DETAILED FEASIBILITY ASSESSMENT OF PILOT BIOMASS PLANT IN TBILISI AND COMPLETE FEASIBILITY STUDY FOR INSTALLING BIOMASS BOILERS IN TBILISI MUNICIPAL FACILITIES

Report prepared by New Technology Center

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Preamble

Below work is prepared on the request of UNDP Tbilisi office by specialists of New Technology Center to determine feasibility of biomass production and utilization in Tbilisi municipality.

Document is comprised of 9 chapters that provide detailed information on viable biomass types, research of biomass sources, description of biofuel production and utilization technologies, production scenarios for efficient conversion of biomass into fuel for Tbilisi municipality through mechanical and chemical transformation.

Authorized by Economic Affairs Office of Tbilisi City Hall opportunities for use of energy from converted biomass in preschool education establishments under subordination of Tbilisi Municipality were assessed. Legal and technological barriers of using biofuel in these establishments are discussed.

Interesting visual demonstration is provided on the map of biomass sources and potential consumers geographical distribution in Tbilisi municipality and its surrounding areas. This illustration also provides information on several scenarios with references and explanations.

Detailed analysis specifies optimal production scenarios and corresponding exploitation conditions, while as a result of technical and economic calculations' analysis efficient business models are selected.

Final part of the study offers conclusions and recommendations of authors that may in some cases go beyond the boundaries of the study, however, in authors' judgment are topical and require additional attention.

Study was conducted from 7th of October to 10th of December 2014 by teamwork of employees of New Technology Center and invited specialists that include:

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Chapter 1: Study of International practice on Types of Beneficial Biomass

1.0. Abstract

Biomass resources include wood and wood wastes, agricultural crops and their waste byproducts, municipal solid waste, animal wastes, waste from food processing and aquatic plants and algae. Biomass is used to meet a variety of energy needs, including generating electricity, heating homes, fueling vehicles and providing process heat for industrial facilities. The conversion technologies for utilizing biomass can be separated into four basic categories: direct combustion processes, thermochemical processes, biochemical processes and agrochemical processes.

Raw materials that can be used to produce biomass fuels come from a large number of different sources, and in a wide variety of forms. All of these forms can be used for fuel production purposes, however not all energy conversion technologies are suitable for all forms of biomass. As our study is limited to biomass in only in solid state (biomass converted to pellets, briquettes or wood chips) in boilers further research will be aimed at exploring the sources of biomass suitable for such conversion.

1.1. Sources of Biomass

International experience shows that the realities of the economics mean that high value material for which there is an alternative market, such as good quality, large timber, are very unlikely to become available for energy applications. However there are huge resources of residues, co-products and waste which could potentially become available, in quantity, at relatively low cost, or even negative cost where there is currently a requirement to pay for disposal.

There are five basic categories of material:

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

1.1.1. Clean wood, from forestry, arboricultural activities or from wood processing

Untreated (clean) wood consists of wood and other products such as bark and sawdust which have had no chemical treatments or finishes applied. Wood may be obtained from a number of sources which may influence it's physical and chemical characteristics.

Untreated wood may range in moisture content from oven dry to 60% or higher as freshly harvested, green wood.

As received there may be physical inclusions from the growing or harvesting processes, such as mud, stones, ice or nails, which may need removing before further processing or combustion.

There may also be chemical contaminants from the soil, water or air, or any pesticides or other sprays used, such as heavy metals, halogens or other trace materials. In general levels of these will be very low.

The primary source for timber includes wood from private and state owned woodland and plantations. As harvested, wood will be at a range of moisture content, and of a variety of physical shapes and sizes.

In addition to harvesting, some level of pre-processing is likely to be required. Transport and storage will also be necessary.

Wood from arboricultural arisings includes residues from: Managing municipal and private parks and gardens, Tree surgery and pruning and maintaining railway and road verges.

In many ways very similar to forestry residues, though possibly including a larger proportion of brash material and less round wood, leading to a higher percentage of bark and leaves.

Material may be chipped on site to reduce volume for removal in general purpose chippers that do not produce chips of sufficient quality for many combustion systems.

As for wood from forestry, pre-processing, transport and storage may need to be considered.

The wood processing industries, such as sawmills and timber merchants are also a source of untreated wood in the form of offcuts, bark and sawdust. Many transport, pre-processing and storage issues may be similar to those for forestry products, however the material obtained is likely to be in different forms from forest or arboricultural products.

There are likely to be a number of different output streams with different characteristics:

Sawmill offcuts may include a high proportion of bark.

Some material may have been kiln dried to extremely low moisture content making it potentially very suitable for wood pellet manufacturing or blending with material at higher moisture content.

There may be sawdust at a range of moisture content from different stages of processing, and again very dry sawdust from kiln dried timber may be very suitable for wood pellet manufacture.

Untreated wood may be in a range of physical forms:

- Bark

Bark may be removed from saw logs and available as a residue from wood processing. Bark typically contains high levels of minerals and consequently is prone to give high levels of ash and slagging in combustion systems. It may, however, be a suitable fuel for generating process heat close to where it is produced, such as for firing drying kilns at a sawmill. Minerals will be retained in the ash and consequently this may be used as a soil fertilizer.

- Brash and arboricultural arisings

This is the form of biomass that is of low value and potentially destined for, at best, composting, or being left in the wood (where it returns nutrients and organic matter to the soil and CO_2 to the atmosphere).

As harvested, brash and arboricultural arisings (that material that is removed as part of tree surgery, management of municipal parks and verges of roads and railways) are typically very low density, including many small diameter branches, twigs, leaves etc.

International practice is that it is likely to be consigned to a bonfire (where all the carbon is converted to CO_2) or to landfill, where the carbon is converted to methane (CH_4). Although methane might be collected as landfill gas, it is a far (21 times) more potent greenhouse gas than CO_2, and much will inevitably escape to the atmosphere.

If they are not to be left at the harvest site, brash and arboricultural arisings are typically chipped using a general purpose chipper to reduce bulk and assist handling. The chips produced will not generally meet the specifications for most domestic and small to medium scale heating and boiler systems and may contain a large proportion of slivers.

Chipping is also likely to be performed with the material green and so will have high moisture content. These properties make it well suited for composting, and there is a growing number of municipal composting sites worldwide to keep such material from landfill, however is not well suited for most energy applications, although there are boilers that are designed to burn green material.

If brash is to be harvested in quantity for energy applications, equipment has been developed (in Sweden) to gather up large quantities of brash and compact it into bales for convenience of handling and transport. These are known as 'residue logs'.

- Logs

Small round wood (SRW) may simply be cut into logs. This may be done in the forest for ease of extraction and handling and to assist drying, and involve de-limbing and cutting into logs of typically 2-3 m in length.

These may be stacked at the roadside for convenience of subsequent collection, which may follow a period of drying. On average 1 m^3 of round wood requires 1 linear meter of roadside space.

If well stacked, a pile of round and split logs can show a bulk density 70% of that of the solid wood, though if loose this can drop to only 40% or less.

Scoring or partial removal of bark may help to accelerate drying. For logs over 15 cm diameter splitting is recommended to assist drying.

Logs may also be sold directly to domestic consumers as fire wood logs to be burned in an open fire or log burner. For this they need to be around 15-50 cm long (for many domestic users 25-30 cm is the optimum) and typically split if greater than 10 cm diameter.

- Sawdust

Sawdust is typically available as a co-product of wood processing or manufacturing.

Sawdust may be of high moisture content, e.g. from cutting green wood in a sawmill, or very dry from furniture manufacturing.

It may have a bulk density only 30% of that of the solid wood and so, even if very dry, has a very low energy density.

It does, however, present an extremely large surface area to volume ratio and is suitable for blowing into some combustion or gasification systems.

Sawdust, especially dry sawdust, is particularly suitable for processing into pellets.

1.1.2. Energy crops: high yield crops grown specifically for energy applications

Energy crops are grown specifically for use as fuel and offer high output per hectare with low inputs.

In general the principle purpose is to maximize the output of the desired harvest. This may simply be measured in terms of tons of biomass per hectare. High levels of biomass production need to be balanced against the potentially damaging impacts of some crop management techniques.

Therefore, in order to achieve these high yields, high levels of fertilizer inputs are required.

For example high levels of nitrogen fertilizer are typically applied. This can lead to emissions of ammonia or NOx into the air and nitrogen compounds into groundwater. If this nitrogen is applied in the form of inorganic fertilizers very large quantities of carbon will be released to the atmosphere. This is because during the production of these fertilizers are Methane (CH4) is converted to ammonia (NH3) by reaction with nitrogen from and water vapor, with the release of the carbon as carbon dioxide (CO2). This is both environmentally undesirable and expensive.

This process takes place in any system reliant on the application of inorganic fertilizer.

It is therefore highly preferable for energy crops to be developed that can achieve high levels of output with minimal or zero inputs.

One further consideration that may influence policy on establishing energy crops is the area of land established with conventional forestry and the potential for harvesting fuel from this resource.

In countries with large areas of existing forest and woodland there tends to be little interest in establishing dedicated energy crops. This is because although conventional forestry produces much lower levels of biomass output per hectare compared to many energy crops, the cost of producing each ton of biomass in the forest are also significantly lower. Consequently there is little attraction in establishing energy crops on high quality agricultural land.

In countries where there is relatively low level of forest cover; demand for biomass fuels could exceed the rate of production of biomass in the existing forest and residue resource. As such it is necessary to consider whether it is appropriate to use agricultural land for biomass production. If this is required, purpose grown energy crops become an attractive option as high yields of biomass can be produced in a short time.

Classes of energy crops are:

Short rotation energy crops

Wood from trees is a biomass fuel that has been used for millennia and it is therefore natural to consider trees as potential energy crops.

Conventional forestry, however, operates on a relatively long time scale. This involves committing an area of land to forestry for many decades, with the bulk of the income from the investment not realizable for many years, which provides poor cash flow.

While in case of short rotation operations the purpose is not the production of timber for saw logs, but for energy and there is not the requirement to operate on such a long time scale.

In addition, the annual rate of increase in biomass per hectare tends to be greater when trees are only a few years old than later in their lifetime, although this varies from species to species.

Consequently, there is considerable interest in short rotation operations that harvest fast growing trees for biomass when they are just a few years old. As the stems are harvested young, the biomass produced tends to have a relatively high proportion of bark.

Grasses and non-woody energy crops

Although short rotation crops (SRC) can offer a harvest cycle of 2-5 years, it does not give an annual return.

According to international experience there are, however, grasses and other plants that can offer high yield on an annual basis.

For example such crops are Herbaceous (e.g. miscanthus, reed canary grass, giant reed). One of the mostly spread of such in Europe is Miscanthus species that are tall (up to 3.5m high) woody, perennial, rhizomatous grasses.

Rhizomatous grasses retains a large proportion of the nutrients in the rhizomes, retaining little in the biomass, so nitrogen and nutrient requirements are very low, and no yield benefits are obtained by applying nitrogen.

Miscanthus uses the C4 photosynthetic pathway, which can make it efficient in fixing carbon and in water use. They are not native to the Europe, originating from Asia, but even under EU conditions have been shown to give very high yields (average 14 oven dry tonnes per hectare per year (odt)), which is higher than those obtained from short rotation coppice (SRC) (9 odt).

The calorific value of miscanthus is slightly lower than that of most wood, and the ash content quite high, similar to straw.

Miscanthus (Miscanthus giganteus) can be planted by rhizome division, and this is the preferred way, though it makes establishment expensive. Conventional agricultural equipment, such as a potato planter can be used, although specialized equipment has been developed.

It is planted in spring at a density of 20,000 per ha and grows strongly to 1-2 m by late August. From late July the crop starts to dry out so that when it is harvested in late winter, most of the leaves have died back, leaving canes of 10 mm diameter and relatively low moisture content. This first year's growth gives poor yield, but in subsequent years greater height, typically 2.5-3.5 m can be achieved, and yield increases over the first 4-5 years.

Once established, a miscanthus plantation can be harvested annually for 15-20 years before needing to be replanted.

Yield depends on sunshine, temperature and rainfall, but miscanthus grows well on a range of soils, and yields of 12-14 t/ha can be achieved from the third year onwards, and even higher on good sites.

Harvesting is undertaken with a modified forage harvester, and moistures below 20% are easily achieved at harvest and can be left to dry further, in the swath, prior to baling.

The crop is then baled using a conventional baler to produce rectangular or round bales, depending upon the requirements of the application.

Agricultural energy crops

A number of conventional agricultural crops, currently grown around the world, also offer the potential for use as energy crops. They can be used either simply as biomass or to provide a specific product for a particular energy application. These are crops with which farmers are already familiar: Sugar crops, Starch crops and Oil crops.

All of such crops are used for production of liquid biofuels (methyl esters and ethanol).

Aquatics (hydroponics)

Aquatic plants offer a number of potential advantages over land based crops.

As the water provides support for the structure of the plant they do not have the requirement to lay down structural material, such as lignin. They can also usually take in nutrients and carbon dioxide from the surrounding water and consequently may not need to develop roots. Many, therefore, can display very high photosynthetic efficiencies.

As they do not require soil, they can be grown in areas unsuitable for conventional agriculture. Marine species also avoid conflict for freshwater resources as well as for land.

There are very many species of algae, both microscopic microalgae and macroalgae such as seaweeds that can grow to over 60 m long, that offer many of the above benefits and that are potentially suitable for use in energy applications. However the very high water content of algae can make them an inconvenient form of biomass.

They must either be used very close to production to avoid costly, inefficient transportation of water, or be dried, though active drying should be avoided owing to the significant energy cost involved. Passive drying is likely to be labor intensive.

1.1.3. Agricultural residues: residues from agriculture harvesting or processing

Agricultural residues are of a wide variety of types, and the most appropriate energy conversion technologies and handling protocols vary from type to type. The most significant division is between those residues that are predominantly dry (such as straw) and those that are wet (such as animal slurry).

Many agricultural crops and processes yield residues that can potentially be used for energy applications, in a number of ways. Sources can include:

- Arable crop residues such as straw or husks
- Animal manures and slurries
- Animal bedding such as poultry litter
- Most organic material from excess production or insufficient market, such as grass silage.

Dry residues

These include those parts of arable crops not to be used for the primary purpose of producing food, feed or fibre, used animal bedding and feathers:

Straw: wheat, barley, oats etc

Barley straw is used for animal bedding and feed, as well as chopped and returned to the soil.

Chopped straw can reduce phosphate and potassium needed for a following crop, and can help conserve soil moisture and structure. It can however give increased weed carry over, cause disease problems, and increased risk of slug damage.

The ash from burning or gasifying straw can be used to return minerals to the soil, however cannot contribute organic matter or help soil structure.

Straw is typically obtained at around 15-25% moisture content and has a net calorific value (net CV or lower heating value (LHV)) of around 13 MJ/kg at this moisture content. It also tends to contain high levels of nutrients as a result of the timing of harvesting, and of silica, which gives a relatively high ash content (around 6%) and can lead to slagging and fouling problems in combustion.

Transport and storage of straw can be a major contributor to cost. It is therefore important to densify as much as possible, and larger or round bales are generally used for larger scale installations, though smaller systems can use small conventional bales. Loose straw can be fed into some systems, however is inefficient for transport or storage.

Corn stover:

Stover is the stalk and leaf residues from harvesting maize for grain, and it may be used as a biomass source in the same ways as straw. Handling and storage of corn stover is less well established than for cereal straw, and can be less efficient.

Poultry litter:

This most commonly consists of the wood shavings or straw used in deep litter broiler houses, together with the accumulated droppings.

It is advised that poultry litter should be maintained in good condition to ensure a healthy flock, keeping moisture, fat and nitrogen content down, requiring litter to be changed regularly. Poor water drinker design or ventilation can lead to high moisture content, but this should not be allowed to exceed 46%.

At present the most common energy application for poultry litter is combustion in dedicated power stations for electricity production, however it can also be burned on a smaller scale for heat or combined heat and power.

Broilers typically produce 16.5 tons per annum per 1,000 hens (with 60% dry matter, at 76% occupancy), and layers 41 tons per annum per 1,000 (at 30% dry matter) giving a potential annual supply of around 3.5 million tons of poultry droppings. It is, however, likely that the collection rate for such material is relatively low.

Although much poultry litter has been spread on the land as a fertilizer, there has been evidence that when spread on land for cattle grazing or for hay or silage, this can cause botulism in cattle and the practice has been urged against by authorities. They advise either incineration or deep ploughing or burial.

Poultry litter contains higher levels of nitrogen, phosphate, potassium, sulphur and magnesium than the original wood shavings or straw, and may also contain zinc and/or copper from feed supplements.

In addition residues of nut processing can be used as biomass. Shells and hulls of nuts such as almonds, macadamias and walnuts are a woody waste that can be used to generate power. However this waste is often used for production fireboards like MDF due to waste's density qualities.

Other agricultural residues that can be used for biofuel production is

Inedible parts of olives, black walnuts, peaches and coconuts have high lignin content, when compared to conventional feedstocks such as poplar and switchgrass. Lignin, upon conversion by fast pyrolysis into aromatic hydrocarbons, has diverse downstream applications that mirror those of fossil fuel. The high energy density and low ash content of endocarp tissue in particular, means that peach stones are cleanest to process into bio-oil.

Unpelletised fuels such as fruit stones should be well dried to about 12% moisture content, otherwise they will not burn well and will create creosote deposits in your stove.

Fruit pits should be un-bleached. Bleached pits can cause corrosion in the venting system. Best examples of fruit stones used as biofuel are: apricot pits, cherry pits, olive pits, peach pits and prune (plum) pits.

Wet residues

These are residues and wastes that have a high water content as collected.

This makes them energetically inefficient to use for combustion or gasification, and financially and energetically costly to transport. It is therefore preferable to process them close to production, and to use processes that can make use of biomass in an aqueous environment.

Typical wet residues include:

- Animal slurry and farmyard manure

Manures collected from animals such as cattle and pigs during periods of the year when they are housed, typically contain 6-10% dry matter and so are not appropriate for combustion or gasification without energetically and financially costly drying.

They are also inefficient to transport any distance or store owing to the high proportion of water.

However some energy technologies make use of biomass in an aqueous slurry, and these can make efficient use of such 'wet' materials. The high water, and low dry matter content means that the most appropriate energy technology for making use of animal slurries is anaerobic digestion for the production of biogas.

Animal slurry can be transported by tanker and pumped into and out of storage receptacles.

Animal slurry is widely used as a fertilizer and there are a number of methods to spread it on the land, though recent concerns about loss of ammonia to the air means that authorities now advises against broadcast spreading.

- Grass silage

Silage is forage biomass harvested and fermented for use as winter fodder for cattle and sheep. Grass silage is harvested in the summer and stored anaerobically in a silage clamp under plastic sheeting, or in a silo.

Although silage is primarily produced as a feed, excess production can also be suitable as a biomass.

Moisture content is high, typically 60-75%, and so it is not efficient to burn it, however it may be used as feedstock for anaerobic digestion.

Big bale silage, typically made later in the year, by tightly wrapping big bales in plastic sheeting, is of significantly lower moisture content, though higher than hay.

1.1.4. Food waste

There are residues and waste at all points in the food supply chain from initial production, through processing, handling and distributions to post-consumer waste from hotels, restaurants and individual houses.

Agriculture also produces its own residues.

Many food materials are processed at some stage to remove components that are inedible or not required such as peel/skin, shells, husks, cores, pips/stones, fish heads, pulp from juice and oil extraction, etc.

Many manufactured foods and drinks, including beer, spirits and wine, and cheese and other dairy products generate large quantities of organic waste material. It has been estimated that up to 92% of ingredients used in brewing ultimately become waste, principally spent grains.

Food preparation on both the commercial and domestic scale yield residues and waste, used cooking oils and food that has had to be disposed of because it has gone bad, for health and safety reasons or because it is surplus to requirements.

Food waste can be divided into dry waste and wet waste, however the majority is of relatively high moisture content.

Wet food waste

It is not efficient to transport high moisture content material very far and consequently any scheme to process it should be locally based.

