping wood)

Cost associated with acquiring wood = 1500*4 = 6000 Rs/year

However, it is important to keep in mind that most often than not this wood can be cut without employing labour and families can help each other out. Then the cost associated with getting the wood will be minimal.

<u>Wood Consumption 3: Chopping of trees that have fallen down due to heavy snowfall/Dried Trees cut for</u> <u>big occasions (in reserve forests) such as weddings</u>

Cost of chopping wood from 1 tree = 1500 Rs/tree (includes costs)

Based on field interviews, this wood will last 1-2 years. The trees cut for big occasions also last for 1-2 years after the occasion. Assuming this wood lasts 1 year,

Cost associated with acquiring wood = 1500 Rs/year (labour costs)

However, it is important to keep in mind that most often than not this wood can be cut without employing labour and families can help each other out. Then the cost associated with getting the wood will be minimal.

Wood Consumption 4: Buying wood from villagers/market

Cost of wood for 1 days cooking = Rs 50/stack

1 "stack" is enough for a day's cooking

Cost associated with acquiring wood = 18250 Rs/year

Wood Consumption 5: Buying wood from forest department

Cost of wood = 1.5 Rs/kg (usually at a higher rate than what is sold to businesses in bulk)

Assuming 5 kg of wood is used per meal[88]

(4-6.5 kg pine wood used per meal, based on field measurements)

Cost of cooking with wood = 8213 Rs/year

Wood Consumption 6: Free procurement of wood by the poor through various means

The poor will not be able to pay for the labour costs. Hence they would travel larger distances to reach forests and cut branches of dried up trees, entire dried up tress or pick up fallen branches (lopping). They would cut themselves or take each other's help. They might also get access to trees that have fallen down due to heavy snowfall and get it cut themselves without paying any money. The other option is the illegal felling of green trees, which is rare as people are generally protective of forests. However, this would also involve them doing the cutting themselves and is mostly free of cost.

LPG Consumption

Families in urban areas that can afford LPG use it as their primary cooking fuel.

Cost of 1 LPG cylinder = 451.5 Rs/cylinder (based on visit to local distributor)

Number of subsidized domestic LPG cylinders used in a year = 12

Cost associated with using LPG = 5418 Rs/year

Kerosene Usage

This is predominantly used by the poor who cannot afford LPG/buy wood and don't have the time to collect wood.

Cost of kerosene = 30Rs/L (unsubsidized price/parallel market price)

1 Litre lasts 6 days

Cost associated with using kerosene = 1825 Rs/year

Torrified Pellets Consumption

Calorific value of torrfied pine needles @ 250° C and 15 minutes residence time = 21.22 MJ/kg (dry basis)

Calorific value of As Received wood = 14.7 MJ/kg [79]

Based on cooking trials done on Avani's charcoal cookstoves,

Amount of charcoal required to cook a meal for 3-4 people = 3.5 kg Now, based on the study carried out in Appendix 6,

$$(\frac{Kg \ charcoal}{kg \ wood})^{1} = 1.11$$
$$(\frac{Kg \ charcoal}{kg \ wood})^{2} = 0.25$$
$$(\frac{Kg \ Torr. Fuel}{kg \ wood})^{1} = 0.70$$

Low estimate of Torr. Fuel consumption = (3.5/1.11)*0.70 = 2.21 Kg/day High estimate of Torr. Fuel consumption = (3.5/0.25)*0.70 = 9.8 kg/day Assuming, the Torr. Fuel is sold at a minimal price of 5 Rs/kg, Low estimate of Torr. Fuel costs = 2.2*5*365 = 4015 Rs/year

High estimate of Torr. Fuel costs = 9.8*5*365 = 17885 Rs/year

APPENDIX 9: VALUE PROPOSITION TO MIGRANT WORKERS

In this calculation it is assumed that the stove is sold for free and the company only charges for the fuel. The following information is based on personal interviews with a group of migrant workers living in the peri-urban town of Berinag, Pithoragarh district.

LPG Usage

Frequency of LPG cylinder usage = 1 cylinder/2months

Cost of subsidized LPG cylinder = 451.50 Rs/cylinder

Cost of using subsidized LPG = 2709 Rs/year/group

Kerosene Usage

Cost of kerosene = 30 Rs/L (non-resident of Uttarakhand, not holding BPL or ration cards)

Duration of use = 6 days/L

Cost of kerosene usage = (30/6)*365 = 1825 Rs/year

Torrified Fuel Use

Based on the research described in Appendix 6,

 $\left(\frac{Kg \ wood}{kg \ LPG}\right)^1 = 1.87$, if a highly efficient wood burning stove is used

 $\left(\frac{Kg \ wood}{kg \ LPG}\right)^2 = 8.95$, if a simple and inefficient three stone stove is used

 $\left(\frac{Kg \ Torr.Fuel}{kg \ wood}\right)^1 = 0.70$, based on calorific value of wood and Torr. pellets

Now, the migrant workers use 1 cylinder every 2 months. Each domestic cylinder has 14.2 Kg of LPG fuel.

Amount of LPG used in a year (kg/year) = 85.2

Converting LPG usage to wood usage, as combustion of wood is more similar to combustion of Torrified pellets as combustion of LPG,

Amount of wood used in a year (kg/year) 1 = 85.2*1.87 = 159.324 Kg wood/year

Amount of wood used in a year (kg/year) $2 = 85.2 \times 8.95 = 762.54$ Kg wood/year

Amount of Torrified pellets used in a year 1 (kg/year) = 159.324*0.70 = 111.23 Kg Torr. pellets/year

Amount of Torrified pellets used in a year 2 (kg/year) = 762.54*0.70 = 533.78 Kg Torr. pellets/year

Assuming minimal price of Torrified pellets at 5 Rs/kg,

Cost of using Torrified pellets in a year 1 (Rs/year) = 111.23*5 = 556.15 Rs/year

Cost of using torrified pellets in a year 2 (Rs/year) = 533.78*5 = 2668.89 Rs/year

APPENDIX 10: VALUE PROPOSITION TO SMALL EATERIES THAT COOK WITH WOOD

In this calculation, it is assumed that the stove is sold for free and the company only charges for the fuel.

Daily wood usage = 25 kg/day

Expenditure on wood = 5000 Rs/month or 60000Rs/ year

Now based on the equation,

$$(\frac{Kg \ Torr. Fuel}{kg \ wood})^{1} = \ 0.70$$

Daily Torr. Fuel usage = 17.5 Kg/day or 6125 Kg/year (assuming 350 working days in a year)

Price of Torr. Fuel Pellets = 14 Rs/kg

Expenditure @ 14 Rs/kg = 17.5*14*350 = 85750 Rs/year (assuming 350 working days in a year)

Price of Torr. Fuel to make it competitive = 60000/6125 Rs/kg = 9.79 Rs/kg

APPENDIX 11: VALUE PROPOSITIONS FOR EATERIES THAT USE COMMERCIAL LPG

<u>LPG Consumption – Domestic</u>

LPG consumption = 6 cylinders/month or 72 cylinders/year

14.2 kg of LPG in one cylinder

LPG usage = 14.2*6 = 85.2 kg/month

Calorific value of LPG = 46.3 MJ/kg[79]

Energy consumption = 72*14.2*46.3 MJ/year = 47337.12 MJ/year

Cost of each cylinder = 800 Rs/cylinder (from parallel market)

Total cost = 800*72 Rs/year = 57600 Rs/year

LPG Consumption-Commercial

LPG consumption = 4 cylinders/month or 48 cylinders/year

19 kg of LPG in one cylinder

LPG usage = 19*4 = 76 kg/month

Calorific value of LPG = 46.3 MJ/kg[79]

Energy consumption = 48*19*46.3 MJ/year = 42225.6 MJ/year

Cost of each cylinder = 1500 Rs/cylinder (from parallel market)

Total cost = 1500*48 Rs/year = 72000 Rs/year

Total LPG cost = 72000+57600 Rs/year = 129600 Rs/year

Estimated Torr. Fuel Consumption

Based on the methodology to convert fuel usage from one fuel to another described in Appendix 6,

$$(\frac{Kg \ wood}{kg \ LPG})^{1} = 1.87$$
$$(\frac{Kg \ wood}{kg \ LPG})^{2} = 8.95$$

Equivalent wood consumption 1 = (76+85.2)*1.87 = 301.44 kg wood/month Equivalent wood consumption 2 = (76+85.2)*8.95 = 1442.74 Kg wood/month Higher Heating Value of wood = 14.7 MJ/kg

Higher Heating Value of Torr. Fuel = 21.22 MJ/kg

(Torrefaction @ 250°C and 15 minutes residence time followed by bomb calorimetry at the process and energy laboratory at TU Delft)

Therefore,

$$(\frac{Kg \ Torr.Fuel}{kg \ wood})^1 = \ 0.70,$$

Torr. Fuel price = 14 Rs/kg

Torr. Fuel use 1 = Equivalent wood consumption 1*0.70 = 210 Kg/month

Torr. Fuel use 2 = Equivalent wood consumption 2*0.70 = 1009.92 kg/month

Torr. Fuel expenditure 1 = Torr.Fuel use 1*14*12 = 35282 Rs/year

Torr. Fuel expenditure2 = Torr.Fuel use 2*14*12 = 169666.56 Rs/year

APPENDIX 12: VALUE PROPOSITION FOR BIG HOTELS AND RESORTS IN URBAN AREAS

Calculation for coal

Amount of coal used per day = 6-8 bags/day

Amount of coal in 1 bag = 10-15 kg

Amount of coal used per day = 7*12.5 = 87.5 kg/day

Cost of 1 bag = 50 Rs/bag

Amount spent to transport coal from the plains = 2500 Rs/month

Cost of using coal = 7*365*50 + 30000 = 157750 Rs/year

Cost of using pine needle charcoal @ 14 Rs/kg = 447125 Rs/ year

Calculation for using biomass boiler system for water heating

Total electricity bill of hotel visited = 80000 Rs/month (water heating and space heating is the main consumption)

The hotel visited had 56 geysers with 1 geyser per room. The volume capacity of each geyser was 30 L. The power capacity of each geyser is 1 kW.

Thus, on a day the peak demand for hot water on a winter morning, with all rooms occupied and using hot water for bathing in a span of 1 hour can be 56*30, or 1680 L. This can be approximated to 2000 L/h to accommodate for people/families that use more hot water for bathing than 1 full tank of the geyser. A biomass pellet based water boiler system with 2200 L/h of water output can be used for this hotel. Based on the specification sheet given by the company, the efficiency of the boiler is 80%. Specifications are shown for water being heated from $20-85^{\circ}C[46]$.

Typically, an electric geyser in a bathroom can heat up its full capacity of 30L in about 15 minutes or 0.25 hours (based on experience of using them). The commercial cost of electricity found out was 5 Rs/kWh. Therefore the cost of using an electric geyser to heat up its full capacity is 1.25 Rs.

To heat 30 L of water from 20°Cto 85°C, the amount of energy required is,

Q = 30*4.18* (85-20)*10^3 J = 8.15 MJ

The efficiency of the boiler in the specification sheet is 80%. Therefore,

Q = 10.18 MJ

Calorific value of Torrified biomass mentioned in chapter 3 = 21.22 MJ/kg

Total amount of Torrified pellets needed for this = 0.48 Kg

Cost of Torrified pellets = 14 Rs/kg

Therefore cost of heating 30 L of water using a pellet based boiler = 6.72 Rs

APPENDIX 13: BISCUIT FACTORY/BAKERY BUSINESS CASE

Abellon Bio Energy sells a biomass pellet fired oven which is ideal for small bakeries and biscuit factories.

The specifications of the oven that were used are as follows[89]:

Pellet Feed Rate: 7-15 Kg/hr

Power Input: 0.75 HP or 0.55 kW

Moreover, the following assumptions were made:

- The oven feed rate is 7 Kg/hr.
- The lifetime of the oven is 5 years.
- The shop is open 350 days/year.
- Average cost of commercial LPG cylinder = 1500 Rs./ cylinder

Commercial LPG fuel costs

The shop that uses an LPG fired oven, consumes 10 commercial cylinders in a month.

Therefore,

LPG fuel cost = 10 x 1500 x 12 =180000 Rs/year

Biomass Oven Usage Cost

Since the oven is used as per demand, ot can be used for 2, 3, 6 and 6 hours/day.

Biomass usage fuel cost $1 = (7 \times 2 \times 14 \times 350) + (0.55 \times 2 \times 5 \times 350) = 70525$ Rs/year

Biomass usage fuel cost $2 = (7 \times 3 \times 14 \times 350) + (0.55 \times 3 \times 5 \times 350) = 105787.5$ Rs/year

Biomass usage fuel cost $3 = (7 \times 4 \times 14 \times 350) + (0.55 \times 4 \times 5 \times 350) = 141050 \text{ Rs/year}$

Biomass usage fuel cost $4 = (7 \times 6 \times 14 \times 350) + (0.55 \times 6 \times 5 \times 350) = 211575$ Rs/year

Average fuel usage costs = 132234.375 Rs. /Year

Biomass Oven Cost = 20,000 Rs

Assuming the lifetime of the oven to be 5 years,

Annualized biomass oven cost = 4000 Rs/year

Total cost of biomass oven usage =136234.38 Rs/year

APPENDIX 14: AVANI BIO-ENERGY PINE NEEDLE GASIFICATION VALUE PROPOSITION

Current Business Case

Assumptions:

- 1. 30% of the pine needles are lost due to rotting.
- 2. The plant operates for 48 hours in a 6 day week.
- 3. There are 300 working days in a year.
- 4. The employees are paid 4000 Rs/month.
- 5. There are 6 employees in the plant.
- 6. The maintenance costs are 7% per annum.
- 7. The sale of charcoal as a by- product is not considered as it is not run as a business yet.
- 8. The pine needle collectors are paid 1 Re/kg of As Received pine needles.
- 9. The electricity sale price is 4.89 Rs/kWh.

Sources: Interviews with staff at Avani.

Biomass input to gasifier (kg/hr) = 180

Adjusted biomass input (kg/hr) = 180/0.7 = 257

Average plant electricity output (kW) = 45 (Based on personal observations)

Duration of plant operation (hr/day) = 8

Electricity produced (kWh/year) = 45x8x300=108000

Income (Rs/h) =45x4.89=220

Income (Rs/year) = 10800x4.89=528120

Biomass required (kg/year) =616800

Biomass costs (Rs/hr) =257x1=257

Biomass costs (Rs/year) =616800x1=616800

Salary to employees (Rs/day) =4000x12/300=160

Labour costs (Rs/hr) =6x160/8=120

Labour costs (Rs/year) =6x160x300=288000

Capital costs (Rs) =10000000

Maintenance costs (Rs/hr)=1000000x0.07/300/8=292

Maintenance costs (Rs/year) =0.07x1000000=700000

Profit (Rs/hr) =220-257-120-292=-449

Profit (Rs/year) =528120-616800-288000-700000= -1076680

Business case of Torrefaction with current operating parameters

Assumptions:

- 1. The plant operates for 48 hours in a 6 day week.
- 2. There are 300 working days in a year.
- 3. The employees are paid 4000 Rs/month.
- 4. There are 6 employees in the plant.
- 5. The maintenance costs are 6% per annum (reduction due to use of Torrified product)
- 6. The sale of charcoal as a by- product is not considered as it is not run as a business yet.
- 7. The Torrefaction company is paid 1.3 Rs/kg of As Received pine needles
- 8. The electricity sale price is 4.89 Rs/kWh.