Anaerobic digestion for the production of biogas is well suited to the processing of high moisture content and wet organic waste. Wastes with high levels of sugar or starch are also potentially suitable for fermentation to bioethanol.

There is development work on other technologies to exploit this potential resource that is at a much more experimental stage, such as hydrothermal upgrading.

High moisture content wastes such as from the food industry and domestic organic waste are potentially available at low, or even negative costs as a mechanism to prevent it being consigned to landfill.

Waste oils

A proportion of food waste that does not have a high water content is oily waste, particularly waste vegetable oils and animal fats.

Much waste oil can be collected, filtered and converted to biodiesel by transesterification.

Waste oil is a much more variable feedstock for the production of biodiesel than virgin oil such as rapeseed oil and typically requires more assessment and pre-processing to remove impurities, and check for free fatty acids and iodine number before use.

1.1.5. Industrial waste and co-products

Many industrial processes and manufacturing operations produce residues, waste or co-products that can potentially be used or converted to biomass fuel. These can be divided into woody materials and non-woody materials.

Woody wastes and residues

Technically, the basic technologies available to make use of woody wastes and residues are the same as those available for clean wood.

Wood waste can be utilized by a range of thermal conversion technologies. It can be burned in combustion systems such as a boiler for the generation of heat for space heating or process heat, or used for electricity generation in a dedicated system or combined heat and power (CHP) co-generation system.

Types of woody wastes and residues include:

- Untreated wood

Offcuts and sawdust from those industries and processes that work with untreated wood can be handled in the same way as other clean wood. They can potentially make a valuable contribution to the supply of woodfuel.

- Treated wood wastes and residues

Some woody material generated as a waste, residue or co-product by manufacturing, processing or other industry may have received some kind of treatment, such as with preservative or stain or some surface finish like paint or varnish.

This may include construction and demolition wood wastes, used pellets and waste wood, offcuts and co-products from the manufacture of furniture and other wood products.

Some material may also have become contaminated by spills or other contact with chemical products during the course of its use, and these will all have an impact on the range of ways in which they can be used.

Wood treatments can be divided into those that mean that the wood is considered as hazardous waste, and those that do not.

According to European authorities the following two are hazardous:

Chromated Copper Arsenate (CCA).

A water-borne, combined fungicide and insecticide that includes arsenic. It was developed in 1933 and has been used widely in the UK and around the world. In 2003 the EU published a directive imposing restrictions on the use of CCA and this was implemented in the UK from 30 June 2004, though wood professionally treated with CCA is still available. Modern alternatives are now widely available.

Creosote.

Obtained as a wood preservative by the distillation of coal tar, but also obtainable from wood. It has been widely used around the world for many years. Creosote is carcinogenic and is the subject of a 2001 EU directive restricting its use, however wood professionally treated with creosote is still obtainable.

The arsenic from CCA treated timber can cause dangerous emissions from combustion as a result of volatilization which makes filtering difficult. Inclusion of limestone has been shown to help increase the size of arsenic particles which can help to make them easier to filter.

Creosote, however, is readily destroyed in a well designed combustion system.

From the point of view of biomass for energy applications, however, many other treatments can also cause difficulties and generate emissions or wastes that can be harmful.

Non-hazardous wood treatments

There are a wide range of wood treatments that are not considered hazardous according to the EC Hazardous Waste Directive. These include:

- Ammoniacal copper quaternary (ACQ)
- Copper azole (CA)
- Copper citrate
- Other copper organics
- Borate preservatives
- Light organic solvent preservatives (LOSP)
- Micro-emulsions
- Wood stain
- Paints
- Varnish
- Fire retardants.

Although these treatments do not classify the wood as hazardous waste according to the EU Hazardous Waste Directive, many contain materials which may cause undesirable or dangerous emissions if used inappropriately.

Heavy metals such as copper, chromium and lead are widely present in preservatives. If wood treated with such preservatives is to be burned in a boiler or combustion unit, these heavy metals will be present in both bottom ash and fly ash, which will therefore need to be handled appropriately. The fly ash will need a high quality dust filter or cyclone to ensure there are no unacceptable emissions.

Halogens and halides will be released in the flue gas emissions which may require a specialist scrubber or trap. They can form halogenated organic compounds, in particular dioxins (polychlorinate dibenzodioxins - PCDDs) and furans (polychlorinate dibenzofurans - PCDFs) which are persistent organic pollutants that bioaccummulate over time. Waste that contains more than 1% halogenated organic compounds is classed as hazardous waste under the Waste Incineration Directive (WID).

Emissions of Hydrocarbons and Volatile Organic Compounds (VOCs) should be minimized by careful storage, efficient combustion and sufficient residence time. Polycyclic Aromatic Hydrocarbons (PAHs) may be formed during incomplete combustion and many are carcinogens, though these can also be formed by the combustion of clean wood under non-ideal conditions.

- **Wood composites and laminates**

Some wood products may be a composite or laminate that incorporates resins, adhesives, fillers or other, non-wood components.

Panel boards are an example of composites, and fall into three basic types:

- Particle board such as chipboard
- Oriented strand board (OSB)
- Fiber board (such as MDF and hardboard).

Plywood and wood with a veneer or non-wood surface such as melamine are examples of laminates that will contain a resin or other adhesive and potentially other materials.

Some of such materials are placed under the jurisdiction of the Waste Incineration Directive (WID) and cannot be treated as untreated wood waste, however fiberboard, provided that it has not been treated with halogenated organic compounds or heavy metals, is still exempt.

Non-woody wastes and residues

A number of industries also generate wastes, co-products or residues that are not primarily woody in nature, but are still biomass derived and are also potentially suitable for use as biomass fuel. These are:

- Paper pulp and wastes

The paper making industry makes use of considerable quantities of biomass. Recycled fiber from both pre- and post-consumer waste paper is now widely used as an ingredient of paper production.

Waste paper, especially low grade paper already incorporating a high proportion of recycled, short or mechanically pulped fibers can be suitable for energy production, usually by combustion.

Waste paper with some inks, dyes or surface treatments may contain heavy metals or other contaminants that may require that bottom ash and fly ash be disposed of appropriately.

During chemical pulping lignin is dissolved from the cellulose fibers required for paper production to yield a liquid waste called black liquor. This is used in a number of countries for energy production by burning or gasification for heat, electricity or biofuel production.

- Textiles

Manufacture of textiles and garments generates significant quantities of waste material at various stages of production.

Garment cutting waste has been estimated at 10-20% of fabric consumption, depending upon the garments and production techniques, and waste from knitting is typically 6% in shaped knitwear, and up to 20% for cut and sew manufacture.

Waste may be fiber, yarn or fabric or liquid effluent from manufacturing.

Most natural and synthetic fabrics can be recycled by shredding and breaking down into separate fibers (shoddy) which can be re-spun into new fabric.

Alternatively textile waste is used for the manufacture of cloths or used for a range of other applications such as for filling or flocking, for thermal and acoustic insulation and in construction composites.

Textile waste can also be burned, gasified or pyrolysis for energy purposes.

There may be heavy metal content in the waste, which will be present in the bottom ash and fly ash, and so disposal must be handled accordingly.

Fibers and material in washing and processing water and solvent effluent are also potentially suitable for use in energy applications. Filtering and separation can be used, while material in water can potentially be used for anaerobic digestion.

- Sewage sludge

As it is a high moisture content material, however, dewatering and drying to sludge cake before such use can be costly in energy and financial terms. As with other high water content biomass, anaerobic digestion is an attractive option that does not require drying.

1.3. Suitability Assessment of Types of Biomass Sources

Based upon above study of materials and requirements put forward by field of study the following sources can be assessed for suitability according the specific qualities:

#	Sources	Group	Suitability
1	• Bark • Brash and arboricultural arisings • Logs • Sawdust	Clean Wood, from forestry, arboricultural activities or from wood processing	These sources of biomass fit criteria for production of solid biofuel (wood chips, briquettes or pellets) and need to be further investigated at the following stages of study
2	• Short rotation energy crops • Grasses and non-woody energy crops • Agricultural energy crops • Aquatics (hydroponics)	Energy crops: high yield crops grown specifically for energy applications	Short rotation energy crops as well as non-woody energy crops require at least 2-3 years for establishment to become suitable sources of biomass. In addition increased investment costs and separate business model development (farm land and farming equipment lease/purchase, agricultural practices etc) are required. In addition as the study is aimed at installing biofuel production in Municipality of Tbilisi, where there is limited area of arable land this type of biomass is not financially attractive as it may require long transportation and therefore higher cost. Due to the above energy crops can be excluded from further study due to it not meeting suitability criteria.
3	Dry Agricultural residues	Agricultural residues: residues	These types of biomass sources

	- Straw: wheat, barley, oats etc., - Corn stover, - Poultry litter - Fruit Stones - Nut shells	from agriculture harvesting or processing	are used to produce solid biofuel and are presented in Tbilisi Municipality and its adjacent areas. There these should be researched at the next activity of task.
4	Wet Agricultural residues - Animal slurry and farmyard manure - Grass silage	Agricultural residues: residues from agriculture harvesting or processing	This type of biomass, due to its high moisture content is used to biogas in anaerobic digestion and is not suitable for conversion into solid biofuel, therefore is not interesting for further study.
5	Wet food waste	Food waste, from food and drink manufacture, preparation and processing, and post-consumer waste	It is not efficient to transport high moisture content material very far and consequently any scheme to process it should be locally based. In addition anaerobic digestion for the production of biogas or fermentation to bioethanol is well suited to the processing of high moisture content and wet organic waste. Due to wet food waste is not suitable for production .
6	Waste oils	Food waste, from food and drink manufacture, preparation and processing, and post-consumer waste	A proportion of food waste that does not have a high water content is oily waste, particularly waste vegetable oils and animal fats. Much waste oil can be collected, filtered and converted to biodiesel by trans esterification and therefore not suitable for solid biofuel production.

7	Woody wastes and residues
	- Untreated wood
	- Treated wood wastes and residues:
	  o Hazardous
	  o Non-hazardous
	- Wood composites and laminates
		Industrial waste and co-products	As technically, the basic technologies available to make use of woody wastes and residues are the same as those available for clean wood, it is suitable to research the sources for wood waste (excluding hazardous waste as is timber treated with Chromated Copper Arsenate

			and creosote). OSB, chipboard, fiberboard, provided that it has not been treated with halogenated organic compounds or heavy metals may provide a suitable source of biomass, as well as plywood without resin based surface is suitable for further studies.
8	Non-woody wastes and residues - Paper pulp and wastes - Textiles - Sewage sludge	Industrial waste and co-products	Paper production waste can be used for production of solid biofuel and commonly is converted (with mixture of wood residue) to briquettes. Residues of textile and sewage sludge are usually used for anaerobic digestion and therefore are outside of this study's objectives.

1.4. Types of Biomass Sources Selected for Further Study

Based on the above assessment biomass sources suitable for solid bio-fuel production in Tbilisi are:

1. Clean Wood, from forestry, arboricultural activities or from wood processing:

- Bark
- Brash and arboricultural arisings
- Logs
- Sawdust

2. Dry Agricultural residues

- Straw: wheat, barley, oats etc.,
- Corn stover,
- Poultry litter
- Fruit stones
- Nut shells

3. Woody wastes and residues

- Untreated wood
- Treated wood wastes and residues:
  - Non-hazardous
- Wood composites and laminates (OSB, chipboard, fiberboard, provided that it has not been treated with halogenated organic compounds or heavy metals, plywood without resin based surface)

4. Non-woody wastes and residues

- Paper pulp and wastes

Next activity involves collection of information on the above sources, in particular:

- Wood processing companies (sawmills, furniture producers, roof truss manufacturers, producers of wooden windows, doors, flooring, wood construction companies)
- Agricultural processors of wheat, barley, corn
- Fruit (apricot, cherry, olive, peach and prune) processing companies
- Nut processing Companies
- Poultry farms
- Paper production plants

List of the entities involved in the above activities will be obtained from customs and statistics departments, farmers and forestry associations, yellow pages. Research will be conducted on all sources without sampling in and around Tbilisi municipality. All sources will be interviewed for relevant data:

volumes per month/season, location, condition of biomass. In addition previously conducted researches will be studied and data given in those will be checked for updates.

Chapter 2: Research of Potentially Beneficial Types of Biomass Sources in Tbilisi and Surrounding Areas

Based on conclusion made in chapter 1 (Study of International practice on Types of Beneficial Biomass) and revealed potentially viable sources research was conducted on the following sources located in municipality of Tbilisi:

- 66 companies involved in processing of timber and production of wood or wood based products
- 28 companies involves in grain (wheat, maze, barley etc) production and processing
- 25 companies involved in processing of fruits and vegetable
- 5 poultry farms
- 58 companies involved in paper and cardboard production
- 6 forestry's around Tbilisi
- Tbilisi National Park

The sources were revealed by collecting information from Statistics department and reference databases (yellow pages).

2.1. Wood residues from processing industry

Companies involved in generating timber residues were asked to provide the answers to the following questions:

- What type of production are they involved in?
- Where is their production located?
- What is the amount of wood waste (tons, volume)?
- What are the type of waste (wood dust, chips, cuttings, shavings etc) and the approximate percentile share of waste among the types?
- Volumes per season (approximate share per season)?
- What is the moisture content?
- What species of wood are used?
- How are they currently utilizing waste?
- Are they willing to sell the waste (if yes what would be the price)?

Only 4 companies operating in Tbilisi represent large business (sales with more than 1.5 mln GEL in last accounting year) and only 6 are medium size (from 100k GEL to 1.5 mln GEL). This means that more than 87% of companies involved in studied field are small size and are scattered in and around Tbilisi

Municipality. Wood residues generated by small businesses are unstable and such companies often exist for less than 2 years. Waste generation in such companies is on average 20-50 m^3 of various wood residues. Total production by small producers amounts to 1603 m^3. However it is important to note that these small companies often exist for a short period of time or operate on a really inconsistent basis.

Company Size	Biomass m^3	Number of Producers	Average Biomass per producer
Small	1,315	58	22.67
Medium	1,340	5	268.00
Large	4,195	3	1,398.33
Total	6,850		

Small companies are eager to sell their waste as it is mostly not used by them for any profit and usually is given for free to various farms and disposed as waste.

As for the medium companies these are:

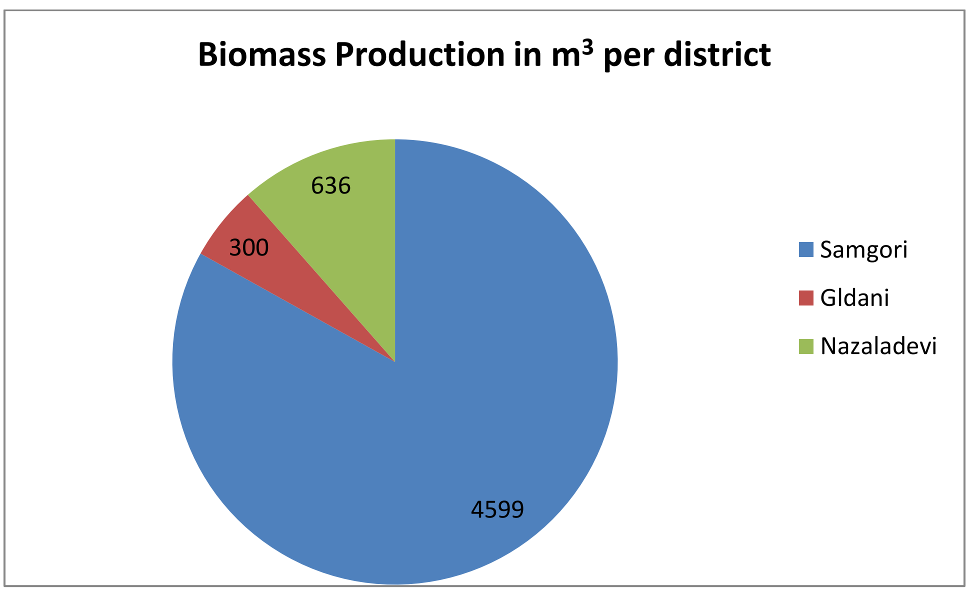
Producer	Biomass m^3	Location	Type of Production	Type of waste	Approx. Moisture Content %	Seasonality	Use	Desire to Sell
Shno	200	Samgori	Doors, flooring	Dust, shavings, cuttings	10	None	Heating In winter	None
Wood Service	300	Gldani	Windows, house construction	Dust, shavings, cuttings	10-20	None	Heating In winter	Only in April - October
Tsunda	204	Samgori	Furniture	Dust, shavings, cuttings	10	None	Heating In winter	Only in April - October
Forest	348	Nazaladevi	Windows and doors	60% dust, 40 shavings	10	None	None	Yes
Jumber Gabaidze	288	Nazaladevi	Furniture	Dust, shavings, cuttings	10	None	None	Yes
	1,340							

Despite the fact that medium sized companies produce approximately same amount that small ones collection of biomass is much easier as there are only 5 of them. However it is important to note that medium size (just as large) producers tend to invest in waste reduction and recycling in their production (like finger-jointing, glue-pressing smaller fractions of timber) that reduces wood residues. These waste reduction technologies are unfeasible in smaller companies. Same occurs in using wood waste for heating of production areas, this is rarely practiced by small producers while is quite common in mid-sized and large producers.

It is also important to note that there is no particular seasonality in medium and large producers as they tend to operate more or less evenly throughout the year.

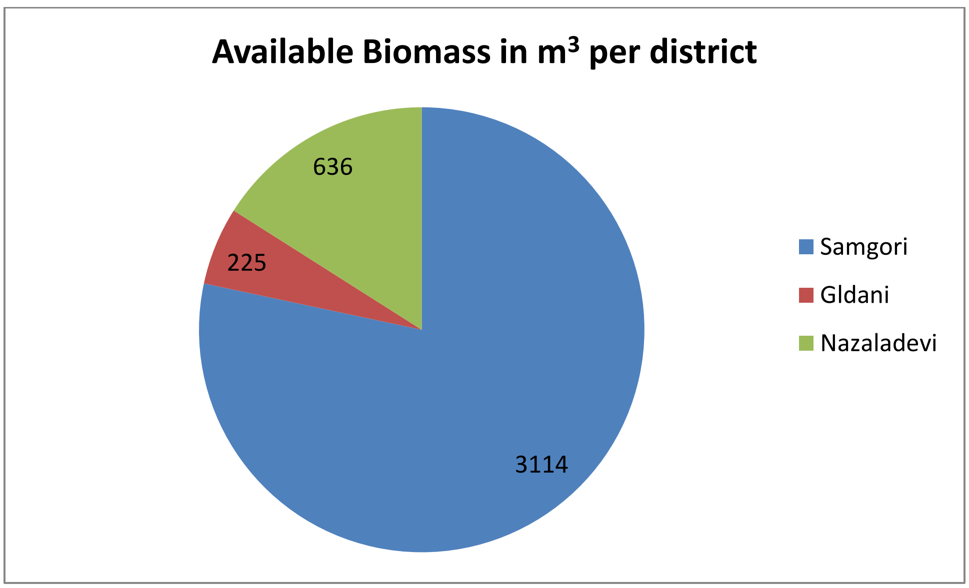
Producer	Biomass m^3	Location	Type of Production	Type of waste	Approx. Moisture Content %	Seasonality	Use	Desire to Sell
Embawood	2,400	Samgori	Furniture	Dust, shavings	10	None	Heating in Winter	Only in April - October
Jadvari	1,555	Samgori	Seed production	Cones	30	Autumn-Winter	None	Yes
Orbeli 91	240	Samgori	Doors, flooring etc	Dust, shavings, cuttings	10-20	None	None	Yes
	4,195							

It is notable that all large and some of medium sized producers are located in Samgori Municipality.



However further analysis of what share of generated biomasses can be obtained from producers is required.

Producer	Available biomass in m^3
Shno	0
Wood Service	225
Tsunda	119
Forest	348
Jumber Gabaidze	288
Embawood	1400
Jadvari	1555
Orbeli 91	240
Total	4175



As for the qualities of biomass all of the producers have mixed amounts of softwood and hardwood (approximately 60% softwood and 40% hardwood), with relative moisture content of 10-20%. Only outlier is residue from seed production which is totally softwood product of 30% moisture content. However its calorific value if dried to the same levels is very close to that of softwood (approximately 18 MJ/kg).

2.2. Wood residues from forestry, Tbilisi National Parks and City Hall

Annual volume of 9, 067 m^3 forest for non-commercial use is cut on territories of State Forest Fund and Tbilisi National Park. The volume of wood residue that is remaining in the forest amounts to 2,708 m^3, however a substantial part of this timber is collected by local populace for heating purposes as firewood. There is no concrete data to estimate the exact amount of residue left in the forest, however according to foresters mostly all branches and brushwood is used for these purposes. According to our estimates the amount is further decreased by a minimum 40% and amounts to 1,624 m^3.

Over 2013 sawmill of Tbilisi City Hall produced 2800 m^3 of firewood and 621 m^3 of timber. Waste from processing is collecting by local population for heating. Therefore only significant waste generation occurs in forests, where amount of wood residue amounts to 1,022 m^3 of biomass.

In 2014 approximately 1000 trees are to be cut due to sanitary cutting and development of a new road and up to now the volume is 250 m3. However this wood residue will be again delivered to socially vulnerable population.

No certain forecast can be made regarding the volume of wood residue for coming years.

Currently there is no particular location for residues (branches, leafs, roots, sawdust and shavings) to be disposed however according to Ecology Department of City Hall there is plan to provide specific territory in Gldani to dispose wood waste.

Another source of wood residue around Tbilisi is represented with waste generated over the years by remnants of sanitary cuttings in forests that include: branches, leaves, roots, decaying wood, brushwood, shavings, sawdust and felled trees and branches.

Every year authorities of each territory assign forest for cutting to be used as firewood for social purposes.

Wood felling and cutting is conducted by local population directly in forests. As a result wood residue is left in the forest despite National Forestry Agency being responsible for removal of residue on the territory of Forest Fund and Protected Areas' Agency for removal at Tbilisi National Park. Therefore biomass is not localized and is scattered around forest. In addition qualities of this timber cannot be identified.

Apart from this there is biomass in these areas that cannot be removed due to distant location and complex landscapes.

Below data represents volume of timber obtained from forestry and National parks that are acceptable for collection for the year of 2013:

Forestry	District	Distance from Tbilisi Km	Felled Wood m3	Biomass m3
Mtskheta-Didgori	Bevreti	24	925	276
Mtskheta-Didgori	Digomi	16	1.124	336
Mtskheta-Didgori	Zegvi	26	1 125	337

Mtskheta-Didgori	Didgori-Lisi	17	982	293
Tsalka-Tetritskaro	Orbeti	27	507	151
Gardabani-Marneuli	Satskhenisi	37	420	125
Tbilisi National Park	Martkhopi, Ghulelebi (Ghulelebi), Ghulelebi (Botchorma), Gldani (Tskhvarichamia), Gldani (Gldani), Saguramo (Saguramo), Saguramo (Galavani)	21- 38	3 984	1 190
Total			**9,067**	**2,708**

The volume of cuttings was the same for the previous 3 years and is expected to stay at the same level in coming years.

2.3. Agricultural Waste

Companies involved in generating solid agricultural residues were asked to provide the answers to the following questions:

- What type of production are they involved in?
- Where is their production located?
- What is the amount of waste (tons, volume)?
- What is the type of waste (fruit stones, straw, corn stover etc)?
- Volumes per season (approximate share per season)?
- What is the moisture content?
- How are they currently utilizing waste?
- Are they willing to sell the waste (if yes what would be the price)?

Conducted research showed that most (up to 90%) of the companies involved in fruit and grain production are managing secondary processing with no solid waste that can be used as biomass. The first stage of processing is conducted outside of Tbilisi at the origins. Only one large producer of grain (sunflower processing) produces solid waste of 1.3 tons annually. The producer is again located in Isani-Samgori district.

It is worth to note that large agricultural producers outside Tbilisi (for instance in fruit processing in Agara, or wheat processor in Sagarejo) are selling the residues to farmers for 200-450 GEL per ton.

2.4. Poultry Waste

Companies involved in poultry farming were asked to provide the answers to the following questions:

- What type of bedding are they using?
- Where is their production located?
- What is the amount of waste (tons, volume)?
- What is the type of waste (wood shavings, chips) and what are approximate sizes?
- Volumes per season (approximate share per season)?
- What is the moisture content and what is the increase in weight after removing of bedding?
- How are they currently utilizing waste?
- Are they willing to sell the waste (if yes what would be the price)?

Only 5 companies involved in poultry farming were identified in Tbilisi Municipality. 4 of them are using suspended cage type technologies therefore use for bedding polyethylene tapes or very small amount of wood shaving (resulting in removed bedding consisting mostly poultry manure – up to 90%).

The only producer that has substantial amount of residue is Chirina Ltd that is located in Martkhopi, adjacent area to Gamarjveba Village.

Details of biomass generated at Chirina are:

1. Pine and Beech shavings are used for bedding. Shavings are produced from purchased as round firewood from various suppliers, milled and dried at own facility. Approximate sizes of fractions are 80-150 x 10-15 x 0.1 mm. Outputs for 1 m3 of roundwood is 5.01 m3 of shavings for Beech and 3.09 m3 for Pine.
2. Monthly demand for shavings is 500-700 m3, approximately 108 tons
3. Average monthly volume of bedding removed from far is approximately 400 tons.

Based on the collected data there is 4800 tons of bedding, that after drying is approximately 1300 tons of shavings – 8400 m3 of biomass.

It is important to note that the biomass outputs are stable throughout the year with small deviations by month.

2.5. Paper and Cardboard Residue

Companies involved in paper and cardboard production were asked to provide the answers to the following questions:

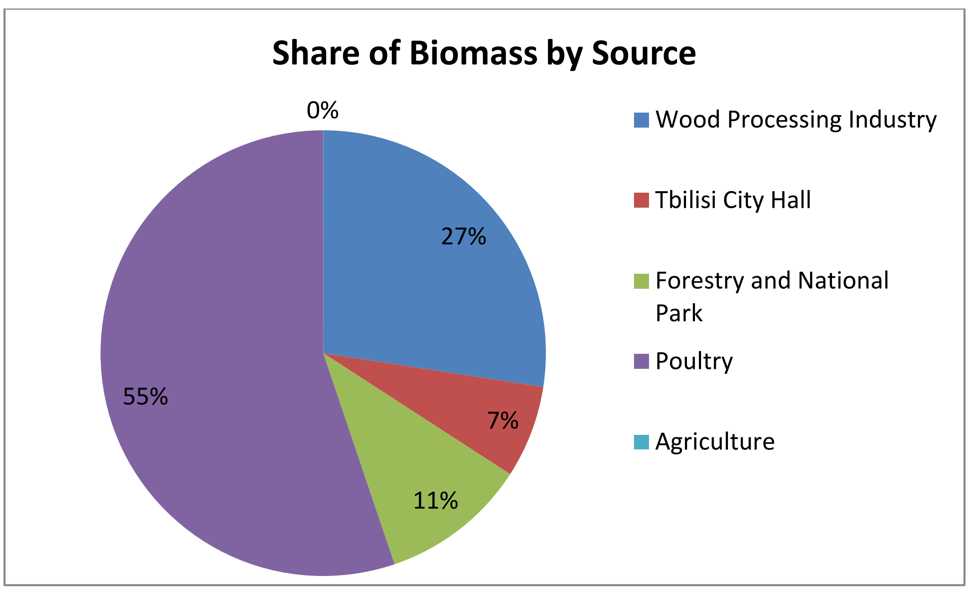
- What type of production are they involved in?
- Where is their production located?
- What is the amount of waste (tons, volume)?
- What is the type of waste and what are approximate sizes?
- Volumes per season (approximate share per season)?

- How are they currently utilizing waste?
- Are they willing to sell the waste (if yes what would be the price)?

Companies involved in the aforementioned sector experience shortage of supply which include waste paper and cardboard. Therefore they are looking for additional sources of this type of biomass and are paying for these 0.15 GEL per Kg.

2.6. Total of Available Biomass Sources in Tbilisi Municipality

Source	Volume m^3
Wood Processing Industry	4175
Tbilisi City Hall	1022
Forestry and National Park	1624
Poultry	8400
Agriculture	1.3
Total	15 222.30



However, it is important to asses amount of biomass not only easily available but the total amount produced in Tbilisi. This amount includes firewood that is distributed to local populace as well as wood residues that are burned for heating in wood processing industry. Currently it may seem inefficient to obtain this biomass from the present beneficiaries due to the fact that it is not feasible for beneficiary (for example furniture production) to sell its biomass resources that it uses for heating in winter season for lower price that it can purchase the gas of same capacity. Otherwise if it sells the biomass for the price that can provide purchase of equivalent natural gas the producers of wood chips or pellets will face increased cost of production that will lead to price of woodfuel that is higher than of its main substitute – natural gas. However as this is an economical barrier to obtaining the biomass, there are chances that other barriers may remove the economical barrier, such barriers can be: decrease of demand among firewood beneficiaries due to increase in distribution of natural gas, improvement of their economic conditions, and various energy efficient measures; legal barriers to burning wood residue in inefficient stoves or boilers, prohibition of wood residue burning in industrial sector if biomass is not conversed into efficient fuel as well as legal barriers prohibiting disposal of wood residues (from small scale producers).

Due to the above total amount of woody biomass shall be assessed as well. Below is data on total amount:

Source	Volume m^3
Wood Processing Industry	6850
Tbilisi City Hall	3822
Forestry and National Park	9607
Poultry	8400
Agriculture	1.3
Total	28 680.3

Chapter 3: Review of Materials in Prospect of Production

The study is limited to assessment of three type of biofuel that are wood chips, briquettes and pellets. 2 out of the three can be produced from various sources of biomass (wood residues, agricultural waste, paper production biomass, etc), while wood chips can only be generated from waste with high percentage timber in it. Considering this factor conversion technologies of biomass to wood chips are limited compared to 2 other biofuel types. Therefore our study will start with assessment of wood chip conversion.

3.1 Wood Chips

Good quality wood chip fuel is produced by machines with sharp knives, with the ability to vary the size of chip produced to meet end-user specifications.

3.1.1. Moisture Content

Moisture content is expressed as percent water of the total weight, and determines to a large degree where the wood chips can be used and if they can be stored. Freshly felled trees have a moisture content range of 40-60%. Conifers (softwood) have a fresh moisture content of at least 55%, while hardwoods such as oak and beech have a moisture content of around 50%. The exception is ash, which has a low natural moisture content of around 40%. Willow, on the other hand, has very high moisture content, between 55 and 60%.

Wood that is to be used as fuel is usually seasoned before use. Leaving felled trees in the forest as whole trees for one summer can reduce the moisture content by between 10 and 15%. An additional benefit is that the needles will drop off which reduces corrosion risk in the boiler and retains nutrients in the forest. Moisture contents of around 30% can be achieved for wood stored as roundwood in a covered pile at the roadside or in a yard.

Given time, natural drying can reduce moisture content levels to a minimum of about 20%. If lower moisture content is required, this can be achieved through artificial drying by ventilation with warm air or dry steam.

The required moisture content depends largely on the size of the installation that is going to burn the chips.

For small installations, i.e. for single households or similar buildings up to 250 kW, dry chips are needed with a maximum of 30% moisture content. For slightly larger installations such as heating boilers in hotels and other large buildings - up to 500 kW - chips with a moisture content of up to 40% can be used. Large installations such as power plants of over 1 MW are usually not very demanding on moisture content with a consistent moisture content being more important than the actual level - boilers are usually adjusted to a certain moisture content and have to be readjusted if the moisture content in the fuel changes significantly.

For all installations, a drier fuel will result in better efficiency of the boiler. Before wood can burn, the moisture has to be evaporated. In large installations, the evaporated moisture can be condensed again and the evaporation heat regained by cooling the flue gas. This process is generally too expensive for small installations.

When wood chips are stored, even for a short period, a process of biological degradation starts immediately. Moisture and nutrients are essential ingredients for degradation of wood: the wetter the chips and the more nutrients they contain, the faster the degradation. The byproducts of degradation are heat, water and carbon dioxide, and dry matter will be lost. Chips from freshly felled conifers will heat up very rapidly to 70-80°C. Rarely, however, will this lead to spontaneous combustion. For that to happen, very large piles of chips, over 12 m high, and very large volumes are needed.

For storage of chips, the ideal moisture content should be below 30%. In such chip stacks, the biological activity will be minimal. Biological activity will increase with increasing moisture content. Chips of up to 40% moisture content can be stored for a short period - up to a few months - while chips over 40% moisture should be burned straight away.

Chips of freshly felled conifers, with needles, will lose up to 2-3% dry matter per month of storage, while losses in dry wood chip are minimal.

3.1.2. Particle Size

The particle size distribution of wood chips depends on the type of chipper, the setting of the knives and the level of maintenance of the machine. To establish the particle size distribution of wood chips, they are sieved through a range of sieve sizes. The amount retained on each screen is divided by the total weight of the sample to give a percentage.

The IS CEN standard classifies chips as P16, P45, P63 and P100; these require that 80% of all particles in a sample can fall through a screen with the indicated gap size.

However, tests have shown that the classes do not cover the correct size spectrum and a revision of this part of the standard is being considered. Generally speaking, however, the smaller the boiler the smaller the size of chip.

For the layman, a simpler measure is the nominal size of the chip. If one selects several particles, one can easily see how they have been cut. The width of the cut is the nominal size of the chip, which relates directly to the setting of the knives of the chipper.

For small boilers (<250 kW) a nominal size of 8-15 mm is required. The amount of oversize particles should be restricted, which means avoiding lumpy chips or overlong particles (longer than 10 cm). Oversize or overlong particles can clog the auger feeding the boiler. In the worst case scenario the safety pin on the auger might shear.

For medium boilers (250 kW<X<1 MW) a nominal size of 8 to 25 mm can be used. The demands on the amount of oversize and overlong chips are not as stringent as for the small boilers. The augers feeding this type of boiler are much larger and more robust than for the small boilers. Too many overlong particles will, however, increase the tendency of the fuel to bridge over openings, which might cause the boiler to stop because of a lack of fuel.

For large boilers (>1 MW) a large nominal size of 25 to 35 mm is usually required. There are hardly any restrictions on oversize or overlong particles, because this type of boiler is usually fed by a crane into a hopper and from the hopper by hydraulic ram into the boiler. Even though the requirements are low, too many overlong particles might get the fuel to bridge over the infeed hopper and thus cause the boiler to stop because of a lack of fuel.

3.1.3. Chipping Machines

The most important equipment to harvest woody biomass is undoubtedly the wood chipper, a machine that cuts the wood into small pieces with sharp tools like knives. There are 2 main types of wood chippers:

- disc chippers

- drum chippers

- screw chippers

Each machine type has its advantages and disadvantages and its best application for the job.

Usually disc chippers deliver a more homogenous chip. The knives of the machine as well as the anvil should be well maintained. If a knife becomes blunt, the amount of fines increases, as well as the amount of overlong particles and the general shape of the chips become less well defined.

Disc chippers

In a disc chipper, the knives are mounted in slots in a disc. The wood is cut against an anvil and once cut, passes through the disc, where casting plates will throw the chips out of the chute. The casting wings also generate a generous air stream, helping in blowing the chips out of the spout.

Since the knife slot can be rather large, often stick breakers are inserted in the slot opening. These stick breakers prevent overlong particles from passing though the slot opening.

The quality of the wood chips from a disc chipper is usually good. The particles are rather uniform in length and shape because the angle of attack of the blade towards the wood is more or less the same all the time. Because of the rotary motion of the disc, the wood is always pushed to the outside of the disc. This concentrates the wear on the blade to the outside 1/3 of the knife. The angle of attack is shown in the drawing below. The angle of attack of a disc chipper is typically around 37 degrees. At that angle experience has shown that the energy consumption of the chipper is at its lowest. The more oblique the chipper is cutting towards the fiber direction of the wood, the higher is the energy consumption.

The size of the chips can be adjusted by pulling the knife further out of the disc, while adjusting the anvil at the same time.

Usually the wood is fed into the chipper by a set or sets of feeding rollers, that push the wood into the chipper. At first, when the knives are really sharp, the chipper pulls the wood in by itself, but as time passes, the knives loose their very sharp edge and the wood has to be helped in. The feed speed has to match the chipping speed, otherwise the feed rollers will press the wood against the disc and then the wood will act as a brake.

Drum chippers

In a drum chipper the knives are mounted on the periphery of a large steel drum. In front of the knife there is typically a pocket, where the chips that have been cut are stored until they can be released behind or below the drum.

A drum chipper does not have fan blades on the drum and therefore an extra fan has to be added to blow the chips out of the spout, or the chips can be dropped onto a conveyor belt.

A drum chipper produces irregular chips because the angle of attack of the blades towards the wood varies with the diameter of the wood. In a thick piece of wood, the angle of attack when the knives first hit the wood is 34 degrees, while at the bottom it might be 79 degrees. The top chips are nice and blocky, while the bottom chips are long and sliver like.

The size of the chips can be adjusted by adjusting the knives and anvil or by inserting a screen with larger or smaller diameter holes in the exhaust opening of the chipper. Particles which are too large to pass through the screen are taken around once more and cut against the anvil.

3.1.4. Tree species

Tree species has an influence on the quality of fuel. Many hardwoods such as oak, beech, ash and sycamore have stiff branches which will give overlong particles in the fuel. Small birch trees have pliable branches, which will give many thin overlong particles.

The bulk density of hardwood chip is much higher than softwood. This means that a smaller volume of hardwood chip needs to be fed into the boiler to get the same amount of energy as for softwood. However, on a unit dry weight basis, the amount of energy is almost equal for all trees. Ash chip has much lower moisture content than chip from other hardwood species, especially when comparing freshly harvested material.

3.1.5. Bulk density

The wet bulk density (the same thing as bulk density received) of chip is expressed as the weight per unit volume of chip, usually in kg per m3 loose volume. Typically for softwood, such as spruce, the weight of a cubic meter of chip with 45% moisture is in the order of 270-300 kg. For the same volume of beech, the weight is in the order of 320-370 kg.

The dry bulk density is the weight of bone dry chip in one cubic metre. For softwoods the dry bulk density is in the order of 150-165 kg dry matter per cubic meter loose volume of chips. For beech this would be 180-205 kg.

3.1.6. Dust and fungal spores

Wood chips will always contain dust and if they have been stored they will also contain fungal and bacterial spores. The dust is generated during the chipping process and little can be done to prevent this.

Bacteria and fungal spores are omnipresent and, given a good growth medium such as moist wood chip, they will flourish. They will convert wood to moisture, heat and carbon dioxide. The temperature in wet wood chip will rise rapidly from the initial 10-20°C to up to 90°C. At such high temperatures the pile will sterilize itself and the fungi and bacteria will die off, but not before they have generated a large amount of spores.

Fungal spores can be the cause of severe allergy. For every exposure to spores, the allergy will increase. At first the reaction is rather mild with a small irritation of the respiratory tract, later it can cause fever. If the exposure is prolonged, and the person is susceptible, then they should do other work where contact with wood chip is avoided.

For these reasons, it is recommended that indoor storage of chip be located as far as possible from areas frequented by people. The storage space should also be well ventilated. For larger installations, it is recommended that the air for the burning process be drawn from the chip silo, which will create a negative pressure in the storage area and reduce the volume of spores in the surrounding air.

3.1.7. Ash content

The ash content of pure wood without bark is quite small, perhaps as low as 0.5%. If wood with bark is burned, the percentage increases to about 1%. If wood chip with bark and needles is burned, the ash percentage might be slightly higher. If the wood has been contaminated with soil, sand or grit, then the ash content can easily reach 5-10%. For this reason alone wood chip should be as clean of soil as practicable.

Garden and horticultural waste, which often includes stumps etc., frequently has an ash content of over 5 or even 10%.