Sources: Interviews with staff at Avani.

Biomass input to gasifier (kg/hr) = 180

Average plant electricity output (kW) = 70 (Increase due to better fuel properties of Torrified biomass)

Duration of plant operation (hr/day) = 8

Electricity produced (kWh/year) = 70x8x300=168000

Income (Rs/h) =70x4.89=342.3

Income (Rs/year) = 16800x4.89=821520

Biomass required (kg/year) =180x8x300=432000

Biomass costs (Rs/hr) =180x1.3=234

Biomass costs (Rs/year) =432000x1.3=561600

Salary to employees (Rs/day) =4000x12/300=160

Labour costs (Rs/hr) =6x160/8=120

Labour costs (Rs/year) =6x160x300=288000

Capital costs (Rs) =10000000

Maintenance costs (Rs/hr)=1000000x0.06/300/8=250

Maintenance costs (Rs/year) =0.06x1000000=600000

Profit (Rs/hr) =342.3-234-120-250=-262

Profit (Rs/year) =821520-561600-288000-600000=-628080

Business case with torrefaction with future planned operating parameters

Assumptions:

- 1. The plant operates for 24 hours/day in a 6 day week.
- 2. There are 300 working days in a year.
- 3. The employees are paid 5000 Rs/month.
- 4. There are 6 employees in the plant.
- 5. There are 2 shifts of 12 hours with 3 employees working in those 12 hours. There is a four hour break for each employee in those 12 hours. Each group of three staff members is responsible for alternate weeks of night duty.
- 6. The maintenance costs are 6% per annum (reduction due to use of Torrified product)
- 7. The sale of charcoal as a by- product is not considered as it is not run as a business yet.
- 8. The Torrefaction company is paid 1.5 Rs/kg of As Received pine needles
- 9. The electricity sale price is 4.89 Rs/kWh.

Sources: Interviews with staff at Avani.

Biomass input to gasifier (kg/hr) = 180

Average plant electricity output (kW) = 90 (Increase due to better fuel properties of Torrified biomass)

Duration of plant operation (hr/day) = 24

Electricity produced (kWh/year) = 90x24x300=648000

Income (Rs/h) =90x4.89=440.1

Income (Rs/year) = 648000x4.89=3168720

Biomass required (kg/year) =180x24x300=1296000

Biomass costs (Rs/hr) =180x1.3=270

Biomass costs (Rs/year) =1296000x1.3=1944000

Salary to employees (Rs/day) =5000x12/300=200

Labour costs (Rs/hr) =6x200/24=50

Labour costs (Rs/year) =6x200x300=360000

Capital costs (Rs) =10000000

Maintenance costs (Rs/hr)=10000000x0.04/300/24=55.55

Maintenance costs (Rs/year) =0.04x1000000=400000

Profit (Rs/hr) =440.1-270-50-55.55=54.55

Profit (Rs/year) =3168720-1944000-360000-400000=464720

Torrefaction Gasification Service System Ideas

PSS1: Torr. Fuel Business for Electricity (Centralized – Small Enterprise)

Pine needle collectors are paid to collect pine needles during the three months of harvest season. The company pays them per kg or hr or they are salaried.

They bring the pine needles to the Torrefaction plant, which is near the gasification plant. Then the biomass is Torrified and stored at the warehouse. The torrefaction company will be distinct from the gasification company. The torrefaction company then sells the Torrified pine needles to the gasification company. It would make sense to have the torrefaction plant at a higher location than the gasification plant, to make transportation to the gasifier easier.

Drawback: This would likely require the pine needle collectors to carry the needles large distances, and thus may limit the amount of biomass that can be used in the nearby areas.

Advantage: The torrefaction plant is, and must be, close to the gasifier. Thus, transportation to the gasifier is minimal.

If land is not available, then this service system is not likely.

PSS2: Torr. Fuel Business for Electricity (Decentralized – Small Enterprise)

Pine needle collectors are paid to collect pine needles during the three months of harvest season. The company pays them per kg or hr or they are salaried. They bring the pine needles to decentralized locations for decentralized torrefaction, such as in each village or collection centre. Then the biomass is Torrified at the village, and stored temporarily in small, buffer storage facilities there in the village. Then, the Torrified biomass is later transported to the plant upon demand. So the company consists of various torrefaction/collection/storage centres, and from these the biomass is transported to the end user upon demand (the end user being the gasifier plant).

The tor coal can be transported to the plant via foot, trolley, cable car, or truck.

Advantage: This will give shorter distances for the collectors to walk, and thus allow them to collect more pine needles. This would also improve the efficiency of transportation, as half of the transporting process would be for Torrified biomass, which is more energy dense.

Drawback: High distances to transport Torrified material to the gasifier.

APPENDIX 15: VALUE PROPOSITION OF DAIRY PLANTS

Field Data:

- 1. 600 kg/day of pine briquettes used in boiler
- 2. Temperature needed in combustion chamber: 700-800°C
- 3. Consumption of pine needle briquettes:70 kg/h
- 4. Steam production capacity of boiler:250kg/h
- 5. Operation of boiler:8-9 h/day
- 6. Temperature of steam produced:250°C
- 7. The briquettes are currently bought at 6-7 Rs/kg, with an additional cost of 1 Re/kg of transporting the briquettes every month. They transport 10 tonnes in 1 load.

Current cost of pine briquettes use=600x8=4800 Rs/day

Potential cost of using locally produced Torrified pine briquettes=600x7=4200 Rs/day

APPENDIX 16: VALUE PROPOSITION FOR GOVERNMENT SCHOOLS

Schools Using Domestic LPG

Number of cylinders used in a month= 3

Current Cost (Rs/month) =1700-1800

1 year ago, the school was using only wood for cooking. They were using 15-20 quintals of wood in a month.

Based on results in Appendix 6, $\frac{Kg \ Torr \ coal}{Kg \ Pine \ Wood} = 0.70$

Equivalent Torrified fuel usage (kg/month) =17.5 x 0.70 x 100 =1225

Cost of using Torrified fuel (Rs/month) @ 5 Rs/kg = 6125

Minimum Cost of Torrified fuel to bring value (Rs/kg) = 1800/1225 =1.47

School Using Firewood

Amount of firewood used in a day (kg/day) = 30

Cost of using wood (Rs/day) = 35

Equivalent Torrified fuel usage $(kg/day) = 30 \times 0.70 = 21$

Cost of using Torrified fuel (Rs/month) @ 5Rs/kg = 21 x26 x5=2730 Rs/month

(26 days in a month-assumption)

Minimum Cost of Torrified fuel to bring value (Rs/kg) = 35/21 = 1.67

APPENDIX 17: MARKET ESTIMATION

Stove Pay Back Period for Torrefaction Company

Cookstove cost to Torrefaction company (1) = 15500 Rs[48]

Fuel sale price (2) = 15 Rs/kg

Assumed fuel use by 1 cookstove (3) = 20000 Kg/year (rough estimation based on 8-9 kg/hr feed rate of cookstove)

Production cost of fuel (4) = 14.57 Rs/kg (after $1^{\text{st}} 6$ years of recovering capital costs)

Production cost of fuel (4') = 10.35 Rs/kg (Between 6th year of operation and 10^{th} year of operation)