3.1.8. Relevancy to Study

As discussed in the above paragraphs wood chips can only be produced from wood residues with particle size no less than 8mm (for small boilers). Considering this factor volume of wood residue biomass available for wood chip production is limited to the following sources:

- Brash and arboricultural arisings
- Large size particles from wood processing industry
- Wood from Forestry

3.1.9. Alternative Source of Wood Chips – Poultry Bedding

Poultry litter is the bedding material collected from broiler sheds. It's usually made up of wood shavings, shredded paper or straw, mixed with the chicken droppings. It has a calorific value of 9-15GJ/ton, which is slightly lower than that for wood. It has a moisture content of between 20-50% depending on the methods of husbandry used by farmers.

The biomass plant uses a combustion system to burn poultry litter to generate electricity and produce fertilizer.

The practice of spreading large quantities of poultry litter on the land is no longer considered acceptable because it can cause serious environmental problems by polluting watercourses and producing odors if not correctly managed.

Poultry litter, specifically broiler litter, has low moisture content, which increases the efficiency of energy production and is easier to handle and transport than other wetter animal waste products. Adding to the ease of transport is the fact that the poultry litter is usually concentrated at specific locations both on the farm and regionally. Of course, the moisture content of the manure may vary depending upon handling and storage at the farm, which is a factor that must be considered when using poultry litter as fuel source. The caloric value of poultry litter decreases with increasing moisture content. There are traditional processes of material handling equipment that can minimize moisture content by using waste heat to dry the litter.

An important distinction as it applies to this project occurs between broilers and layers. Broilers are raised for meat production while layers are grown to produce eggs. The birds are housed differently as well. Broilers are grown in a house lined with wood shavings or bedding. Layers are housed in a facility with raised, mesh floors. This allows their droppings to fall to the floor which can then be scraped out with a tractor and other equipment.

When it is time to clean out the broiler house, there are two types of cleaning that may occur. The first is a complete cleanout. This means the manure that has collected on the wood shavings as well as the wood shavings are removed from the house. The second scenario is a partial clean-out or "de-caking". This process removes the surface layer or concentrated manure in the house while leaving the rest of the wood shavings or bedding.

3.1.10. Conclusions

- Wood chip production is limited to source of timber due to particle size requirement, therefore only residues from brash and arboricultural arising including sanitary cuttings from parks, recreational areas, cuttings from trees along the roads, forestry and large sized particles from wood processing industry can be considered. As there is no forestry production practices inside and near Tbilisi municipality and wood processing industry's (participants of which are scattered around the city, increasing costs through transportation) wood residue share of large size particles is very low, the only source of virgin wood for chip production is brash and arboricultural arising including sanitary cuttings from parks, recreational areas, cuttings from trees along the roads that is implemented by Tbilisi municipality authorities.

- Alternative source for wood chips is poultry bedding. Considering volume of this biomass in poultry farms it seems an interesting option for further study.

3.2. Briquettes

Biomass briquettes are a replacement for fossil fuels such as oil or coal, and can be used to heat boilers in manufacturing plants, and also have applications in developing countries. Biomass briquettes are a renewable source of energy and avoid adding fossil carbon to the atmosphere.

Biomass briquettes, mostly made of green waste and other organic materials, are commonly used for electricity generation, heat, and cooking fuel. These compressed compounds contain various organic materials, including rice husk, bagasse, ground nut shells, municipal solid waste, agricultural waste. The composition of the briquettes varies by area due to the availability of raw materials. The raw materials are gathered and compressed into briquette in order to burn longer and make transportation of the goods easier.

Based on research of available materials in chapter Review of available raw materials that indicated unsufficient volumes of agricultural biomass and other waste products (i.e. paper manufacturing) production of pellets is limited to only woody residues. Therefore below review will only discuss wood residues.

3.2.1. Process residues

All residues obtained from the processing of a crop or wood are included, for example: coffee husks, groundnut shells, rice husks, coir dust, sawdust, furniture waste etc. In principle, the briquetting process works quite well for a wide range of feedstocks provided they are homogeneous and contain moisture below 15 %.

In general, the evaluation of a plant based upon process residues is less complex than for one based on field wastes. The main problem is to establish the quantitative availability of material from a limited number of point sources, possibly only one. This is inherently simpler than to establish the potential residue yields from shifting agricultural patterns of several outside farms. In effect, the transport costs of gathering, which can be the main barrier to utilization of crop residues, have been absorbed by the transport of the valuable food-component of the crop.

At the other extreme, a briquettor tied to a particular process residue from a single plant may find itself stranded if the supply of residues fails to meet expectations as the plant itself fails to find any raw material. Changes in agricultural practices or simple miscalculation can lead to that the feed-plants simply cannot deliver enough residues. The small value of the briquettes relative to the total value of the crop means that the issue of providing briquetting raw-material was irrelevant to the wider agricultural changes going on.

3.2.2. Briquetting technologies

Industrial methods of briquetting date back to the second part the the 19th century. Since then there has been widespread use of briquettes made from brown coal, peat and coal fines. The briquetting of organic materials requires higher pressure as additional force is needed to overcome the natural springiness of these materials. Essentially, this involves the destruction of the cell walls through some combination of pressure and heat. The following overview presents the most common machines used for briquetting biomass.

Piston presses

In piston presses, pressure is applied discontinuously by the action of a piston on material packed into a cylinder. They may have a mechanical coupling and fly wheel or utilize hydraulic action on the piston. The incoming raw material is pressed against the compacted material inside the pressing tube and leaves the die in the rhythm of the piston action. Through pressure and friction forces inside the pressing tube, the material is strongly heated and cooling mechanisms might be considered. To produce briquettes with high density (up to 1.25 g/m3) the raw material eventually needs to be milled (less than 10 mm) and dried (<15% of water content) before briquetting. The capacity of piston presses depends both on the diameter of the die and the pretreatment of the raw material.

The capacity spectrum of piston presses range from only 25 up to 1800 kg/hr. Their typical specific energy use requires between 50 and 70 kWh/t.

Screw compaction or Extrusion

The aim of compaction using an extruder is to bring the smaller particles closer so that the forces acting between them become stronger, providing more strength the densified bulk material. During extrusion, the material moves from the feed port, with the help of a rotating screw, through the barrel and against a die, resulting in significant pressure gradient and friction due to biomass shearing. The combined effects of wall friction at the barrel, internal friction in the material, and high rotational speed of the screw, increase the temperature in the closed system and heat the biomass. This heated biomass is forced through the extrusion die to form the briquettes with the required shape. If the heat generated within the system is not sufficient for the material to reach a pseudo-plastic state for smooth extrusion, external heat might be added. In principle, screw presses reach slightly higher compaction but lower capacity (tons per hour) when compared to piston presses.

Pan grinder presses for pelletizing

Pellets are the result of a process which is closely related to the briquetting processes described above. The main difference is that the dies have smaller diameters and each machine has a number of dies arranged as holes bored in a thick steel disk or ring. The material is forced into the dies by means of rollers moving over the surface on which the raw material is distributed. The pressure is built up by the compression of this layer of material as the roller moves perpendicular to the centerline of the dies. Thus the main force applied results in shear stresses in the material. The pellets will still be hot when leaving the dies, where they are cut to lengths normally about one or two times the diameter. Successful operation demands that a rather elaborate cooling system is arranged after the densification process.

There are two main types of pellet presses: flat and ring types. The flat die type has a circular perforated disk on which rollers rotate whereas the ring die press features a rotating perforated ring on which rollers press on the inner perimeter. The output of pellet presses range from about 200 kg/hr up to 8 ton/hr. Their specific energy consumption is reported to be around 1,5% of the energy content of the final pellets.

Roller Presses

Densification of biomass using roller presses works on the principle of pressure and agglomeration, where pressure is applied between two counter-rotating rolls. Ground biomass, when forced through the gap between the two rollers, is pressed into a die, or small pockets, forming the densified product. Roller presses are considered the world standard technology to produce ovoid (pillow-shaped) charcoal briquettes from a variety of biomass types. In a roller press, a mixture of charcoal and binder is fed to the tangential pockets of two rollers to produce briquettes. The smooth production of charcoal briquettes using this technology requires high-quality rollers with smooth surfaces on which the briquettes are shaped. The type of roller determines the shape of the briquettes. Currently, roll presses available in developed countries have production capacities of 1 t/hr and more. The 1 ton/hr capacity press with controlled feeding device costs about $ 320,000. Much cheaper roller-type charcoal briquetting machines can be sourced in India and China: Seboka (2009) indicates that a roller press with a capacity of 1.5 ton/hr costing $ 19,000 can be found in India.

Agglomeration

Agglomeration is a method of increasing particle size by gluing powder particles together. Usually the equipment consists of a rotating volume that is filled with balls of varying sizes and fed with powder and often a binder. The rotation of the agglomerator results in centrifugal, gravitational and frictional forces from the smooth rolling balls. These forces, together with inertial forces, press the balls against the powder, helping them to stick together and grow. NL Agency reports applied agglomeration technology in small-scale briquetting processes in several developing countries. The charcoal is milled to powder, binders are added, the components are mixed together, and the mix is then agglomerated. Agglomerated charcoal briquettes are produced using a motor-driven agglomerator, the typical nominal capacity of which is 25-50 kg/hour. Agglomerated charcoal briquettes are spherical and typically have diameters between 20-30 mm. The briquettes can be used for household cooking as well as for fuelling industrial furnaces. Agglomerated briquettes are said to be stronger than most other briquette types

3.2.3. Production Overview

As seen above, there are different technologies to produce densified biomass briquettes. The following table summarizes their main characteristics. For the right choice of an adapted machine, two main issues should be considered:

- Quantity and quality of the raw material
- Market availability of briquetting machines and spare parts

	Screw press	Piston Press	Roller press	Pellet mill	Agglomerator
Optimum moisture content of the raw material	8–9%	10–15%	10–15%	10–15%	No information
Particle size	Smaller	Larger	Larger	Smaller	Smaller
Wear of contact parts	High	Low	High	High	Low
Output from machine	Continuous	In strokes	Continuous	Continuous	Continuous
Specific energy consumption (kWh/ton)	36.8–150	37.4–77	29.91–83.1	16.4–74.5	No information
Through puts (ton/hr)	0.5	2.5	5–10	5	No information
Density of briquette	1–1.4 g/cm^3	1–1.2 g/cm^3	0.6–0.7 g/cm^3	0.7–0.8 g/ cm^3	0.4–0.5 g/ cm^3
Maintenance	Low	High	Low	Low	Low
Combustion performance of briquettes	Very good	Moderate	Moderate	Very good	No information
Carbonization of charcoal	Makes good charcoal	Not possible	Not possible	Not possible	Not possible
Suitability in gasifiers	Suitable	Suitable	Suitable	Suitable	Suitable
Suitability for cofiring	Suitable	Suitable	Suitable	Suitable	Suitable
Suitability for biochemical conversion	Not suitable	Suitable	Suitable	Suitable	No information
Homogeneity of densified biomass	Homogenous	Not homogenous	Not homogeneous	Homogeneous	Homogenous

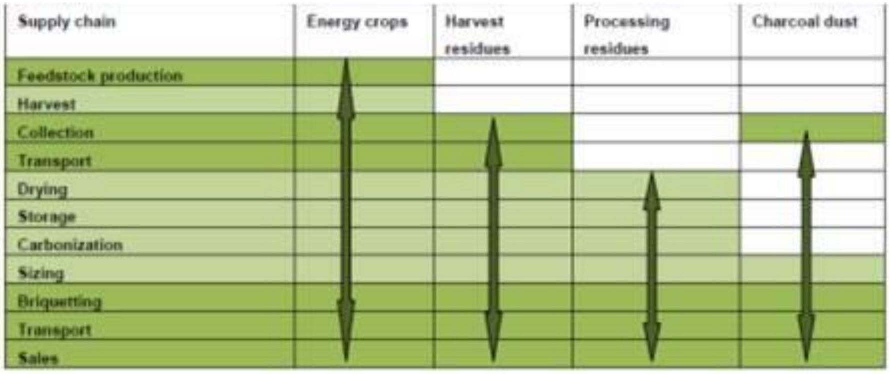
Problems arise often if the die has not been shaped correctly or if the feeding mechanism has not been sized for the material to be used. It is normal for machines made in Europe or North America to be designed to operate on wood wastes. The use of agro-residues normally de-rates the throughput and may require some modification to the feeder. Therefore, when searching for briquetting machines, best is finding machines which are already running with similar raw material and under similar conditions.

3.2.4. Auxiliary equipment

Only in few cases will the briquetting press be the only equipment needed to set up a briquetting plant. From the starting point, the complexity of briquetting plants increases up to the fully automated wood waste briquetting plants in which the raw material is fed by a tractor into a hopper from where it is crushed, screened, stored, dried, stored again, fed into the presses and transported to the product storage in fully automatic process, supervised by a couple of operators. Without going into details, the following text is a brief listing of a few common types of necessary auxiliary equipment and its applications which might have to be considered as also important economic factors:

- Storage (rainy seasons, both the raw material and the product)
- Handling (conveyors, elevators etc.)
- Comminution (chipper, hammer mill, conditioner, mixing with binder)
- Classification (separation, cleaning)
- Drying

To demonstrate the necessary steps for charcoal briquetting of different raw materials, NL Agency (2013) created table below. Charcoal dust has the shortest supply chain, only a collection and briquetting step is needed to produce charcoal briquettes. On the contrary, the charcoal production chain based on the growing of dedicated energy crops involves a considerable number of steps. Each step in the supply chain represents efforts, money and possible complications, and this indicator shows that charcoal dust and processing residues have a logistic advantage over other types of feedstocks.



3.3. Pellets

Based on research of available materials in chapter Review of available raw materials that indicated unsufficient volumes of agricultural biomass and other waste products (i.e. paper manufacturing) production of pellets is limited to only woody residues. Therefore below review will only discuss wood residues.

The CEN/Technical Specification 14588 Solid biofuels – Terminology, definitions and descriptions describes biofuel pellets as: densified biofuel made from pulverized biomass, with or without pressing aids, usually with a cylindrical form, random length typically 5 to 30 mm, and broken ends.

In CEN/Technical Specification 14961 Solid Biofuels – Fuel specifications and classes densified biofuel is further sub-divided into briquettes, which have a diameter larger than 25 mm, and pellets, which have a diameter of less than 25 mm. The same technical specification also provides more details on the specifications of properties for wood pellets. Requirements and classes are formulated for diameter, moisture content, ash percentage, sulphur contents, mechanical durability, amount of fines, additives, and nitrogen content.

The requirements for sulphur and nitrogen are only valid for chemically-treated wood or if additives have been used.

Durability is measured to see how well the pellets are pressed. The higher the number, the better is the quality. The amount of fines is measured at the final point in the production chain, just before the pellets are loaded out.

Pressing aids, slagging inhibitors or any other additives have to be declared for the product.

3.3.1. Raw Material

Wood pellets are usually made from clean conifer sawdust and planer shavings. The wood must have been debarked prior to passing through the sawmill. Sawdust of hardwoods can be mixed in with that of softwood, but successful production of hardwood pellets without binders is more difficult.

If at all possible, dry sawdust and shavings (less than 15% moisture content) are used, because then the drying step can be skipped. If the sawdust is wetter, a drying process is needed before pellets can be pressed.

Sometimes a small amount of wood chip is added during the drying process to increase the amount of feedstock; this is then pulverized in the hammer-mill. Alternatively, where production of wood pellets directly from round wood is envisaged, this will require additional debarking and chipping steps in the process, which can add significantly to cost. Since chips are many times the size of sawdust, a single pass through a hammer-mill might not be sufficient to obtain the required fine material for the pressing process; an additional pass through may be required.

Chips dry at a slower rate than sawdust, so a much larger drying capacity is needed if roundwood is the wood supply for the pelleting plant.

3.3.2. Production steps

The production of wood pellets involves:

- reception and intermediate storage of the sawdust;
- drying and possibly intermediate storage again;
- screening for foreign materials such as stones and metal;
- hammer-milling and possibly intermediate storage;
- pressing of the pellets;
- cooling of the pellets;
- screening of fines;
- storage;
- bagging;
- loading out.

3.3.3. Reception

At reception all sawdust coming in should be weighed on the weighbridge and samples taken to determine the moisture content.

For storage it is preferable to separate wet and dry sawdust. Wet sawdust can be stored for a short period out in the open. The moisture content is not too badly affected if some rain falls on the base material, and wet sawdust does not blow about as easily. Dry sawdust should be stored indoors immediately to prevent the material getting wet. If the material is stored outside, the sawdust can blow about and create dust hazards. Very high levels of dust are encountered in buildings as dry sawdust is being unloaded.

All personnel, including the delivery vehicle driver, should wear a P3 dust mask at all times during and after unloading. Vehicle windows should be kept closed while they are inside the building.

In large plants that handle a lot of sawdust, under-pressure in the building is created to retain the dust inside. The exit gate from the building is equipped with an airbrush system that blows sawdust from the outside of the vehicles before they leave.

In the reception building it is possible to mix the sawdust before it goes into the hammer-mill, so hardwood sawdust could be mixed in at this stage.

3.3.4. Drying

The wet sawdust needs to be dried before hammer-milling as wet sawdust requires much more energy to reduce the particle size than when it is dry. There is also a significant risk of screens becoming clogged or smeared.

Drying can either be done in a drum drier, a so-called flash drier that works with high temperatures, or on a flatbed drier, which works at a relatively low temperature. The first option is better suited for fine material, while coarse material needs a lower temperature. So, if chips are going to be mixed in, a flatbed drier is preferable.

It is likely that the throughput capacity of the drier will be less than the rest of the system, so there should be a facility for intermediate storage of dried sawdust after the drier.

The heat for the drier can be supplied by any kind of fuel, e.g. gas, oil or even biomass. The biomass boiler could use bark, wood chips, short rotation coppice or other wood waste that is not suitable for pellet production.

3.3.5. Screening

Before the sawdust can be passed to the hammer-mill for homogenizing, it has to be screened for stones, pieces of metal, plastic etc. Stone is usually removed by a stone trap, where the sawdust passes at speed over an opening.
Sawdust should also be passed over a magnet that removes metal objects. Foreign particles in the sawdust are likely to damage the press or could conceivably cause sparks in the hammer-mill, which might lead to a dust explosion.

3.3.6. Hammer-milling

The homogenizing of the sawdust to an even-sized feedstock for the pellet presses takes place in the hammer mill. Here small lumps of wood, dead knots, etc. are pulverized, so that they can pass through the matrix of the presses. The mixing of the material is also completed here. The hammer-mill should be equipped with a venting hatch to the outside of the building. If a dust explosion occurs, the membrane in the escape hatch will blow out and ventilate part of the pressure to the outside of the building. The opening of the vent on the outside of the building needs to be located at a sufficient height or cordoned off in a way that reduces the propensity for injury to any bystander or passer-by in the event of an explosion.

Again, the hammer-mill will not necessarily have the same capacity as the presses, so there should be an intermediate store of hammer-milled material. This material is very fine and very dry, so precautions against fire should be taken. This part of the building should only be entered when wearing a face mask with a P3 dust filter.

3.3.7. Pellet pressing

Many presses need the sawdust to be warmed up to 120-130°C using dry steam. The heat makes the lignin in the wood become more plastic which helps to stick the particles together. The sawdust is extruded through a matrix and the pellets are cut off on the outside of the matrix.

The matrix can either be standing, with the pressure rollers moving on its inside, or can be lying down with the rollers moving over the matrix in a revolving fashion. The wood is pressed through the matrix under very high pressure.

Vegetable oil is added to lubricate the last pellets at the end of a working period. The matrix will then slowly cool off with the lubricated pellets in the holes of the matrix. If this is not done, the last pellets may become stuck in the matrix, making it difficult to start the press again. The oil saturated pellets can be returned to the press again the next time it is due to be stopped.

Usually the presses are kept operating overnight, because the matrix and the whole machine operate best at an elevated temperature. Many pellet plants operate from Monday morning until Friday afternoon on a continuous basis. This is another reason for having intermediate storage following drying and hammer-milling; otherwise the press can run out of raw material if it is in continuous operation for periods of up to five days.

3.3.8. Cooling

Once the pellets leave the press, they are plastic and hot. During cooling, the pellets become rigid and lose moisture, so that the final moisture content after the cooler can be as low as 6%. They will take up moisture from the surrounding air and stabilize at a content of between 8 and 10%. After cooling the pellets are transported by conveyor belt to the storage shed, where they condition.

3.3.9. Packaging and delivery

Pellets should be screened for fines before packaging or delivery. The fines can be returned to the production line.

If the pellets are destined for the domestic market, many customers prefer to receive them in bags. These bags typically come in 12, 15 or 20 kg sizes. It is also possible to ship the pellets in one ton bags or in bulk. The small bags are usually delivered on pallets of 960 kg or one ton. These pallets are wrapped in plastic and can withstand moisture well. Small bags are, however, a better guarantor of quality, since the pellets are less subject to abrasion during delivery.

Pellets delivered in bulk can be transported by truck, tipped off at the receiving end, or be transported by a vacuum vehicle that sucks up the pellets in the factory and blows them into the silo at the receiving end. These trucks are also equipped with weigh cells so that they can measure the exact amount that is delivered.

Pellets delivered by truck should always be dumped inside a building or in absolutely dry weather conditions as they will rapidly take up moisture, swell and disintegrate if exposed to water. The truck should always be carefully covered with a water-tight tarpaulin to keep rain out.

3.3.10. Storage

During summer, usually the production of wood pellets probably exceeds the demand and the pellets may have to be stored for several months. The storage facility should be constructed of high concrete side walls that can withstand the pressure of the pellets. A cubic meter of pellets weighs around 650 kg, so if they are stored at a height of 5-6 m, a considerable pressure is exerted at the bottom of the pile. As stated, pellets easily disintegrate once they get wet, so it is very important that the building is water-tight, to prevent rain or condensation.

3.3.11. Quality control

During production it is advisable to check pellet quality at least once a day. A sample is taken and fines are sieved out. The resulting sample is weighed and tested for durability in a durability tester. After tumbling the required number of revolutions, the pellets are screened again and weighed again. The amount of whole pellets should be in excess of 97.5% to classify as good grade wood pellets.

A check should also be made for the amount of fines before the pellets leave the plant. At the final point in the production line the amount of fines in the goods should not exceed 1%.

A declaration should be delivered with the pellets describing the raw material used, their durability and fines content, as well as their moisture content. If the figures are available, it is also useful to declare the energy and ash content.

3.4. Comparison of Biofuel Types

As outline in the previous chapters of Review of Materials in Prospect of Production the following alternatives are considered:

- Production of wood chips from wood residue
- Production of wood chips from poultry bedding
- Production of briquettes from wood residues
- Production of pellets from wood residues

Compared to wood chips the advantages of processing and densifying of biomass are not only limited to the higher energy content. Both of the techniques, briquetting and pelletizing, are based on compacting the raw material to yield certain advantages:

- High volumetric energy density
- Favorable dosing characteristics
- Lower water content in the fuel and therefore greater storage stability (less biodegradation)
- Option to use additives to change the chemical/material properties
- Less dust produced when handling
- High homogeneity of the fuel

Briquette processing is more efficient than pelleting because the biomass materials do not necessarily have to be preprocessed or uniformly ground up, which results in less preparation. Another advantage of briquetting is it can be set onsite. Briquetting waste byproducts and reusing them onsite for energy rather than transporting them to another location or to a landfill can save on disposal costs. Briquetting generally use less horsepower. From the investment point of view, the purchase capital and maintenance costs to make briquettes are less than for pellets. If transportation is one of the main criteria, pellets are more advantageous because there are more pounds per foot than briquettes. This is especially true if the briquettes are larger because it allows for more air between them when they are stacked.

Considering the above alternatives production-wise priorities of each type of biofuel is following (1-Highest/best, 4-Lowest/worst):

	Wood Chips (wood residue)	Wood Chips (Poultry bedding)	Briquettes	Pellets
Availability of Biomass	4	1	3	2
Availability of ready to use biomass	4	2	3	3
Availability of biomass that needs processing	4	1	3	2
Distribution of Sources	3	1	3	2

Ease of Purchase/Price of Biomass (based on alternative uses of biomass)	3	1	2	2
Production Establishment Costs	2	2	3	4
Ease of Processing (drying, hammer-milling, screening etc)	1	1	3	4
Ease of Transportation of Biofuel	3	3	2	1
Biomass Storage (based on seasonality of supply; Good: Autumn-Spring; Bad: Summer)	3	3	2	2
Risks of supply stoppage (based on number of sources)	3	4	2	1
Total	31	20	25	20

Based on the above the following conclusions shall be made:

- Assuming capital costs (production establishment and operational costs) need to be as low as possible most suitable biofuel would be Wood Chips from Poultry bedding;
- Considering risks of biomass supply stoppage risks most suitable options would be Briquette and Pellet productions;
- Assuming technological ease (simplicity of processes and production techniques) most suitable production options would be wood chips;s
- Assuming that all criteria are equally relevant most viable biomass fuel in perspective of production would be Wood Chip from Poultry Bedding, followed by Pellets

Chapter 4: Review of Materials in Prospect of Utilization

This chapter outlines the general principles of the use of wood as a fuel in household and commercial appliances. Household application range is up to 100 kW output, while commercial installations range up to 500 kW. Industrial appliances start at 500 kW.

In most cases a wood consuming heating system consists of several main parts:

- Fuel storage
- Fuel handling system
- Conversion appliance
- Ash handling system

These parts will be discussed in separate chapters.

Not every fuel is suited for every boiler and local circumstances may dictate what fuel to use. Therefore advice is given below on what fuel to use where.

However before dealing with all the technicalities of appliances, knowledge of which wood fuels exist and their general specifications is very useful.

In general wood fuels can divide wood fuels into several broad categories:

- Firewood
- Wood chips
- Wood pellets
- Wood briquettes
- Hog fuel

However in this chapter study will be only limited to biomass fuel types identified in previous sections: wood chips (from wood residues and poultry bedding), briquettes and pellets.

For wood chips, the main properties of importance are the moisture content, the nominal size of the particles and their size distribution, and for wood pellets and briquettes, the durability and amount of fines.

4.1. Moisture Content

Wood fuels can be divided into four main groups according to moisture content:

Very dry fuels (moisture content less than 10%):

- wood pellets
- wood briquettes

Dry fuels (moisture content over 10 and below 20%)

- dry wood chips

Wet fuels (moisture content over 20 and below 30%)

- wood chips

Very wet fuels (moisture content over 30 and below 60%)

- fresh wood chips

In general the drier the fuel, the more expensive it is, as it will provide more heat per unit weight or volume than wet fuel. For this reason, payment according to the energy value of the fuel - per Giga Joule (GJ) or Mega Watt hour (MWh) - is the most transparent way to go. For firewood and woodchip in particular the fuel should be sold at specified moisture content and by weight. Since wood pellets and briquettes have fairly standardized moisture content, they can be traded by weight only.

The moisture content of wood fuels is expressed as a percentage of total weight as received. The moisture content is determined by drying a sample in a drying cabinet at 105 degrees C for at least 24 hours or until constant weight has been achieved. By dividing the weight loss by the total weight before drying and multiplying the result by 100, one gets the moisture content in percent.

For ease of use, the moisture content of biofuels is often expressed in M classes in the European standards with intervals of 5%. If for example a fuel belongs to moisture class M35, it means that the fuel contains between 30 and 35% moisture. A sample can belong to one only class.

4.2. Nominal size and size distribution

Not only the moisture content of fuels is important, but also the size distribution of the wood chip particles. For wood pellets and briquettes it is important that the amount of fines in the fuel is kept very low. Also the variation is size between the pellets should be small, and overlong pellets should be avoided. In firewood the length of the pieces and the amount of splitting are important as these influence moisture content and flammability.

For wood chip the size distribution and also the actual nominal size of the chips are very important. Wood chips are cut with sharp tools (such as knives) and have a more or less regular shape. The nominal size is the cutting length of the particles to which the chipper has been adjusted. In the size distribution it is important to know how much fines the fuel contains, as well as how many percent of oversize particles there are. Fines can cause problems because they are lifted from the fuel by the air that is blown into the boiler and tend to whirl up into the heat exchange tubes or the flue gas filtering system, which may become clogged. Oversize particles can cause fuel feeding problems because the fuel bridges-over openings and thus prevents the fuel from flowing from the hopper to the boiler.

It is obvious that the size of wood chips should be adapted to the size of the boiler. Small boilers need small chips, while very large boilers can handle very large chips.

In the European Standard EN14961 (and the coming ISO standard) the size of the chips is expressed in P-classes.

The following classes are relevant for the boilers in this chapter:

- P16 small chips
- P31 medium chips
- P45 large chips
- P63 very large chips.

In these classes, the number indicates the screen size through which 70% of all particles have to fall to belong to that class. Of course there are many other requirements which can be found in the relevant EN/ISO standards.

4.3. Durability of wood pellets and briquettes

Wood pellets and briquettes are made by compressing ground wood particles together under application of heat and high pressure. The lignin in the wood becomes plastic and bonds the particles together without having to use any glue. The intensity of the compression decides the durability of the wood pellets and briquettes.

During handling, pellets and briquettes undergo a lot of wear and tear and if the durability of the particles is not high enough, fines will occur in the fuel. Since fines burn much faster than whole pellets, they can cause problems in the boiler, but also in the hopper, where they prevent the pellets from sliding down to the feeding auger.

The European Standard as well as the coming ISO standard requires a durability of at least 97.5%, meaning that this percentage of pellets has to survive a tumbling test of 15 minutes duration as whole pellets.

4.4. Fines in wood pellets

Fines in wood pellets can cause several problems, such as excessive dust in the air during handling, accumulation at the bottom of the hopper thus preventing the pellets from sliding down to the feeding auger and finally in the boiler, where they burn much hotter than wood pellets. Such high temperatures may cause the ash to sinter or fuse, which then causes problems during the removal of the ash from the boiler.

The European Standard as well as the coming ISO standard requires wood pellets to contain a maximum of 1% of fines at the last point of loading, meaning at the factory gate or when the pellets leave the gate of the seller. This is valid for both pellets in bulk volume, as well as pellets in bags, be they large of small.

4.5. Influence of tree species

It is commonly assumed that hardwoods, such as beech, oak, ash and birch have a higher heating value than softwoods such as spruce, larch and pine. This may be true if one looks at the volume, but it is false if one looks at the weight at the same moisture content. It is a fact that one has to put fewer hardwood logs on the fire than pieces of softwood, but that is when measured by volume. If one would weigh the hardwood logs and the softwood logs, the amount of fuel used would be more or less the same for the same amount of energy produced. The reason is that hardwoods are denser than softwoods, meaning that there is more dry matter per unit of volume than softwood.

However the amount of fuel one uses is determined by the weight and the moisture content, not the volume. By unit of weight at the same moisture content, softwoods have in fact a slightly higher energetic value than hardwoods, because they contain resins that have a very high energy value.

This than is another good reason why one should buy wood chips by the tons and at specified moisture content, because then one knows how much potential energy one is getting.

4.6. Conversion methods

In general there are two main conversion methods that turn solid fuel into useable energy:

- burning with excess air
- gasification with an air deficit.

In the burning process excess air is added, so that fuel is converted from the carbon-hydrates to carbon dioxide (CO_2), water, energy and very low amounts of other gasses and substances (like ash). The flue gasses still contain a surplus of oxygen, the carbon dioxide, water vapor and the other gasses, as well as a tiny amount of fine dust.

In the gasification process, the air supply is deliberately kept low. By heating the fuel, the volatiles are transformed to carbon-monoxide (CO), hydrogen gas (H_2) and often a spectrum of tars and other poly-aromatic hydrates, the so called PAHs. Both the tars and the PAHs can be detrimental to health. The gasses are later burned with excess air if one wants to produce heat or can, after rigorous cleaning, be used as a fuel in piston engines, and power a generator to produce electricity. The cooling of the engine and the generator can be used to heat water for a district heating system.

In order for a fuel to burn in an appliance, the first thing that has to happen is the evaporation of the moisture in the fuel (everyone knows that water does not burn). Evaporation requires energy from the fuel itself and this limits the amount of useful energy that can be taken from the appliance. It is thus clear that the amount of useful energy one can take out of a boiler that runs on a very dry fuel like wood pellets is much higher than from a similar boiler that runs on wood chips, with say 50% moisture content. For most domestic appliances though, wood chip needs to be at moisture content below 30% for the appliance to work satisfactorily. The drying of the fuel is aided by the primary air that is blown through the fuel layer. After drying, the volatiles in the wood are driven off (wood contains almost 85% volatiles!). These gasses burn above the fuel layer, aided by the secondary air that is blown into the burning chamber. After the volatiles are removed, the remaining charcoal burns out and that leaves ashes. They consist mainly of the nutrients the trees have absorbed over their lifetime as well as sand and dirt that have accumulated during the harvesting and production process.

In fact, most boilers are constructed with a specific fuel in mind: boilers that are specifically built to burn wood pellets usually cannot burn dry wood chips and certainly not wet fuels. On the other hand, a boiler which has been designed to handle wet fuels can have problems in dealing with very dry fuels. Wet fuel boilers usually have a ceramic lining, which absorbs first the heat from the burning process and then radiates it onto the fuel to assist in the drying. If too dry a fuel is used in these boilers, the brick lining gets too hot and might crack, so therefore stick to the moisture limits (both under and upper limit) of a boiler.

As pointed out, for domestic use, in almost all cases only dry fuels are suitable. For larger installations however one should consider using wet fuels, even though such a boiler might be more expensive than one that runs on a drier fuel. This is because dry fuels tend to be more expensive and more difficult to obtain.

In large boilers it is possible to recover the evaporation heat of the water in the fuel by cooling the flue gasses with the returning water of the (district) heating system. Normally flue gasses leave the chimney at a temperature well above 100 degrees C, but if these gasses are cooled to below 65 degrees C, then the moisture in the flue gasses condenses and releases the energy that was used to evaporate it. The condensate must be purified of the fine dust it washes out from the flue gas, before it is released into the waste water system. Another advantage of these so-called condensing boilers is that the flue gasses have a very low content of fine dust on leaving the chimney.

4.7. Boilers

By definition a boiler is connected to a water-based central-heating system, run out to radiators in the building. In some modern houses there is under-floor heating and no or very few radiators. Boilers are usually placed in a boiler room separate from the rest of the house or even the rest of the building.

Boilers can handle all kinds of fuel depending on their make and model, but again it is not very likely that every boiler can handle every fuel, so again one should consider what fuel one wants to use. Some boilers which run fully automated on wood pellets or wood chips can also burn firewood or briquettes, but only with manual batch feeding. The fuel is usually stored in a hopper, which can contain enough fuel for several days or even weeks of operation. Sometimes the fuel hopper is situated in another room than the boiler, which reduces exposure to dust and fungal spores.

Nearly all of these appliances need a very dry or dry fuel, except for special boilers which can accept wet or very wet fuel. These boilers have a ceramic lining that aids in the drying of the fuel, but usually they are of such a size that they are not suitable for domestic purposes.

4.7.1. Burning boilers

These boilers normally have automatic feeding and use either wood pellets or wood chips as fuel. The fuel is fed on demand into the boiler by an auger. These boilers can be modulated to some extent, meaning that they do not have to run on full load all the time, but their output can be varied within certain limits. Modulation is governed by a room thermostat.

Any boiler will operate best when it is warm, because the drying of the fuel will be better. Every time a boiler has to be restarted from cold, extra emissions of unburned gasses and more dust will occur, therefore a wood burning boiler should be kept warm for most of the time. Boilers operate best at some 60% to 100 % of their rated output.

When properly maintained these boiler systems can run almost as automatically as oil or gas boilers. The only difference being that one every now and then has to remove the ash from the burning chamber and clean the heat exchange tubes.

The most luxurious models (and also the most expensive) have automatic start-stop, meaning that the boiler itself can restart the burning process by an ignition system.

4.7.2. Gasifying boilers

These boilers use a gasification process to convert the fuel from solid to gas. The fuel is batch loaded into the gasification chamber and consists either of firewood or briquettes.

The gasses are burned in a separate burning chamber. This conversion process can is difficult to modulate, so a large output can be expected until the batch of fuel has been used. The boiler can then be refueled with a new batch or the fire can go out until the heat in the storage tank has been used. These domestic size gasifiers should be equipped with a water storage tank, so that the surplus heat can be stored in the water in the tank until it is needed. Needless to say such tanks should be well insulated. The size of the tank depends on the size of the boiler.

4.7.3. Appliance types for commercial or industrial applications

The larger appliances are meant for heating of large buildings, the supply of process heat or steam for industry, for district heating of large building complexes, villages or even towns or the co-production of heat and electricity for the aforementioned purposes.

As stated before, biofuel boilers operate best when they are warm, that helps in drying the fuel and reduces emissions of any noxious substances and dust. Boilers should preferably run on 60 to 100% of their rated output.

This means that boilers should be chosen so that they cover the base load of a building, meaning the amount of heat that is needed to provide hot water and heat on a normal day. The peak load is when all the most adverse conditions occur at the same time: cold, wet and windy weather. Peak loads do not occur very often, and a rule of thumb says that a boiler that can cover 60% of the peak load can cover 92% of the annual load.

What to do when a peak load occurs and the boiler does not have enough capacity:

- Burn a drier fuel (when burning chips), this will give a higher output of the boiler

- Equip the system with a heat storage tank, that can take up heat in periods when there is no peak load and release it when one occurs
- Have a back-up system in the form of either the old boiler that was replaced by the biofuel boiler or an extra (small boiler) that will run on fossil fuel
- In larger buildings two boilers could be attached to the same fuel storage and handling system. One should be slightly larger than the second. The small boiler is used during summer; the big one will be used in spring and autumn, while both will operate during winter. This system allows the boilers always to be warm and operate on at least 60% of their rated capacity.

A very important message: do not size your biofuel boiler after the size of the gas or oil boiler it replaces. Usually these fossil fuel boilers are larger than needed, but since they can be easily modulated, that does not matter, but for biofuel boilers an oversize means that they do never get really hot, which has a bad influence on the level of emissions and the longevity of the appliance. More maintenance and repairs will be needed on an oversize biofuel boiler than one that is the right size.

An even more important message is to resist the inclination to add 10-30% output capacity when replacing a fossil fuel boiler in an attempt to ensure that there is enough "umpf" to heat a building. This will only result in the biofuel boiler being really oversized and it will almost certainly run badly most of the time.

For new buildings, which are better insulated than older build, one can use the degree day system to calculate the required boiler size.

As a rule of thumb: a building of 140 square meters would need a 12 kW boiler to keep the building comfortably warm all year round and to provide hot water.

In most cases it is the size of the fuel store which will determine which fuel to use, but also the capacity of the total system is important.

Small systems need a simple fuel to run smoothly, so here it should be either wood pellets or dry woodchip. Large systems use a lot of fuel and here it would be more economical to use wood chips or briquettes instead of wood pellets.

In towns, space is usually restricted, while standalone houses in the countryside usually have much more room. We have seen in a previous chapter that wood pellets have a much higher energy density per ton than wood chip or firewood, so this leads to the use of wood pellets in domestic situations in town.

In the country small systems can run on dry wood chips. One can produce dry wood chip by storing the required amount of roundwood off the ground and under cover in a sunny and windy place. Close to beginning of the heating season, the wood is chipped and the chips stored under roof in a well-ventilated space close to the boiler system.

As stated, large systems should preferably run on wet wood chip. It is easy to produce and is also cheap.

To produce dry wood chip, one has to harvest the wood as roundwood and store it under the right circumstances for a long period of time before it can be chipped. Harvesting roundwood is an expensive system and the cost of storage and covering has to be added to harvesting costs. On top of that the fuel will have to be stored under roof after chipping at the supplier, which also is a cost factor.