Revenue (5) = 3*(2-4) = 8600 Rs/year

Revenue (5') = 3*(2-4') = 93000 Rs/year

Payback time (6) = 1/5 = 1.80 years

Payback time (6') = 1/5' = 0.17 years

Equations used for calculations done in Table 22

Data used in this section such as Mass Yields, packing density, number of batches possible in a year is based on field testing of the chosen reactor design (reactor 2) mentioned in chapter 3 and experimental testing of pine needles for Mass and Energy Yields.

$$\begin{aligned} Fuel \ production\left(\frac{Kg \ Fuel}{Year}\right) \\ &= Packing \ Density\left(\frac{Kg \ A. R. Biomass}{m_{reactor}^3 * batch}\right) * cumulative \ reactor \ size(m^3) \\ &* \ No. \ of \ batches \ in \ a \ year\left(\frac{batches}{year}\right) * \ Mass \ Yield^{A.R.Basis}\left(\frac{kg \ fuel}{kg \ A. R. biomass}\right) \end{aligned}$$

$$= No. of batches in a day \left(\frac{batches}{day}\right) * Torrefaction weeks \left(\frac{weeks}{year}\right) \\ * Weekly Torrefaction days \left(\frac{days}{week}\right)$$

Number of batches in a day (14 hour workday assumed) = 4 batches/day

(3.5 hours per batch based on field experiments with reactor 2)

The Torrefaction will be carried out in the three months when pine needle collection will take place. Therefore, Torrefaction Weeks = 12 weeks/year

Weekly Torrefaction days = No. of working days in a week = 6 days/week

The number of reactors needed to meet this demand is given by,

Number of reactors needed =
$$\frac{Cumulative reactor volume to meet market demand (21m3)}{Volume of 1 reactor (0.064 m3)}$$

The daily Torrified fuel production is given by the following equation,

Fuel production
$$\left(\frac{kg \ fuel}{day}\right) = \frac{Fuel \ production \left(\frac{kg \ fuel}{year}\right)}{72}$$

(Since the process of Torrefaction is concentrated in a period of three months and it is assumed that there are 24 working days in a month.)

Raw pine needle demand
$$\left(Kg \ A. R. Pine \frac{needles}{day}\right) = \frac{Fuel \ production \ (kg \ \frac{fuel}{day})}{0.75 * 0.8631}$$

Where 0.75 is the fraction of dry pine needles if they are As Received (assuming 25% moisture content) and 0.8631 is the Mass Yield for the chosen Torrefaction process conditions of 250°C and 15 minutes residence time.

The delivery of the fuel to the market is distributed over the year and assuming 350 working days in the market,

Fuel delivery
$$\left(\frac{kg fuel}{day}\right) = \frac{Fuel \ production\left(\frac{kg \ fuel}{year}\right)}{350}$$

APPENDIX 18: DETAILS OF ROPEWAY SYSTEMS

Details of ropeway system based on information provided by Avani staff:

- 1. Length of ropeway cables = 150m (Avani uses ropeway cables that are 1500 m long)
- 2. Amount of pine needles it can carry = 40 kg
- 3. Total cost of motorized ropeway = 600000 Rs
 - a. Cable cost = 200000 Rs
 - b. Electric work = 150000 Rs

Avani's electrically operated ropeway which was 1500m long cost Rs 750000.

- 4. Total cost of manually operated ropeway = 300000 Rs (after excluding costs for electric work and motor)
- 5. Motor specification
 - a. 7.5 kW
 - b. 2800 RPM

Calculation A

Based on the market demand calculated in section 2.4,

Daily As Received biomass requirement by the plant = 8055 Kg/day

Maximum collection allowed per collector in a day = 45 kg

Therefore, number of pine needle collectors required = 8055/45 = 179

Based on field visits, typical number of pine needle collectors in a villages = 12 collectors (Approx.)

Therefore, number of villages associated with the plant = 179/12 = 15 villages

Amount of pine needles handled by each collection centre in a day = 8055/7 = 1150 Kg/day

Calculation B

Load capacity of each ropeway system = 40 kg

Number of round trips per ropeway system assumed = 30

Therefore number of cable cars needed = 8055/(40*10) = 6.71 or 7 ropeway systems

Number of villages per cable car = 15/7 = 2.14 or 3 villages/ropeway system

Calculation C

Number of additional Tarpaulin covers needed at the collection centres = 7

Size of each Tarpaulin cover = $45' \times 39'$

Cost of each tarpaulin cover = 5454 Rs

Total cost of additional Tarpaulin covers = 7*5454 = 38178 Rs[54]

APPENDIX 19: FOOT COLLECTION + HIRED TRUCK

Bulk density of As Received Pine Needles = 85 Kg/m^3 (an average value obtained through measurement and literature[49]). Therefore,

Raw Pine Needle Demand Per Day
$$\left(\frac{m^3}{day}\right) = \frac{Raw Pine Needle Demand Per Day \left(\frac{kg}{day}\right)}{Bulk density of A.R.Pine Needles}$$

Volume of cargo container in the truck $(m^3) = 4.342*2.005*1.773 m^3 = 15.435 m^3$ [90] (height was measured)

As one can see from Table 46(below), the daily volumetric demand of pine needles exceeds the truck cargo container volume after a cumulative reactor size of $3m^3$. Hence multiple trips would have to be made to fulfil higher demands.

Moreover, for each complete loading of pine needles, the payload = 15.43*85 = 1311.55 kg

This is well below the payload capacity of a truck, which is 4210 kg [90]. Hence due to the voluminous nature of pine needles, the truck is being under-utilized.

Based on information provided by staff at Avani, such a truck which is hired costs 3000 Rs/day to make multiple trips between two locations. Labour costs and fuel costs are additional. Avani had to bear the same costs to transport pine needles to the plant from a site 30 km away, with the truck doing three round trips, being able to carry roughly 1 ton each time.

Here, it is assumed that 2 people are hired as labour for loading and unloading at 350 Rs/day.

Distance of the forest from the plant = 10 km

Fuel economy of the vehicle = 17.86 km/L[90]

Diesel cost in Almora = 57 Rs/L (during field research)

A cumulative reactor size of 21 m³ would require a truck of this volume capacity to make 7 round trips. The numbers in brackets indicate the number of round trips that needs to carry every full truckload $(15m^3)$ of biomass. The total collection costs will be the sum of foot collection costs calculated earlier and the hired truck collection costs calculated here.

			Truck	Truck	
Cumulative	Raw Pine	Raw Pine Needle	Collection	Collection	Foot
Reactor Size	needle demand	Demand Volume	Costs	Costs	Collection+Hired
(m3)	(Ka.A.R./day)	$(m3A_R/day)$	(Rs/day)	(Rs/year)	Truck(Rs/year)
0(1)	0	0	0	0	0
1	384	5	3764	270996	312419
2	767	9	3764	270996	3538/2
3	1151	14	3764	270996	395265
A(2)	153/	18	3878	275593	1/128/
	1918	23	3828	275593	482707
6	2301	23	3828	275593	524129
7	2685	32	3828	275593	565552
8(3)	3068	36	3892	280189	611571
9	3452		3802	280185	652994
10	3835	41	3802	280185	69//17
11(4)	/219	45 50	3055	280185	7/0/36
12	4603	50	3955	284786	781859
12	4005	59	3955	284786	823281
1/(5)	5370	63	///10	284780	869301
15	5753	68	4015	280382	910723
15	6137	72	4015	285382	952176
10	6520	72	4015	285582	003560
19(6)	6004	01	4013	289382	1020599
10(0)	0904	01	4085	293979	1039366
20	7287	80	4083	293979	1122/22
20	7071	90	4065	293979	1122433
21(7)	8/38	90	4147	208575	1200875
22	8877	104	4147 //1/7	298575	1251298
23	9205	104	4147 //1/7	298575	1292721
24	0580	112	4147	200170	1232721
25(8)	9389	115	4211	303172	1280162
20	10256	122	4211	202172	1/21585
27	10330	122	4211	207768	1421383
28(9)	11122	120	4275	207769	1407003
29	11125	125	4275	307768	1550/150
31(10)	11800	1/0	/338	312365	1596/69
27	12272	1//	4330	312365	1637802
22	12657	1/0	4000	212265	1670215
34	13040	153	4338	312365	1720738

TABLE 45: HIRED TRUCK COLLECTION COSTS VS CUMULATIVE REACTOR VOLUME

Thus,

35(11)

For a daily raw pine needle demand of 8054 kg, the cost of collecting pine needles using a hired truck are 4147/8054 = 0.52 Rs/kg As Received biomass



FIGURE 90: A TYPICAL LARGE TRUCK THAT CAN BE USED TO DELIVER COLLECTED BIOMASS TO THE PLANT[90]

APPENDIX 20: FOOT COLLECTION + HIRED TRUCK TRANSPORT WITH BALING

Baling costs = 0.64 Rs/kg of As received pine needles, inclusive of cost of renting a tractor, 4 people as labour, diesel for running baling machine and tractor.

TABLE 46: COSTS ASSOCIATED WITH FOOT COLLECTION + HIRED TRUCK COLLECTION WITH BALING VS CUMULATIVE REACTOR VOLUME

								Foot
Cumulative		Raw Pine	Raw Pine Needle			Foot		collection+hired
Reactor Size	Foot Collection	needle demand	Demand Volume	Truck Collection	Truck Collection	Collection+Hired	Bailing Costs	truck+baling
(m3)	Costs (Rs/year)	(Kg.A.R./day)	(m3 A.R./day)	Costs (Rs/day)	Costs (Rs/year)	Truck(Rs/year)	(Rs/year)	cost (Rs/year)
0(1)	0	0	0	0	0	0	0	0
1	41423	384	5	3764	270996	312419	17674	330093
2	82845	767	9	3764	270996	353842	35347	389189
3	124268	1151	14	3764	270996	395265	53021	448286
4	165691	1534	18	3764	270996	436687	70695	507382
5	207114	1918	23	3764	270996	478110	88368	566479
6	248536	2301	27	3764	270996	519533	106042	625575
7	289959	2685	32	3764	270996	560956	123716	684671
8	331382	3068	36	3764	270996	602378	141390	743768
9(2)	372805	3452	41	3828	275616	648421	159063	807484
10	414227	3835	45	3828	275616	689843	176737	866580
11	455650	4219	50	3828	275616	731266	194411	925677
12	497073	4603	54	3828	275616	772689	212084	984773
13	538495	4986	59	3828	275616	814111	229758	1043870
14	579918	5370	63	3828	275616	855534	247432	1102966
15	621341	5753	68	3828	275616	896957	265105	1162062
16	662764	6137	72	3828	275616	938380	282779	1221159
17(3)	704186	6520	77	3892	280224	984410	300453	1284863
18	745609	6904	81	3892	280224	1025833	318127	1343960
19	787032	7287	86	3892	280224	1067256	335800	1403056
20	828455	7671	90	3892	280224	1108679	353474	1462152
21	869877	8054	95	3892	280224	1150101	371148	1521249
22	911300	8438	99	3892	280224	1191524	388821	1580345
23	952723	8822	104	3892	280224	1232947	406495	1639442
24	994145	9205	108	3892	280224	1274369	424169	1698538
25(4)	1035568	9589	113	3955	284760	1320328	441842	1762171
26	1076991	9972	117	3955	284760	1361751	459516	1821267
27	1118414	10356	122	3955	284760	1403174	477190	1880363
28	1159836	10739	126	3955	284760	1444596	494864	1939460
29	1201259	11123	131	3955	284760	1486019	512537	1998556
30	1242682	11506	135	3955	284760	1527442	530211	2057653
31	1284105	11890	140	3955	284760	1568865	547885	2116749
32	1325527	12273	144	3955	284760	1610287	565558	2175846
33(5)	1366950	12657	149	4019	289368	1656318	583232	2239550
34	1408373	13040	153	4019	289368	1697741	600906	2298646
35	1449795	13424	158	4019	289368	1739163	618579	2357743
36	1491218	13808	162	4019	289368	1780586	636253	2416839
37	1532641	14191	167	4019	289368	1822009	653927	2475936
38	1574064	14575	171	4019	289368	1863432	671600	2535032

APPENDIX 21: TRANSPORTATION USING OWN VEHICLE (SMALL PICK UP TRUCK)

1 round trip
2 round trips

The truck would have to make just 1 round trip if the amount of fuel that needs to be transported to the market is less than 1 tonne.

TABLE 47: TRANSPORTATION COSTS USING OWN VEHICLE VS CUMULATIVE REACTOR VOLUME

Cumulative Reactor Size (m3)	Amount of fuel that needs to be transported to city shop (kg fuel/day)	Transportation Costs (Rs/day) to city shop	Transportation cost (Rs/year) to city shop
0.00	0.00	0.00	0.00
1.00	51.07	31.92	11172.00
2.00	102.14	31.92	11172.00
3.00	153.20	31.92	11172.00
4.00	204.27	31.92	11172.00
5.00	255.34	31.92	11172.00
7.00	357.48	31.92	11172.00
8.00	408.55	31.92	11172.00
9.00	459.61	31.92	11172.00
10.00	510.68	31.92	11172.00
11.00	561.75	31.92	11172.00
12.00	612.82	31.92	11172.00
13.00	663.89	31.92	11172.00
14.00	714.96	31.92	11172.00
15.00	766.02	31.92	11172.00
16.00	817.09	31.92	11172.00
17.00	868.16	31.92	11172.00
18.00	919.23	31.92	11172.00
19.00	970.30	31.92	11172.00
20.00	1021.37	63.84	11172.00
21.00	1072.43	63.84	11172.00
22.00	1123.50	63.84	11172.00
23.00	1174.57	63.84	11172.00
24.00	1225.64	63.84	11172.00
25.00	1276.71	63.84	22344.00

26.00	1327.78	63.84	22344.00
27.00	1378.84	63.84	22344.00
28.00	1429.91	63.84	22344.00
29.00	1480.98	63.84	22344.00
30.00	1532.05	63.84	22344.00
31.00	1583.12	63.84	22344.00
32.00	1634.19	63.84	22344.00
33.00	1685.25	63.84	22344.00
34.00	1736.32	63.84	22344.00
35.00	1787.39	63.84	22344.00
36.00	1838.46	63.84	22344.00



FIGURE 91: SMALL PICK- UP TRUCK TO BE UTILIZED TO DELIVER TORRIFIED FUEL[53]

APPENDIX 22: TRANSPORTATION USING RENTED VEHICLES

TABLE 48: COSTS ASSOCIATED WITH DIFFERENT RENTED MODES OF FUEL TRANSPORTATION BASED ON DIFFERENT MARKET DEMANDS

Shared Taxi(No.of round trips)	
Hired Truck with 1 round trip	
Hired Truck with 2 round trips	
Current Business Case	

Cumulative Reactor Size (m3)	Amount of fuel that needs to be transported to city shop (kg fuel/day)	Transportation and distribution cost with shared taxi or hired truck (Rs/day)	Transportation cost with shared taxi or hired truck (Rs/year)
0	0.00	0(0)	0
1	51.07	35(1)	12250
2	102.14	70(2)	24500
3	153.20	105(3)	36750
4	204.27	140(4)	49000
5	255.34	175(5)	61250
7	357.48	1247.88	436758
8	408.55	1247.88	436758
9	459.61	1247.88	436758
10	510.68	1247.88	436758
11	561.75	1247.88	436758
12	612.82	1247.88	436758
13	663.89	1247.88	436758
14	714.96	1247.88	436758
15	766.02	1247.88	436758
16	817.09	1247.88	436758
17	868.16	1247.88	436758
18	919.23	1247.88	436758
19	970.30	1247.88	436758
20	1021.37	1247.88	436758
21	1072.43	1247.88	436758
22	1123.50	1247.88	436758
23	1174.57	1247.88	436758
24	1225.64	1247.88	436758