Recommendations on fuels for different locations and applications are:

Location	Small Buildings	Commercial Applications	Industrial Applications
Inside Town	Pellets Dry Wood Chip Wet Wood Chip	Pellets Dry Wood Chip Wet Wood Chip	Pellets Dry Wood Chip Wet Wood Chip
Outside Town	Pellets Dry Wood Chip Wet Wood Chip	Wet Wood Chip Pellets Dry Wood Chip	Wet Wood Chip

Green: Preferred Fuel; Yellow: more expensive fuel; Red: Unfeasible

4.8. Auxilaries

4.8.1. Fuel Storage

The fuel storage space should be as close to the boiler as possible to avoid long transfer systems. It should be well ventilated and be fully moisture-proof from the outside.

Another very important point, and one that is often overlooked, is that the storage system should be easy to reach for supply vehicles, so that the delivery time and handling costs can be kept as low as possible.

For wood pellets a simpler storage tank can be used than for wood chips, because wood pellets flow much more easily than wood chips.

The volume of the fuel storage should be adapted to the fuel consumption but also taking into account the delivery costs of the fuel in consideration. For the supplier it will cost about the same to deliver 3 tons of fuel as for 1 tons, meaning that the 1 ton delivery is considerably more expensive per ton delivered. In general, with wood fuels one should not store more than one year’s consumption at any one time. At the end of the heating season one can clean the fuel storage space and then buy fuel well before the season starts again. At that time of the year, fuel tends to be cheaper than at a time when everyone needs fuel supplied.

The fuel storage system of a wood chip burning installation is normally equipped with a forwarding system that delivers the chips to the handling system. This can be either in the form of a type of a walking-floor that pushes the fuel out onto an auger or by a rotary arm under the fuel that pushes the fuel to an auger.

The advantage of a walking-floor system is that it is not as prone to blockages as the rotary system. Since the walking-floor delivers the fuel onto an auger, one can simply open the auger box and remove the blocking oversize particle. In the rotary system, one has to remove all the fuel on top of the auger before one can remove the blockage.

Also, the rotary system is less suitable for rectangular storage tanks, because the arms will leave pillars of fuel in the corners, where the fuel can clump together and be attacked by fungi, because they are a long time in the same place. Cleaning of the fuel storage system is needed at least once a year, ideally before a delivery. Before any storage system is entered or cleaned it must be well ventilated in advance.

4.8.2. Fuel Handling

The objective of the fuel handling system is to transfer the fuel from the storage tank to the boiler in the right quantity at the right time. At the same time it should also act as a separation between the fuel storage area and the boiler, to prevent the fire in the boiler back-burning into the fuel storage area.

For most domestic or commercial boiler systems the transfer of fuel from the storage area to the boiler is carried out by augers, typically a very long screw encased in piping. The diameter of the screw depends on the size and the amount of fuel to be transported. For wood pellets the auger it can be less than for wood chips.

If there are changes in the direction that the fuel has to travel then normally several augers are used. The first one transports the fuel slightly upwards, to that it can drop it onto the next auger that is aligned in another direction. It is important that the size of augers remains the same or increases in diameter from start to finish. If the auger decreases in size, the risk of blockage increases because the first auger may carry particles that are too large for others in the line.

Augers should be accessible and easy to open, so that any blockage can be removed without too much delay.

Longer augers should only be fixed at the end where the motor is attached to the auger. At the other end the auger should rest in a kind of U shaped bed of bronze. The shape of the auger tube should be like a U with a lid.

If a large particle enters the auger, the particle can ride on top of the auger or if it might come under the auger, the auger can lift up to let the oversize particle pass.

To summarize: the fuel handling line should be as short as possible with as few changes of direction as possible. The auger should be adapted in size to the fuel type and the amount that has to be moved to the boiler.

In the fuel feeding system and at a distance from the boiler there should be a sensor that will detect any back burn. If back burn is detected a sprinkler will activate automatically to douse fire. The boiler has to be restarted manually after the wet fuel has been removed. The valve that admits the water should be checked regularly to see if it functions ok, especially that it closes properly after use. If the valve does not close properly, the fuel will get so wet that the fire in the boiler will go out. This is especially the case with wood pellets which swell up when they come in contact with water and will totally block the feeding system.

Another way to avoid any back burn to the storage area is by the use of an air sluice. The fuel is transported upward by the next to last auger and dropped in a box where there is a rotor with four wings. The space between the wings is only open when it passes the top or the bottom of the box, so that the system is air tight when the opening is at the sides of the box. This system prevents eventual back burn to spread to the fuel storage.

4.8.3. Ash Handling Systems

Ash should be carefully handled; it is a highly alkaline material (the pH can be as high as 12) and can cause skin damage, so during handling gloves should be worn at all times.

For the smaller appliances, the ash pan is emptied using a small shovel. Ash should be put in a metal bucket until the last sparks have died out. Thereafter it should be disposed of as waste after careful wrapping. Wood ash contains small amounts of heavy metals that the trees have taken up from the soil during growth. While amounts are small, the ash should not be used as a fertilizer in a kitchen garden or on other areas where plants or animals are grown for human consumption. Wood ash is however suitable as a fertilizer for garden lawns or on flowers and shrubs, or in the forest, where the application of wood ash can compensate for nutrients removed during harvesting of the wood.

Larger appliances are equipped with automatic de-ashing, usually a small auger that transports ash out of the boiler into a container. The ash container is often made of heavy steel so that it does not become deformed by heat if the ash is not totally burned out. The weight of the ash container can be substantial and therefore there needs to sufficient space around the container to empty it. If a larger boiler is situated in the basement of a building one should consider installing a longer auger that can take the ash directly out of the building and into a closed ash container.

Ash has also some cement-like properties, so it will harden when it comes in contact with moisture.

4.9. Comparison of Biofuel Types

Considering the above alternatives utilization-wise priorities of each type of biofuel is following (1-Highest/best, 4-Lowest/worst):

	Wood Chips (wood residue)	Wood Chips (Poultry bedding)	Briquettes	Pellets
Cost of equipment	1	4 (needs special outflow filters)	2	3
Ease of handling fuel (Automatic - Manual Handling)	2	3	4	1
Storage Space required	3	3	2	1
De-Ashing	3	4	2	1
Calorific Value	3	3	2	1

Automatic control of heating	2	2	4	1
Total	14	19	16	8

Based on the above the following conclusions shall be made:

- Assuming cheapest installation is required and there is plenty of space for storage and fuel delivery wood chips is least expensive alternative

- Assuming the priorities are ease of operation, heating quality and ergonomic characteristics of storage and delivery most suitable option is wood pellets

- Assuming difficulties of operation (manual fuel handling) and quality of heating (automatic control of temperature) is not a significant issue most viable option is briquettes

Chapter 5: Integrated analysis of production/utilization

This chapter involves weighing advantages and disadvantages of each fuel type in terms of production and utilization, providing integrated comparison indicating outcomes of selected biomass and fuel type.

Based on conclusions made in pervious chapters most viable biomass types were:

According to production:
- Wood Chips (Poultry Bedding)
- Pellets

According to Utilization:
- Pellets
- Wood Chips (wood residues)

5.1. Pellets

Pellets showed good results in terms of both, therefore it is important to assess its production and utilization according to SWOT analysis.

Strengths:

- Highest resource availability compared to other biofuels (production can use all types of timber including poultry bedding containing wood chips and sanitary cuttings as well as agricultural waste)
- Easy to store and deliver to customers
- Ease of handling fuel (Automatic)
- Smallest Storage Space required
- High calorific value
- Automatic control of heating
- Easy de-ashing
- Low cost conversion of existing gas boilers into pellet boilers

Weakness:

- Quite low availability of ready to use biomass
- Production Establishment Costs
- Multi-stage Processing (drying, hammer-milling, screening etc) required
- Intensified Quality Control

Opportunities

- Potential to export
- Increase of energy costs and fossil fuels

Threats

- Threats to production as biofuel may be imported or sourced regionally (country-wise from regions with large sawmills) by competitors
- Development of new technologies that can substitute use of fuels (heat pumps, solar heaters etc)

5.2. Wood Chips

Wood Chips (of poultry bedding) showed one of the best results in terms of production and wood chips from wood residues appeared second best in terms of utilization, therefore it is important to assess its production and utilization according to SWOT analysis.

Strengths:

- Availability of Biomass
- Availability of ready to use biomass (directly in wood chip burner)
- Low costs of production establishment
- Easy Processing (drying, hammer-milling) into biofuel
- Ease of handling fuel (Automatic)
- Automatic control of heating

Weakness:

- Multi-stage Processing (drying, hammer-milling, screening etc) required
- Transportation of Biofuel due to low density
- Large Storage Space required
- Low calorific value
- Expensive boiler equipment and system

Opportunities

- Development of production into Pellet manufacturing
- Increase of energy costs and fossil fuels
-

Threats

- Risks of supply stoppage (based on small number of sources)
- Number of alternative uses (poultry bedding as a fertilizer, wood chips from sanitary cuttings directly as firewood)

- Development of new technologies that can substitute use of fuels (heat pumps, solar heaters etc)
- New regulations controlling burning of biomass from biofuels from poultry farms (it is currently regulated in many countries of EU)

5.3. Briquettes

Briquettes displayed average results in both production and utilization terms. Its analysis shows that briquettes are either inferior to Pellets or Wood Chips in almost all parameters. In addition this type of biofuel has other shortcomings that include:

- Automatic handling of fuel is only efficient in large industrial boilers, otherwise it needs manual loading
- Control of heating levels is complicated in smaller size boilers
- Briquette production transformation to pellet production is substitute development (unlike wood chip to pellet)
- Low potential for export (due to low demand in developed markets, and really strong competitions in developing countries)

Based on the above briquette production is not best option to be used in municipal buildings (that are not suitable for industrial size boilers).

5.4. Conclusions

Based on assessment of the above SWOT analysis following conclusions can be made:

- Briquette production and utilization is not a feasible option considering the goals of study
- Wood Chip and Pellet production and utilization shall be investigated further
- 2 stage development starting from wood chip production and adding pellet production is a promising opportunity that must be studied further

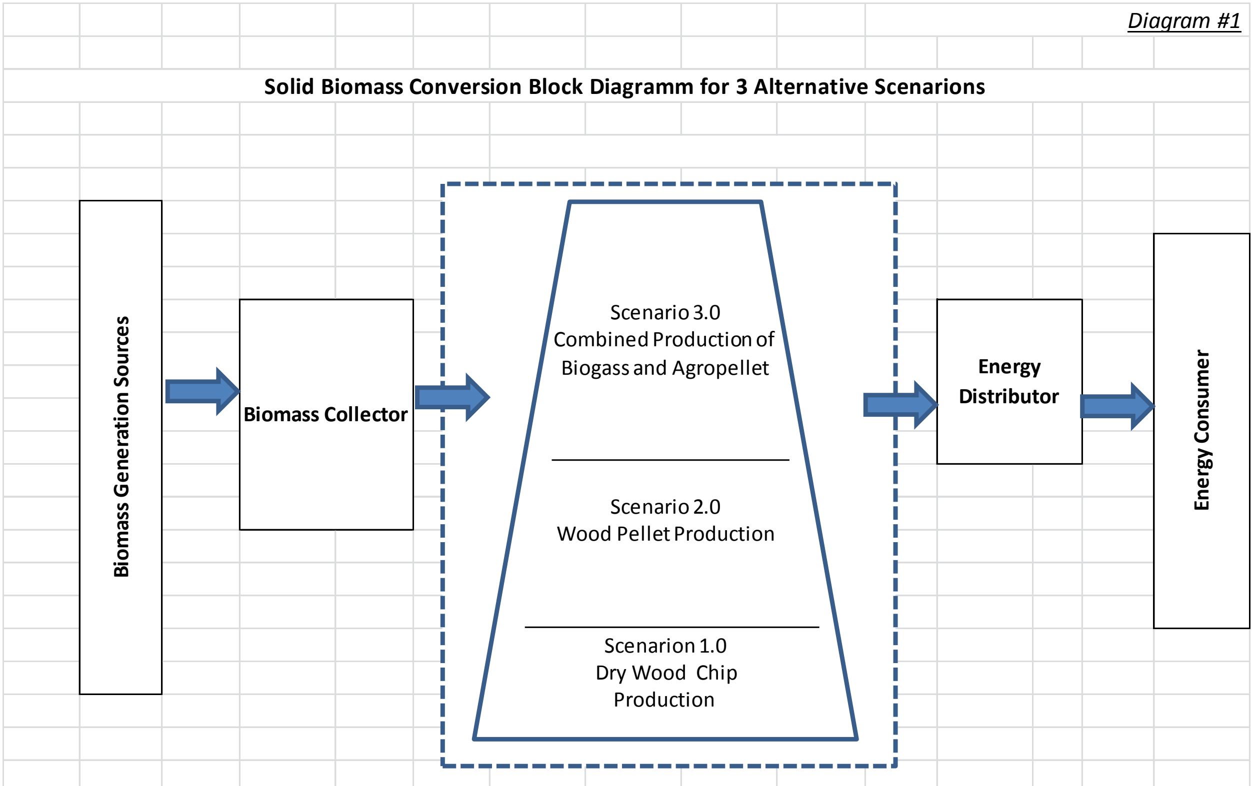
Chapter 6: Production Scenarios

Based on conclusions and recommendations made in previous chapters several types of solid biomass in Tbilisi Municipality were revealed. These are: biomass generated by forestry and Tbilisi National Park sanitary and thinning cutting (40-60cm diameter logs and smaller size residues of softwood and hardwood), solid residues generated by wood processing industry (shavings, sawdust, small pieces of wood) and shavings augmented by manure in poultry farm adjacent to Tbilisi.

As a result of analysis of qualities and location of sources of prevailing types of biomass several scenario of biomass conversion into biofuel can be identified. This chapter will provide general review of these scenarios while next chapter will analyze technical capabilities, volume of consumed energy, projected and existing capacities of municipal buildings of Tbilisi. This will enable matching of qualitative and quantitative parameters of production and consumption and revealing optimal production scenario.

Geographic analysis of biomass shows that establishment of biomass conversion plant is expedient on the detour highway of Tbilisi on the section of Zakhesi-Ponichala road. Production parameters shall be proper to the demands of this geographic area.

Below are presented three scenarios that represent hierarchal pyramid of production development where logical transformation from one scenario to another is achievable. This is accomplished by using same components of production (collection-distribution) while transforming into the next stage of development with the same capacity of required infrastructure (raw material and stock warehouses). See figure 1.



6.1. Scenario 1.0: Wood Chip Production

Wood chip production represents lowest stage of development in the hierarchal pyramid and requires least capital investment. In this case ready products are represented by Wood Chips and Wood Chips augmented by manure. Conversion of this biomass into energy required specific burning cameras. Wood chips with manure require additional equipment to utilize gases generated during burning process.

In case of wood chips its consumer must be equipped with proper technical boiler and silo and should be able to receive and store right amount of biofuel. Therefore for an average size (500 sq. m building) kindergarten establishment of such systems (including boiler and necessary peripheral infrastructure) require capital investment around 10,000 – 30,000 Euro. In addition it is noteworthy that operation of this type of systems requires proper technical supervision and specific conditions of maintenance.

For establishment of wood chip production plant 0.5-0.7 ha of land is required. As for approximate investment capital for a production of 2000 tons annual capacity (such capacity of production is based on the following: easily obtainable/free biomass of this volume is existent considering 5000 m3 of biomass ≈ 200 tons of biofuel) it is around 650-750k Euro. Apart from this efficient collection and distribution systems require additional investment of 200-250 k Euros.

6.2. Scenario 2.0: Wood Pellet Production

Wood pellet production represents second stage development of the hierarchal pyramid. Transportation and storage of this type of fuel is more cost-efficient compared to wood chips, therefore much bigger geographical area can be supplied with pellets.

Conversion of pellets into energy does not require specific boiler and existing gas boilers used for heating can be augmented by a special sub and installation of burning block. In comparison to scenario 1.0 operation of such equipment does not require installation of silo and even 1-2 m^3 bunker would be sufficient.

Wood chips with manure from poultry bedding can be converted into so call agropellet. This product can be used as fuel; however cleaning gases after burning of such fuel require cleaning which as a result leads to increase of cost of generated thermal heating.

Installation of such equipment requires a capital investment (for 500 sq. m. heated area) from 5,000 to 10,000 Euros, which is substantially lower than the scenario 1 budget.

Investment capital required for establishment of production is 20-30% more than in scenario 1 and is estimated at 1.2-1.3 ml Euros.

In case of considering heating of 10 kindergartens total investment cost is 20-25% lower than in scenario 1.

6.3. Scenario 3.0: Combined Production of Biogas and Bio-Pellets

This scenario represents logical development of previous stage. Its implementation will enable generation of most thermal energy. This case is based on chemical transformation of biomass before the mechanical processing aimed at generation gas that will be converted to electrical and thermal energies through co-generation aggregate. Below depiction provides information of all cycles of such production. It is worth to note that there is an extra product for this scenario which is agropellets that can be used as fertilizer for farming activities. Budget of such production is 70% higher than its predecessor and amounts to 1.8-2.0 ml Euros due to high level of energy generation (biogas production and utilization scenarios are illustrated on the diagram).

Cost of production pellets and chips in this scenario is lower by 15-20% compared to previous scenarios due use of self-produced electrical and thermal energy in production of solid biofuels. In addition surplus energy can be sold for profit as well as biogas can be used to shift biomass collection and distribution vehicles from diesel reducing costs further.

Chapter 7: Feasibility Study Report on Wood Fuel Production

The purpose of this chapter is to provide an overview of the feasibility of wood chip production and wood pelletization operation in Tbilisi Municipality. This study was primarily produced from a survey of existing literature and research, a survey of wood milling and pelletizing equipment manufacturers, and localized market survey. Further study will be necessary to fit the needs of particular operation. The reader should be alert to the assumptions made in this report.

The feasibility of a wood chip production and pelletization is dependent upon several assumptions which include the following:

- Manufacturing high quality wood chips and/or pellet which meets European industry standards
- A ten year loan investment
- An interest rate of 12%
- Straight line deprecation over 10 years for equipment and 30 years for building and infrastructure

Other Assumptions are:

1	Currency used for calculation	Euro	Euro was selected due to the fact that major inputs need to be imported and in addition eliminating GEL currency fluctuations at the reporting period – end of 2014
2	Cost of land	100,000	10 euros per sq. m. of land in Gldani-Nazaladevi adjacent to Tbilisi detour road (based on research of offering on makler.ge). It important to note that such production is very specific and in case of rent of land and existing building and infrastructure it will need substantial reconstruction while costs of reconstruction will not be considered by renter as payments, again due to specificity of pellet and wood chips production.
3	Average Cost of collection per ton	10	Euro, with 3 ton truck traveling along the detour road to sources in 5-15 km

4	Co-financing grants	30	% of total capital investment
5	Production Capacity	2	Ton per hour, smaller producers to achieve feasibility are operating only on the wood residues like sawdust and shavings generated in their own production and conversed biofuel is usually utilized in stoves and not in automatic boiler systems due to quality reasons. 2 ton/hour production is minimal size full-scale pellet and wood chip production plant operation (considering differences in biomass input, requirement of dryer etc) with required quality end-product.
6	Production volume	2,000	Tons (easily available biomass that can be obtained without raw material purchase costs – approx. 5000 cubic meters of biomass)
7	Conversion from EUR to GEL	2.41	

7.1. Manufacturing Process

The pellet process involves 6 steps using 6 basic pieces of equipment. These include the following:

1. Primary Grinder (necessary if using slab material)
2. Secondary Grinder (hammermill)
3. Dryer
4. Pellet Mill
5. Cooler
6. Bagging Machine

In addition, a log debarker may be necessary at the beginning og the process to prevent "clinkers" in the pellets with high ash content

In case of wood chip production the process includes only Primary Grinder and Dryer.

In case of pelletizing typically, wood waste must be dried to 10-12% moisture content and then run through a hammermill to produce a maximum particle size smaller than the pellet diameter being produced. The hammermill or grinder, comes in two types: a primary and secondary grinder. The primary grinder reduces large wood pieces, these are further reduced to smaller particles after running through the secondary grinder.