25	1276.71	1295.76	453516
26	1327.78	1295.76	453516
27	1378.84	1295.76	453516
28	1429.91	1295.76	453516
29	1480.98	1295.76	453516
30	1532.05	1295.76	453516
31	1583.12	1295.76	453516
32	1634.19	1295.76	453516
33	1685.25	1295.76	453516
34	1736.32	1295.76	453516
35	1787.39	1295.76	453516
36	1838.46	1295.76	453516

Distance of factory from peri-urban market = 5 km

Distance travelled in 1 round trip = $5 \times 2 = 10 \text{ km}$

Number of working days for the market = 350

Transportation Using Shared Taxi

Cost rate for using shared taxi = 3.5 Rs/km

This is based on personal travels in shared taxis in the region. The cost usually works out to 2 Rs/km, but adjustments have been made here to accommodate extra luggage in terms of the fuel being delivered.

Transportation Using Hired Small Pick- Up Truck

Based on information provided by staff at Avani, a typical small pick- up truck can be hired for 1200 Rs/day, exclusive of labour and fuel costs. These are essentially small pick- up trucks with a 1.25 ton weight capacity and 2.80 m^3 volumetric capacity, as was used in the case of a factory owned pick-up truck.

In these calculations it is assumed that in each trip made by the truck to the market, it travels a distance of 10 km to and fro from the market and covers 5 km within the market, delivering the fuel to various end users and Torrified pellets sales shops.

Further it is assumed that no additional labour is needed to load the fuel on to the truck and deliver it to the end users. These will be done by the plant employees.

Thus,

$$\begin{aligned} Transportation \ costs(\frac{Rs}{day}) &= \ 3000 \ + \ Fuel \ Costs \\ &= \ 3000 \ (\frac{Rs}{day}) + \ \{[(No. \ of \ trips \ in \ a \ day \ x \ total \ distance \ of \ 1 \ round \ trip) \\ &+ \ 5] \ (km) \ x \ Fuel \ Economy \ (\frac{L}{km}) \ x \ Fuel \ Costs \ (\frac{Rs}{L}) \end{aligned}$$

$$Transportation \ costs\left(\frac{Rs}{year}\right) = Transportation \ costs\left(\frac{Rs}{day}\right) * 350$$

Fuel Economy = 17.85 km/L[53]

Diesel Costs in Almora = 57 Rs/L (fuel costs during field visit)



FIGURE 92: A TYPICAL SHARED TAXI



FIGURE 93: A TYPICAL SMALL TRUCK THAT CAN BE HIRED[53]
APPENDIX 23: STORAGE COSTS

A study which carried out the design of a warehouse to store wheat grain estimated that 3000MT of wheat grain occupied 1646 m² of land[91]. Only 70 % of the warehouse's surface capacity was considered as available for actual storage space. The remaining 30% is to ensure proper ventilation, passageways, handling space and packaging areas. As it is impractical to fill a warehouse till the roof, the storage capacity was calculated at least a meter below the actual height of the ceiling. The study calculated storage cost value for 20 stacks, with each stack consisting of 15 bags.

Therefore, Density of storage =
$$\frac{3000000}{1646}$$
 = 1822.60 $\frac{kg}{m^2}$

Based on the equation,

Max. Fuel Storage
$$\left(\frac{kg}{day}\right) = \left(Fuel Production\left(\frac{kg fuel}{day}\right) - Fuel Delivery\left(\frac{kg fuel}{day}\right)\right) * 72,$$

for a cumulative reactor volume of $21m^3$, the fuel storage at the end of three months of production comes out to be 298137 kg.

Space occupied by Torrified pine needles
$$=$$
 $\frac{Max. fuel storage}{Density of storage} = 163.57 m^2$

Storehouse cost $(Rs/m^2) = 1900$ [92]

Thus, the total cost of shed space (Rs) = 310783

Total cost of shed pace per reactor (Rs/reactor) = 310783/330 = 941.76

Volume of each reactor $(m^3) = 0.064$

Shed space cost per cumulative reactor volume $(Rs/m^3) = 941.76/0.064 = 14715$

APPENDIX 24: DISTRIBUTED PLANTS LOGISTICS CALCULATIONS

These calculations are for when the number of villages selected is 15. It was assumed that there are 350 working days in a year.

For vehicular transport using own vehicle, the distances of all the villages were varied from 5 km to 30 km from the plant (assuming all the 15 villages are equidistant from the plant) and the corresponding transportation costs were calculated using the following equation:

Self owned vehicle truck costs
$$\left(\frac{Rs}{year}\right)$$

= 2(for a round trip) * Distance of village from plant (km)
* Fuel economy $\left(\frac{L}{km}\right)$ * Fuel price $\left(\frac{Rs}{L}\right)$ * 350 * Number of villages

An average value was taken for different distances, which was used as the final value to calculate the transportation costs.

For pellet transportation using a hired truck, as information given by Avani, a small pick-up truck can be hired for 1200 Rs/day exclusive of fuel costs. Similar to the previous method, village distances were varied from 5 km to 30 km and the final average value was used.

Hired truck costs
$$\left(\frac{Rs}{year}\right)$$

= $\left[1200 + \left(2 * Distance of village from plant (km) * Fuel economy $\left(\frac{L}{km}\right) * Fuel price(\frac{Rs}{L})\right)\right] * 350 * Number of villages$$

Based on time spent in the region, shared taxis usually cost 3.5 Rs/km. Applying the same method of using an average of different distances,

Shared taxi costs
$$\left(\frac{Rs}{year}\right)$$

= 3.5 $\left(\frac{Rs}{km}\right)$ * Distance of village from plant)km) * Number of Villages * 350

Table 50 gives the calculated costs associated with different fuel transportation option mentioned. Table 51 gives an overview of fuel production in a distributed system and the final fuel transportation costs. All the parameters in Table 51 have been calculated by the same method employed for an Integrated system, with a per village number wherever needed.

TABLE 49: COSTS ASSOCIATED WITH DIFFERENT METHODS OF TRANSPORTATION ADOPTED FOR A DISTRIBUTED SYSTEM

Distance of Village from	Pellet Transport Using own	Pellet Transport Using Hired	Pellet Transport Using
City (km)	vehicle (Rs/year)	Truck (Rs/year)	Shared Taxi (Rs/year)
5	167580	6467580	183750
6	201096	6501096	220500
7	234612	6534612	257250
8	268128	6568128	294000
9	301644	6601644	330750
10	335160	6635160	367500
11	368676	6668676	404250
12	402192	6702192	441000
13	435708	6735708	477750
14	469224	6769224	514500
15	502740	6802740	551250
16	536256	6836256	588000
17	569772	6869772	624750
18	603288	6903288	661500
19	636804	6936804	698250
20	670320	6970320	735000
21	703836	7003836	771750
22	737352	7037352	808500
23	770868	7070868	845250
24	804384	7104384	882000
25	837900	7137900	918750
26	871416	7171416	955500
27	904932	7204932	992250
28	938448	7238448	1029000
29	971964	7271964	1065750
30	1005480	7305480	1102500
	Average =586530	Average = 6886530	Average = 643125

Decentralized System								
			Amount of	Amount of				
			fuel produced	fuel to be				
No of	No. of		during high	delivered per			Transportation	
reactors	reactors	Total reactor	season per	village(kg	Transportation	Transportation cost	costs with hired	
needed in	needed for	Volume per	village (kg	fuel	cost shared taxi in	with own vehicle in	truck in total	
total	each village	village (m3)	fuel/day)	pellets/day	total (Rs/year)	total (Rs/year)	(Rs/year)	
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
15.7	1.0	0.1	16.5	3.4	643125.0	195510.0	2295510.0	
31.4	2.1	0.1	33.1	6.8	643125.0	195510.0	2295510.0	
47.2	3.1	0.2	49.6	10.2	643125.0	195510.0	2295510.0	
62.9	4.2	0.3	66.2	13.6	643125.0	195510.0	2295510.0	
78.6	5.2	0.3	82.7	17.0	643125.0	195510.0	2295510.0	
94.3	6.3	0.4	99.3	20.4	643125.0	195510.0	2295510.0	
110.0	7.3	0.5	115.8	23.8	643125.0	195510.0	2295510.0	
125.8	8.4	0.5	132.4	27.2	643125.0	195510.0	2295510.0	
141.5	9.4	0.6	148.9	30.6	643125.0	195510.0	2295510.0	
157.2	10.5	0.7	165.5	34.0	643125.0	195510.0	2295510.0	
172.9	11.5	0.7	182.0	37.5	643125.0	195510.0	2295510.0	
188.6	12.6	0.8	198.6	40.9	643125.0	195510.0	2295510.0	
204.3	13.6	0.9	215.1	44.3	643125.0	195510.0	2295510.0	
220.1	14.7	0.9	231.7	47.7	643125.0	195510.0	2295510.0	
235.8	15.7	1.0	248.2	51.1	643125.0	195510.0	2295510.0	
251.5	16.8	1.1	264.8	54.5	643125.0	195510.0	2295510.0	
267.2	17.8	1.1	281.3	57.9	643125.0	195510.0	2295510.0	
282.9	18.9	1.2	297.9	61.3	643125.0	195510.0	2295510.0	
298.7	19.9	1.3	314.4	64.7	643125.0	195510.0	2295510.0	
314.4	21.0	1.3	331.0	68.1	643125.0	195510.0	2295510.0	
319.1	21.3	1.4	336.0	69.1	643125.0	195510.0	2295510.0	
330.1	22.0	1.4	347.5	71.5	643125.0	195510.0	2295510.0	
345.8	23.1	1.5	364.1	74.9	643125.0	195510.0	2295510.0	
361.5	24.1	1.5	380.6	78.3	643125.0	195510.0	2295510.0	
377.3	25.2	1.6	397.2	81.7	643125.0	195510.0	2295510.0	
393.0	26.2	1.7	413.7	85.1	643125.0	195510.0	2295510.0	
408.7	27.2	1.7	430.3	88.5	643125.0	195510.0	2295510.0	
424.4	28.3	1.8	446.8	91.9	643125.0	195510.0	2295510.0	
440.1	29.3	1.9	463.4	95.3	643125.0	195510.0	2295510.0	
455.9	30.4	1.9	479.9	98.7	643125.0	195510.0	2295510.0	
471.6	31.4	2.0	496.5	102.1	643125.0	195510.0	2295510.0	

TABLE 50: DECENTRALIZED/DISTRIBUTED SYSTEM PLANT PARAMETERS AND TOTAL LOGISTICS COST

APPENDIX 25: HEAT TRANSFER SURFACE AREA TO VOLUME RATIO

Reactor 1

Based on Figure 31,

Volume of packed bed (V) =
$$\frac{\pi}{4} * (0.60^2 - 0.28^2) * 0.90 m^3 = 0.199 m^3$$

Heat transfer surface area (S) = $\pi * 0.28 * 0.90 m^2 = 0.79 m^2$

 $S/V = 3.97 m^2/m^3$

Reactor 2

Volume of packed bed (V) = $\frac{\pi}{4} * 0.30^2 * 0.90 \ m^3 = 0.064 \ m^3$

Heat transfer surface area (S) = $\pi * 0.30 * 0.90m^2 = 0.85 m^2$

 $S/V = 13.36 m^2/m^3$

APPENDIX 26: HAND DRAWINGS USED TO MANUFACTURE REACTOR 2



FIGURE 94: REACTOR 2 ASSEMBLY



FIGURE 95: PACKED BED VESSEL



FIGURE 96: COMBUSTION CHAMBER +OUTER DRUM ASSEMBLY



FIGURE 97: CHIMNEY HOOD

APPENDIX 27: MOISTURE % DETERMINATION FOR PINE NEEDLES

Moisture % determination

S.No	Weight of Container(g)	Weight of pine needles+container(g), i	Weight of pine needles+container(g),f	Weight of pine needles i (g)	Weight lost (g)	% moisure
1	118	188	178	70	10	14.285714
2	12	74	66	62	8	12.903226
3	12	82	74	70	8	11.428571
4	12	144	126	132	18	13.636364
5	12.6	138	122.2	125.4	15.8	12.599681
6	13	161.6	143.2	148.6	18.4	12.382234
Avg						
moisture						
content						
(%)						12.87263

APPENDIX 28: MATLAB CODE FOR DATA OBTAINED FROM DIRECT CONVECTIVE HEATING PACKED BED EXPERIMENTS

```
function Tcurves
clear all
clc
filename = '230 45 PN';
TIC301 = xlsread(filename,1,'D:D'); %Temp after column top
TIC201 = xlsread(filename,1,'E:E'); %Temp before column bottom
TI103 = xlsread(filename,1,'G:G'); %Middle Column
TI104 = xlsread(filename,1,'J:J'); %Top Column
TI102 = xlsread(filename,1,'K:K'); %Bottom Column
tmin = xlsread(filename,1,'R:R'); %Time in minutes
Tstart = 228;
Tramp = 180;
  [Tavg102 Tavg103 Tavg104, Tavg102corr, Residence time, Ramp time102,...
      Ramp time103, Ramp time104, Tavg201] = ...
     avgtemp(tmin,TI103,TI104,TI102, Tstart, Tramp,TIC201)
%Function to determine the average temperature for a given residence time
%The ramp time and residence time is also determined
    function [Tavg102, Tavg103, Tavg104,Tavg102corr, time, ramptime102,...
            ramptime103,ramptime104,Tavg201] =
            avgtemp(tmin,TI103,TI104,TI102,Tstart, Tramp,TIC201)
% Curve smoothing command
        TI102 = smooth(TI102,19, 'rlowess');
        TI103 = smooth(TI103, 19, 'rlowess');
        TI104 = smooth(TI104, 19, 'rlowess');
        TI102res = zeros(length(tmin),1);
        TIC201 = smooth(TIC201, 19, 'rlowess');
        for i = 1: length(tmin)
            if TI102(i) > Tstart
                TI102res(i) = TI102(i);
            else
            end
        end
        Area102 = trapz(tmin,TI102res);
        I = find(TI102res);
        time = tmin(I(end)) - tmin(I(1));
        Tavg102 = Area102/time;
        TI103res = zeros(length(tmin),1);
        TI104res = zeros(length(tmin),1);
        TIC201res = zeros(length(tmin),1);
        TI102corr = zeros(length(tmin),1);
        TI103res(I(1):I(end)) = TI103(I(1):I(end));
        TI104res(I(1):I(end)) = TI104(I(1):I(end));
        TI102corr(I(1):I(end)) = TI102(I(1):I(end));
        TIC201res(I(1):I(end)) = TIC201(I(1):I(end));
```