A live bottom bin is necessary for the storage of particles before they enter the pellet machine. Pellet machines have a small mixing chamber. The mixing chamber mixes the material to reduce feedstock variation. The pellet machine compresses the particles to wood pellets. All machines from pellets by forcing the raw material under high pressure through die openings. These opening are the same diameter as the pellets. The addition of a binder material is usually not required to make wood pellets. This is due to lignin in the wood particles. Lignin naturally flows within the pellets when heated and provides the binding material. Several types of pellet machines are on the market, depending on the amount of horsepower needed.

Air is blown through the pellets in the cooler to reduce their temperature and prevent breaking of the pellets. After cooling, the pellets are screened to remove dust and broken pellets.

Bagging is the last step in the process to prepare the product for consumer use.

7.2. Plant investment costs

For purpose of developing this feasibility study, we assumed that a building would need to be constructed to house the pellet producing equipment and provide storage for the final product. We also assumed that in order to produce quality pellets a log debarker must be added to the mill operation. In addition, we assumed that a standard dryer would be needed to reduce moisture content in the wood material used to make pellets. All equipment was assumed to be new. We also assumed that 3 employees would be hired and the only benefit would be worker's compensation. Other costs are estimates and should be carefully analyzed.

Estimated Pellet plant investment costs for an annual 2000 ton production

	Pelletizing Plant	
1	Land purchase	100,000
2	Building and infrastructure	450,000
3	Misc. conveyors	10,000
4	Installation of conveyors	5,000
5	Feed hopper	5,000
6	Installation of feed hopper	3,000
7	Log debarker	65,000
8	Primary Grinder	15,000
9	Installation of primary grinder	10,000
10	Secondary Grinder	20,000
11	Installation of secondary grinder	15,000
12	Dryer, burnenr and air system	140,000
13	Installation of dryer system	75,000
14	Pellet mill	65,000
15	Installation of Pellet mill	55,000
16	Pellet cooler	16,000
17	Installation of pellet cooler	12,000
18	Pellet shaker	10,000
19	Installation of pellet shaker	8,000
20	Bagging bin	3,000

21	Installation of bagging bin	2,000
22	Bagging system	25,000
23	Installation of bagging system	5,000
24	Live bottom bin	12,000
25	Installation of live bottom bin	10,000
26	Collection truck	40,000
27	Forklifts and other loading machines	30,000
28	Distribution vehicles	40,000
	Total	1,246,000

Estimated wood chip plant investment costs for an annual 2000 ton production

	Wood Chip Production Plant	
1	Land purchase	100,000
2	Building and infrastructure	350,000
3	Misc. conveyors	10,000
4	Installation of conveyors	5,000
5	Feed hopper	5,000
6	Installation of feed hopper	3,000
7	Log debarker	65,000
8	Primary Grinder	15,000
9	Installation of primary grinder	10,000
10	Dryer, burnenr and air system	140,000
11	Installation of dryer system	75,000
12	Chip shaker	10,000
13	Installation of chip shaker	8,000
14	Live bottom bin	12,000
15	Installation of live bottom bin	10,000
16	Collection truck	40,000
17	Forklifts and other loading machines	30,000
18	Distribution vehicles	40,000
	Total	928,000

7.3. Raw Material Cost

The wood residue for this operation is assumed to be essentially "free". That is, it is a waste from wood processing industry that needs to be disposed of. Wood chip production and pelletize is an alternative opportunity to dispose of the waste. However this residue needs to be transported to the conversion plant from various sources therefore cost of raw material would be its collection and transportation to the production site.

Based on assessment of geographical distribution of biomass sources transportation average transportation cost per one ton is 10 Euros.

3 ton load capacity truck that moves along detour road for 5-15 km, with 1-2 destinations for collection per trip requires about 30 Euro including loading of biomass to the truck.

7.4. Operation Costs

Annual operating costs are:

Labor		**Pellets**	**Wood Chips**
	Manager	8,400	8,400
	Technician	4,800	4,800
	Warehouse Manager	4,800	4,800
	Operator 1	4,800	4,800
	Operator 2	4,800	-
	Worker 1	3,000	3,000
	Worker 2	3,000	3,000
	Worker 3	3,000	-
	Security	2,400	2,400
	Other	4,000	4,000
	Total	**43,000**	**35,200**
Utilities			
	Electricity	8,631	6,141
	Gas	-	1
	Water	186	130
	Waste disposal	5,975	5,975
		14,792	**12,247**
Maintenance (3% of equipment costs)		**37,380**	**27,840**
	Total	**95,172**	**75,287**

7.5. Administrative, management and sales costs

Annual costs are:

Communication		Pellets	Wood Chips
	Internet	249	249
	Phone	124	124
Administrative Staff			
	Salary	4,800	4,800
	Other	1,200	1,200
Distribution		5,809	11,618

Total		**12,183**	**17,992**

7.6. Loan Payment Schedule

The following calculations assume that the business entity borrows funds for investment in capital costs (minus grant component of 30%). Interest for investment is assumes at 10% for 10 year loan.

Pellet Production

Loan Amount	872,200
Annual Interest Rate	12%
Term of Loan in Years	10
First Payment Date	01-01-15
Frequency of Payment	Monthly

Summary

Rate (per period)	1.000%
Payment (per period)	12,514
Total Payments	1,501,624
Total Interest	629,424

Wood Chip Production

Loan Amount	649,600
Annual Interest Rate	12.00%
Term of Loan in Years	10
First Payment Date	01-01-15
Frequency of Payment	Monthly

Summary

Rate (per period)	1.000%
Payment (per period)	9,320
Total Payments	1,118,385
Total Interest	468,785

7.7. Depreciation costs

Pelletizing Plant

			Annual Depreciation	Depreciation in Years
1	Building and infrastructure	450,000	15,000	30
2	Misc. conveyors	10,000	1,000	10
3	Feed hopper	5,000	500	10
4	Log debarker	65,000	6,500	10
5	Primary Grinder	15,000	1,500	10
6	Secondary Grinder	20,000	2,000	10
7	Dryer, burnenr and air system	140,000	14,000	10
8	Pellet mill	65,000	6,500	10
9	Pellet cooler	16,000	1,600	10
10	Pellet shaker	10,000	1,000	10
11	Bagging bin	3,000	300	10
12	Bagging system	25,000	2,500	10
13	Live bottom bin	12,000	1,200	10
14	Collection truck	40,000	4,000	10
15	Forklifts and other loading machines	30,000	3,000	10
16	Distribution vehicles	40,000	4,000	10
	Total	946,000	**64,600**	

Wood Chip Production Plant

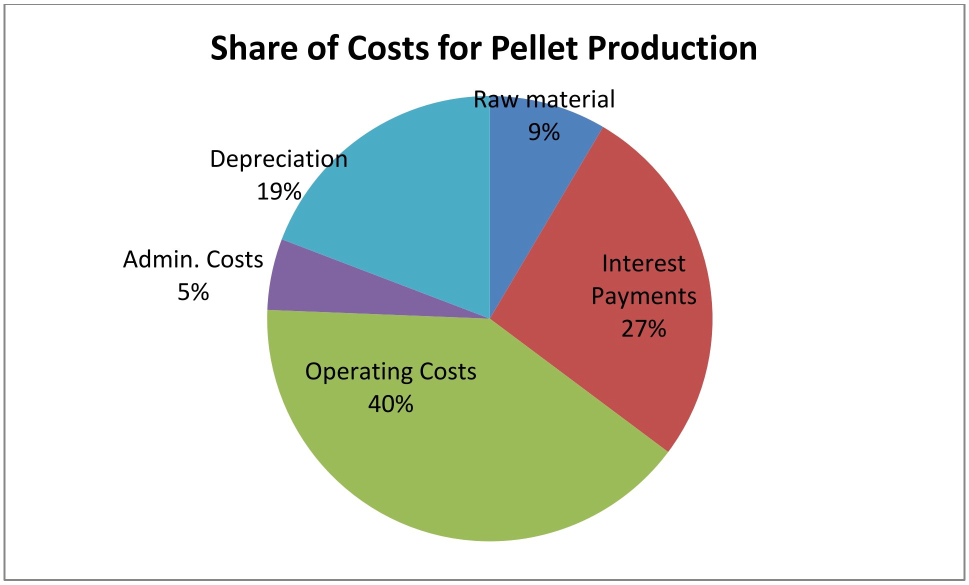
			Annual Depreciation	Depreciation in Years
1	Building and infrastructure	350,000	11,667	30
2	Misc. conveyors	10,000		10

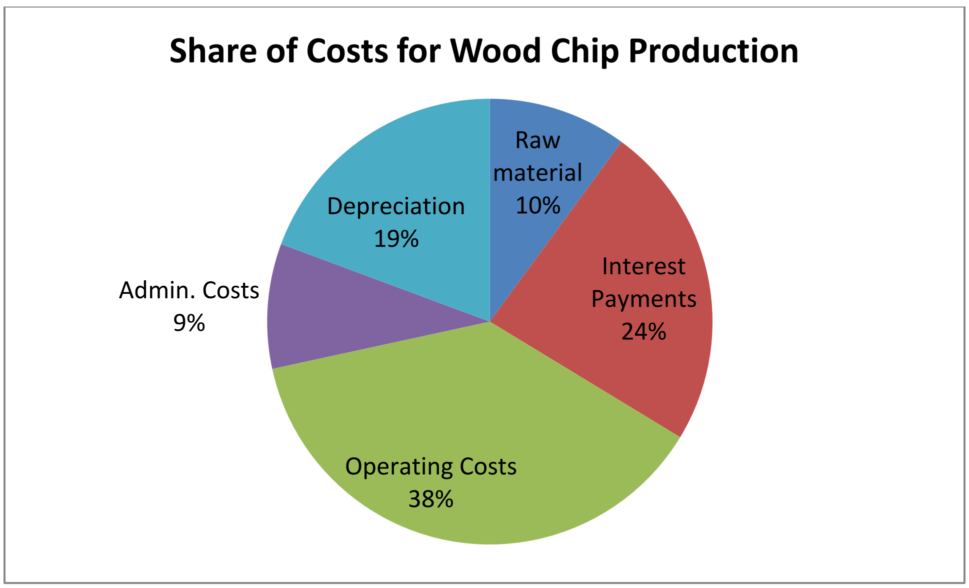
			1,000	
3	Feed hopper	5,000	500	10
4	Log debarker	65,000	6,500	10
5	Primary Grinder	15,000	1,500	10
6	Dryer, burnenr and air system	140,000	14,000	10
7	Pellet mill	65,000	6,500	10
8	Chip shaker	10,000	1,000	10
9	Live bottom bin	12,000	1,200	10
10	Collection truck	40,000	4,000	10
11	Forklifts and other loading machines	30,000	3,000	10
12	Distribution vehicles	40,000	4,000	10
	Total	782,000	**54,867**	

7.8. Total Annual Costs for 2000 ton Production

	Pellets	**Wood Chips**
Raw material	20,000	20,000
Interest Payments	62,942	46,878
Operating Costs	95,172	75,287
Admin. Costs	12,183	17,992
Depreciation	64,600	54,867
Correction of Depreciation*	(19,380)	(16,460)
	235,516	**215,024**
Cost per ton	**106.81**	**96.62**

*Correction of depreciation involves reduction of depreciation by the amount of grant share in this case by 20%, as these will not be direct cost per production.





The above charts show that approximately 50% of cost per ton of pellets or chips is generated by capital investment (depreciation) and interest payment to cover loan for capital investment. Therefore cost structure is heavily affected by the costs of establishing of production.

7.9. Analysis in comparison to Natural Gas

The below table provides comparison of biofuel to natural gas supplied in Tbilisi. To provide correct comparison each type of fuel is assessed in terms of its calorific value and cost of one MJ for each type.

In addition for illustration purposes average gas consumption of a typical kindergarten in Tbilisi is provided and then converted into cost for each type of fuel.

	Calorific Value MJ/m3/kg	Cost in Eur		Cost of MJ	Av. Consumption of gas per Kindergarten in m3	Equivalent in MJ	Equivalent in kg	Cost in Eur	Cost in GEL
Gas	38.1	0.19	m3	0.005009747226	15,000	571,500.00		6,900.00	2,863.07
Pellets	17	0.11	kg	0.006283161791			33,617.65	9,540.60	3,590.83
Wood Chips	14.7	0.10	kg	0.006572653938			38,877.55	10,073.33	3,756.27

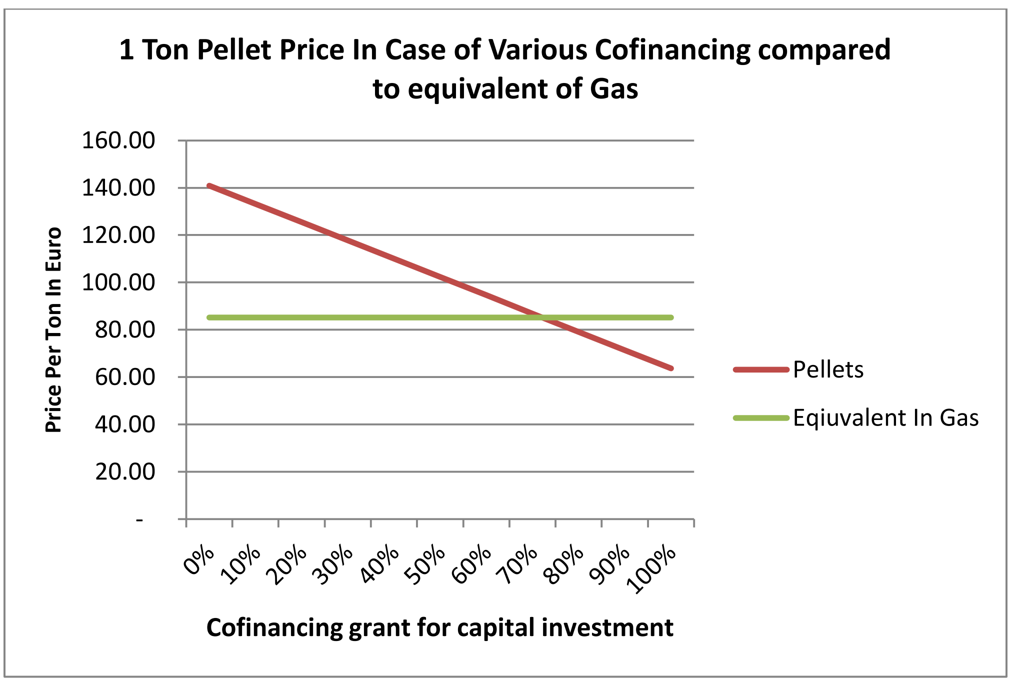
The above analysis shows that price for MJ of each type of biofuel is higher than of natural gas. Considering the fact the above calculation do not involve profit margin production will not be able to compete with natural gas making it unfeasible.

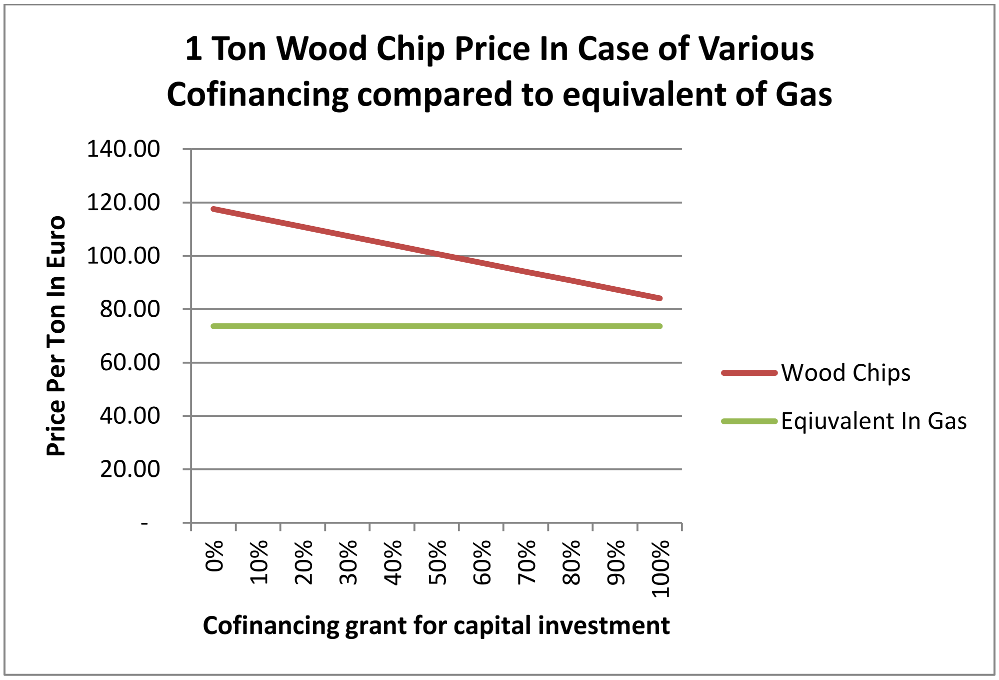
7.10. Cost Analysis with Significant Mitigation Measures

Considering the unsatisfying results of the above cost analysis below is given a feasibility assessment in case heavy mitigation measures are available to the project.

First mitigation measure to include in the project is capital investment co-financing grant. The cost per ton of pellets or wood chips in case of (0-100%) and its comparison to cost of gas to produce the same amount of MJ is given below:

Co-financing grant component	Pellets cost per ton	Equivalent In Gas	Wood Chips cost per ton	Equivalent In Gas
0%	140.94	85.17	117.56	73.64
10%	133.21	85.17	114.21	73.64
20%	125.48	85.17	110.86	73.64
30%	117.76	85.17	107.51	73.64
40%	110.03	85.17	104.16	73.64
50%	102.31	85.17	100.82	73.64
60%	94.58	85.17	97.47	73.64
70%	86.85	85.17	94.12	73.64
80%	79.13	85.17	90.77	73.64
90%	71.40	85.17	87.42	73.64
100%	63.68	85.17	84.07	73.64

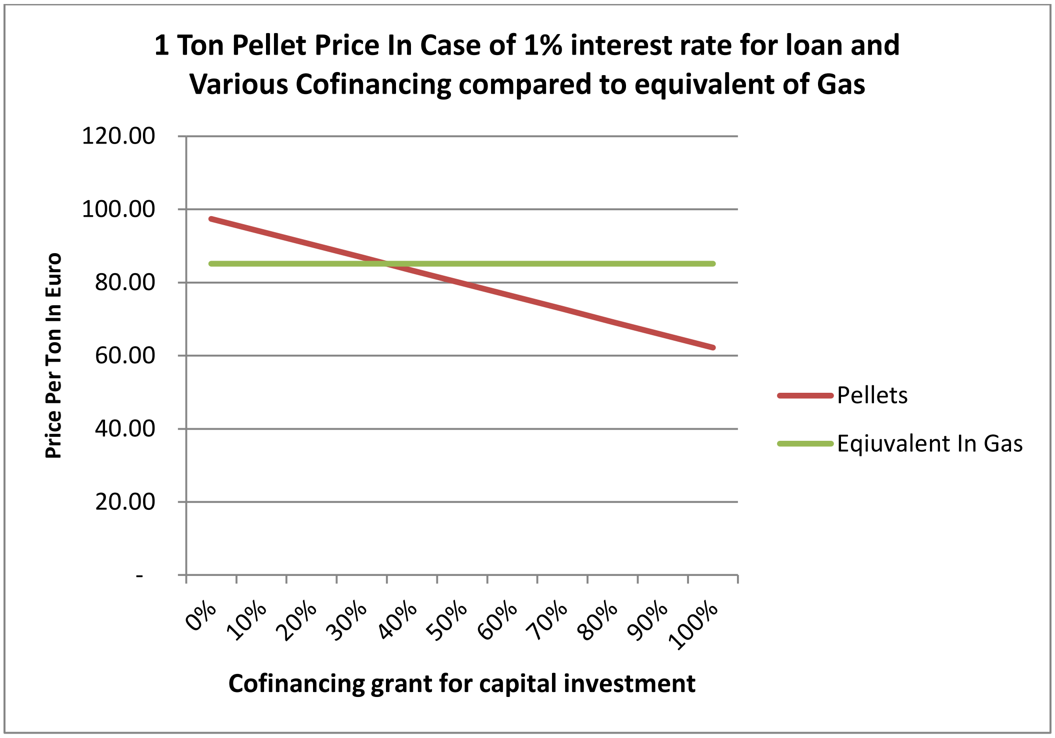


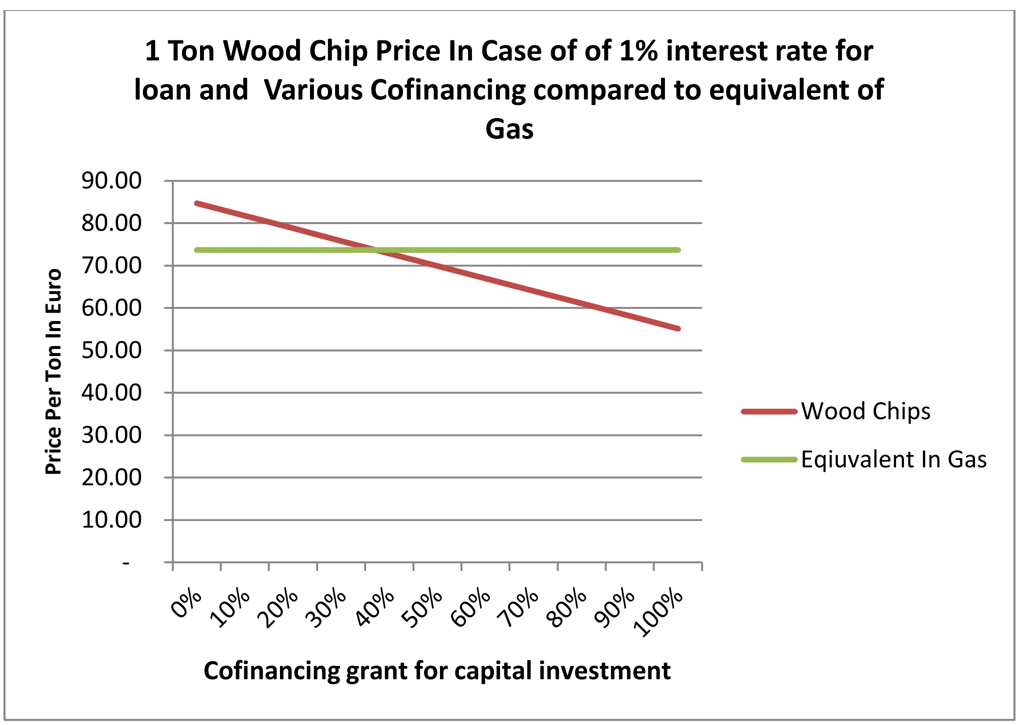


The above charts shove that cost of pellet production reaches gas cost at 80% co-financing grant component, while in case wood chips even 100% co-financing grant will not enable wood chip produced heat to be lower than that of natural gas.