Iramp102 = find(TI102>Tramp);

```
Iramp103 = find(TI103>Tramp);
Iramp104 = find(TI104>Tramp);
ramptime102 = tmin(I(1)) - tmin(Iramp102(1));
ramptime103 = tmin(I(1)) - tmin(Iramp103(1));
ramptime104 = tmin(I(1)) - tmin(Iramp104(1));
figure(1)
plot(tmin, TI102, 'b')
hold on
plot(tmin, TI102corr, 'b')
hold on
legend('Thin slice temperature')
Area102corr = trapz(tmin,TI102corr);
Area103 = trapz(tmin,TI103res);
Area104 = trapz(tmin,TI104res);
Area201 = trapz(tmin,TIC201res);
Tavg201 = Area201/time;
Tavg102corr = Area102corr/time;
Tavg103 = Area103/time;
Tavg104 = Area104/time;
```

end

 end

APPENDIX 29: PINE NEEDLE AND VERGE GRASS ASH CHARACTERIZATION

	Compound	Conc.	Absolute
	Name	wt(%)	Error (%)
1	CaO	45.398	0.1
2	SiO2	13.876	0.1
3	MgO	13.858	0.1
4	K2O	7.333	0.08
5	P2O5	6.183	0.07
6	Al2O3	4.979	0.07
7	SO3	3.811	0.06
8	Fe2O3	2.719	0.05
9	MnO	0.863	0.03
10	TiO2	0.296	0.02
11	Na2O	0.285	0.02
12	ZnO	0.141	0.01
13	Cl	0.117	0.01
14	SrO	0.064	0.008
15	CuO	0.022	0.004

TABLE 51: ASH COMPOSITION OF PINE NEEDLES

TABLE 52: ASH COMPOSITION OF VERGE GRASS

	Compound	Conc.	Absolute
	Name	wt(%)	Error (%)
1	SiO2	37.884	0.1
2	K2O	20.33	0.1
3	Cl	11.239	0.09
4	CaO	10.836	0.09
5	P2O5	9.433	0.09
6	SO3	5.574	0.07
7	MgO	2.998	0.05
8	Na2O	0.849	0.03
9	Fe2O3	0.241	0.01
10	Al2O3	0.231	0.01
11	Au	0.222	0.01
12	TiO2	0.036	0.006
13	SrO	0.034	0.006
14	MnO	0.029	0.005
15	ZnO	0.025	0.005
		0.040	0.000

APPENDIX 30: OVERALL ENERGY EFFICIENCY CALCULATIONS FOR REACTOR 2

The overall energy efficiency is based on the equation,

η

Energy contained output Torrified Pine Needles

Energy Contained in input As Received Pine Needles + Energy to provide heat for Torrefaction

Heat Input- Wood Combustion

All calculations are on per batch per reactor basis.

Amount of wood used for combustion based on experiments carried out with reactor 2 in India = 7.65 kg

Higher Heating Value of dried wood = 20 MJ/kg[93]

HHV of wood on A.R. Basis assuming 25% moisture = 20*(1-0.25) = 15 MJ/kg

Energy used for wood combustion (1) = 15*7.65 = 114.75 MJ

Mass input of A.R. pine needles for Torrefaction based on experiments with reactor 2 in India = 6.1 kg

For the 250-15 Torrefaction conditions, the Mass Yield and Higher Heating Value based on the experiments carried out in the faculty of Process and Energy, TU Delft, is:

Mass Yield (Dry Basis) = 0.8631

HHV of Torrified pine needles (Dry Basis) = 21.22 MJ/kg

HHV of dried pine needles = 20.12 MJ/kg

Assuming 25% moisture content in the As Received pine needles used in real time conditions,

HHV of As Received pine needles = 15.09 MJ/kg

Energy content of input pine needles (2) = 15.09*6.1 MJ = 92.05 MJ

Output of Torrified pine needles = 6.1*0.8631*0.75 = 3.95 kg

Energy content of output pine needles (3) = 3.95*21.22 MJ = 83.78 MJ

% Overall efficiency = (3)/[(1)+(2)] = 83.78/(92.05+114.75) = 40.51%

TABLE 53: OVERALL ENERGY EFFICIENCY OF REACTOR 2 USING WOOD COMBUSTION TO PROVIDE HEAT FOR TORREFACTION

Amount of Wood Needed(kg wood), A.R. Basis	HHV of Wood (MJ/kg wood), A.R. Basis	Energy used on wood combustion, MJ	Mass Input of Pine Needles for Torrefaction (Kg A.R. Biomass)	Reactor Volume (m ³)	Packing Density (Kg A.R.Biomass/ m ³ reactor)
7.65	15	114.75	6.1	0.064	95.9
Mass Yield, (250-15), Dry Basis	HHV of Torrefie d Pine Needles (MJ/kg) , Dry basis	Drying Ratio (Kg dry Biomass/kg A.R.Biomass) (Assuming 25% moisture content)	Reactor Output (Kg Torrified Biomass	Initial Energy in Pine Needles (MJ)	Energy Output in Terms of Product Produced (MJ)
0.8631	21.15	0.75	3.95	92.05	83.54
Overall Energy Efficiency (%)			40.40		

Heat Input- Electric Heating

 $(\rho.C_p)_{bed} = 173.1 \text{ KJ}//\text{m}^3\text{K}$ (based on calculations done by Ryan Helmer)

 $(\rho.C_p)_{bed =} [\varepsilon(\rho.C_p)]_{air} + [(1-\varepsilon)(\rho.C_p)]_{pine needles}$, where '\varepsilon' is porosity

Heat of Vapourization of water $(H_v) = 2260 \text{ KJ/kg}$

Mass input of A.R. pine needles for Torrefaction based on experiments with reactor 2 in India = 6.1 kg

Temperature rise till Torrefaction temperature of $250^{\circ}C = 230^{\circ}C$ (Assuming environment temperature to be $20^{\circ}C$)

Assuming 20% loss of heat,

Energy input using a heat tracer =

 $(\rho.C_p)_{bed}$ * Volume of reactor*1.2*230+ (H_v*A.R. moisture content*Amount of biomass packed in reactor) = 6486 kJ =6.486 MJ

For the 250-15 Torrefaction conditions, the Mass Yield and Higher Heating Value based on the experiments carried out in the faculty of Process and Energy, TU Delft, is:

Mass Yield (Dry Basis) = 0.8631

HHV of Torrified pine needles (Dry Basis) = 21.22 MJ/kg

HHV of dried pine needles = 20.12 MJ/kg

Assuming 25% moisture content in the As Received pine needles used in real time conditions,

HHV of As Received pine needles = 15.09 MJ/kg

Energy content of input pine needles (2) = 15.09*6.1 MJ = 92.05 MJ

Output of Torrified pine needles = 6.1*0.8631*0.75 = 3.95 kg

Energy content of output pine needles (3) = 3.95*21.15 MJ = 83.78 MJ

% Overall efficiency = (3)/ [(1) + (2)] = 83.78/(92.05+6.486) = 85%

Note: Heating for isothermal Torrefaction is not considered.

Energy Ii	uput for To Pine Need (MJ)	rrefaction of les	Mass Input of Pine Needles for Torrefactio n (Kg A.R. Biomass)	Reactor Volume (m ³)	Packing Density (Kg A.R.Biomass/ m ³ reactor)
	6.49		6.1	0.064	95.9
Mass Yield, (250-15), Dry Basis	HHV of Torrifie d Pine Needles (MJ/kg) , Dry Basis	Drying Ratio (Kg Dry Biomass/kg A.R.Biomass) (Assuming 25% moisture content)	Reactor Output (Kg Torrified Biomass	Initial Energy in Pine Needles (MJ)	Energy Output in Terms of Product Produced (MJ)
0.8631	21.15	0.75	3.95	92.05	83.54
Overall Energy			84.77		

TABLE 54: OVERALL ENERGY EFFICIENCY OF REACTOR 2 WHEN HEAT FOR TORREFACTION IS SUPPLIED THROUGH ELECTRIC TRACERS