Additional mitigation measure that can be included in the production establishment is lowering of interest rate for capital investments (there are number of funds like Energy Credit, state fund, NAMA and other). In case of donor organization covering 11% of interest and only 1% covered by production cost per ton would be:

Co-financing	Pellets cost per ton	Equivalent In Gas	Wood Chips	Equivalent In Gas
0%	97.41	85.17	84.69	73.64
10%	93.89	85.17	81.74	73.64
20%	90.37	85.17	78.78	73.64
30%	86.84	85.17	75.83	73.64
40%	83.32	85.17	72.87	73.64
50%	79.80	85.17	69.92	73.64
60%	76.27	85.17	66.96	73.64
70%	72.75	85.17	64.01	73.64
80%	69.22	85.17	61.05	73.64
90%	65.70	85.17	58.09	73.64
100%	62.18	85.17	55.14	73.64


1 Ton Pellet Price In Case of 1% interest rate for loan and Various Cofinancing compared to equivalent of Gas
120.00
100.00
80.00
60.00
40.00
20.00
-
Price Per Ton In Euro
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Cofinancing grant for capital investment
Pellets
Eqiuvalent In Gas

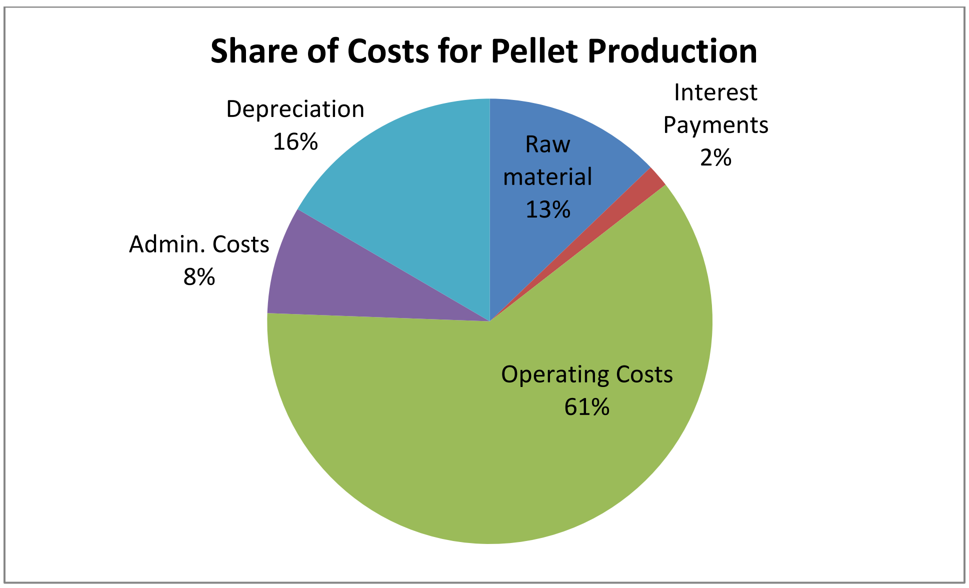

1 Ton Wood Chip Price In Case of of 1% interest rate for loan and Various Cofinancing compared to equivalent of Gas
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
-
Price Per Ton In Euro
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Cofinancing grant for capital investment
Wood Chips
Eqiuvalent In Gas

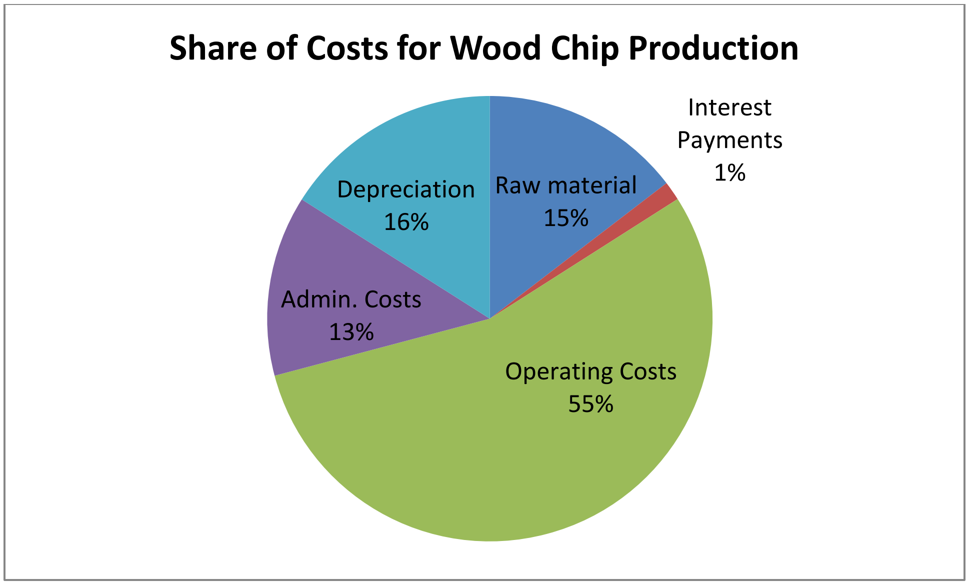
In case of interest rate coverage by energy-credit pellet production is lower than of gas equivalent in case of 40% co-financing grant component. For wood chips it is estimated at below 40%.

In this case Cost structure would be:

	Pellets	**Wood Chips**
Raw material	20,000	20,000
Interest Payments	3,831	2,854
Operating Costs	95,172	75,287
Admin. Costs	12,183	17,992
Depreciation	64,600	54,867
Correction of Depreciation	(25,840)	(21,947)
	169,946	**149,052**
Cost per ton	**84.97**	**74.53**

Such cost structure would significantly decrease share of capital costs (depreciation) and interest payment in total costs per biofuel, as illustrated below:





Considering the fact that the above production does not include income for the producer the below assessment is made at 60% grant component and 1% interest rate.

The analysis of cost comparison shows that mitigation measures enable pellet and chip production to compete with natural gas.

In case of 9% and 7% profit add-on on cost of pellet and chips respectively, the price of 1000 MJ would be:

	Price for 1000 MJ
Gas (no profit)	5.0097
Pellets (9% add-on)	4.9931
Wood Chips (7% add-on)	4.9907

Based on the calorific values 2000 tons of each type of biofuel would produce approximately the below amount of energy.

Pellets	34,000,000	MJ
Wood Chips	29,400,000	MJ

In this case use of biofuels would provide the following annual savings based on total amount of MJ available by Pellets and Chips:

	Price for 34 ml MJ in Eur
Gas	170,331
Pellets	169,766
Savings	565.67

	Price for 29.4 ml MJ
Gas	147,287
Chips	146,727
Savings	559.67

It is important to note that 2000 tons of biofuel could supply heat to approximate 59 kindergartens in case of pellets and 51 in case of wood chips.

The profits for production would be:

	Pellets		Wood Chips	
	Euro	Total Euro	Euro	Total Euro
Sales	84.88	169,765.73	73.36	146,726.90
Cost	76.27	152,543.38	66.96	133,922.94
Profit	8.61	17,222.35	6.40	12,803.96

These calculations show that 2000 ton production is heavily influenced by operation costs and taking into consideration that calculations do not include VAT and income taxes such production can not be operated as a business entity but a state company.

7.11. Cost Analysis for 4000 ton Production

The cost analysis for 4000 ton production is based on the assumption that almost half of woody biomass generated in Tbilisi and surroundings (including not available for sale biomass by Wood Processing Industry, firewood distributed to populace by Tbilisi City Hall, Forestry and National Park).

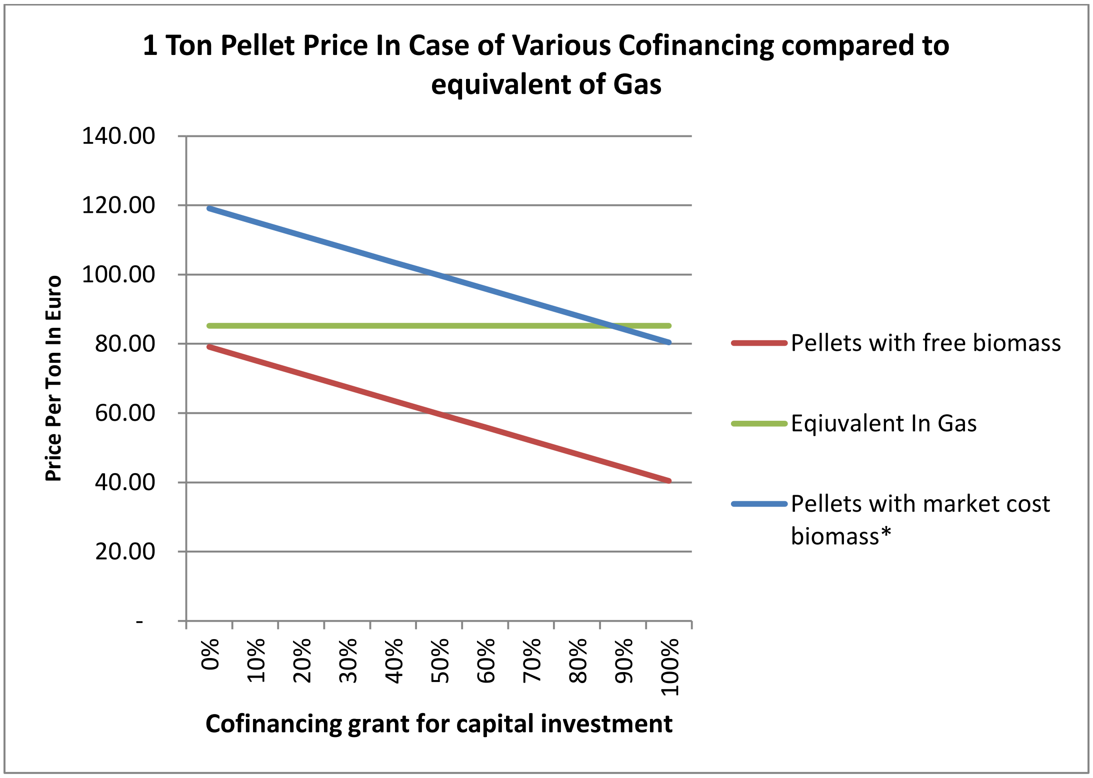
For ease of comparison with other scenarios assumptions remain same as in 2000 ton production.

1	Currency used for calculation	Euro	Euro was selected due to the fact that major inputs need to be imported and in addition eliminating GEL currency fluctuations at the reporting period – end of 2014
2	Cost of land	100,000	10 euros per sq. m. of land in Gldani-Nazaladevi adjacent to Tbilisi detour road (based on research of offering on makler.ge)
3	Average Cost of collection per ton	10	Euro, with 3 ton truck traveling along the detour road to sources in 5-15 km
4	Co-financing grants	0	% of total capital investment
5	Production Capacity	2	Ton per hour
6	Production volume	4,000	Tons
7	Conversion from EUR to GEL	2.41	

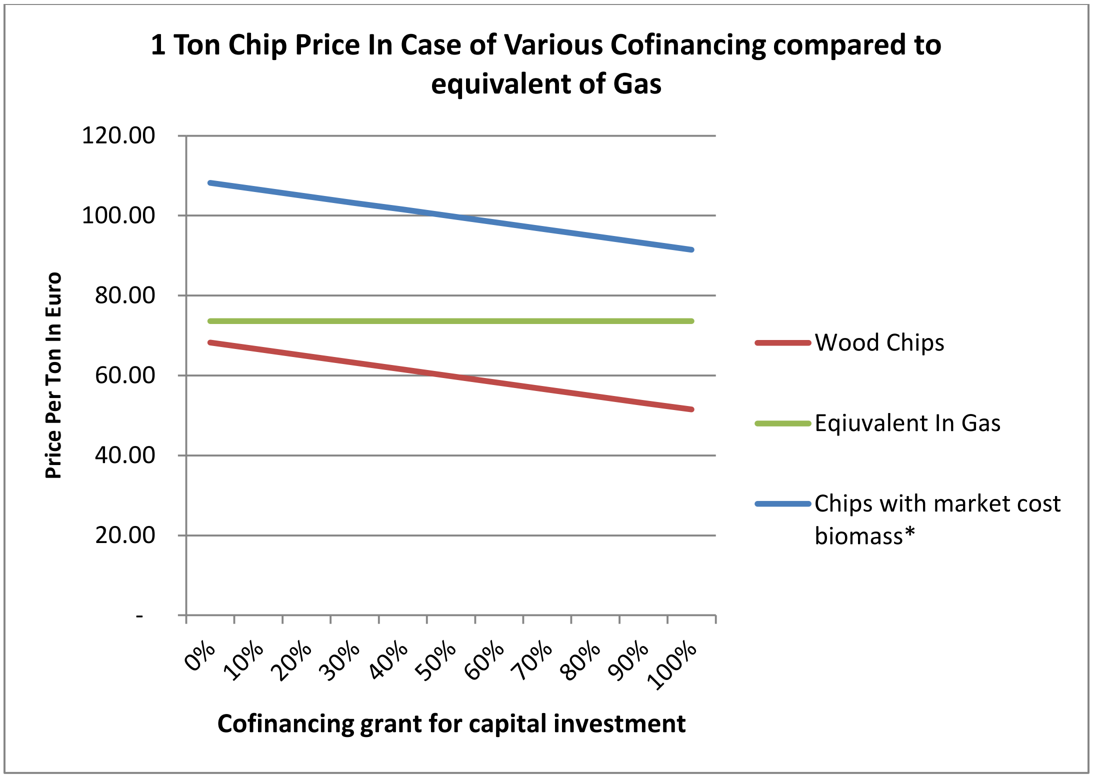
In this case personnel and management costs would remain the same as in case of 2000 ton production therefore heavily decreasing share of operating expenses in the cost structure. Below is comparison of cost to gas equivalent.

Co-financing	Pellets	Equivalent In Gas	Wood Chips	Equivalent In Gas
0%	79.08	85.17	68.22	73.64
10%	75.21	85.17	66.54	73.64
20%	71.35	85.17	64.87	73.64
30%	67.49	85.17	63.20	73.64
40%	63.63	85.17	61.52	73.64
50%	59.76	85.17	59.85	73.64
60%	55.90	85.17	58.17	73.64
70%	52.04	85.17	56.50	73.64
80%	48.17	85.17	54.82	73.64
90%	44.31	85.17	53.15	73.64

100%	40.45	85.17	51.48	73.64



* Market cost (Pellets with market cost biomass) is based on the fact that 2000 tons area obtained for no price while remaining 2000 tons are purchased for market price of 80 euro per ton.



* Market cost (Chips with market cost biomass) is based on the fact that 2000 tons area obtained for no price while remaining 2000 tons are purchased for market price of 80 euro per ton.

Volume of such production would approximately satisfy heating needs of more than 100 kindergartens; however there will be a shortage of available inexpensive supplies and production will have to purchase biomass from sources like firewood supplied to local populace. In this case leading to increased cost (cost of firewood logs per cubic m. is approximately 80 GEL, that would be 80 Euros per ton). This mean no matter the share of grant component purchase of the firewood will lead to losses. Therefore the only chance of operating the production at profitable level would be obtaining biomass for free or close to 10-20 Euro per ton.

It is important to note that selling Price per ton in Various European countries (Italy 200-227 Euros; Germany 185-230; Ukraine 130-170 Euros; Austria 140-240; Russia 100-190; Turkey 100-180 - the price range depends on quality of pellets as well as type of sale (bulk ex-works to bagged retail) and VAT in the specific country) is cheaper source of energy than natural gas. Therefore efficient supply of pellets and/or wood chips to any of the buildings in the municipality of Tbilisi or elsewhere in Georgia where natural gas is supplied is only an option if biomass resources are free to the production.

Economic indicators for 4000 ton annual production (with free biomass, no income and VAT taxes, and selling price equal to equivalent of gas) of pellets and wood chips with 10% discount rate are following:

		NPV	IRR
0% Mitigation	Pellets	(996,703)	-44.5%
	Chips	(722,427)	-42.6%
10% Mitigation	Pellets	(797,117)	-37.7%
	Chips	(600,654)	-38.2%
20% Mitigation	Pellets	(597,531)	-31.8%
	Chips	(478,882)	-34.0%
30% Mitigation	Pellets	(397,945)	-25.9%
	Chips	(357,109)	-29.6%
40% Mitigation	Pellets	(198,359)	-19.6%
	Chips	(235,337)	-24.7%
50% Mitigation	Pellets	1,227	-12.2%
	Chips	(113,564)	-19.0%
60% Mitigation	Pellets	200,813	-2.7%
	Chips	8,208	-11.7%
70% Mitigation	Pellets	400,398	11.2%
	Chips	129,981	-1.3%

Chapter 8: Prospects of Supplying Kindergartens in Tbilisi Municipality with Biofuel, Technical and Economic Analysis and Review of Legal basis for regulation of preschool education

After analysis of buildings subordinated to Tbilisi Municipality and consulting with Economic Affairs Department of Tbilisi City Hall it was identified that the only category of municipal buildings that can be supplied with thermal energy produced by biofuel is Kindergartens. Study involved feasibility assessment of operation of heating system of pre-school education establishments on wood pellets and chips. Below chapter provides analysis of opportunities related to switching the aforementioned buildings to biofuel, legal barriers and technological aspects, as well as technical and economic analysis.

8.1. Review of Legal basis for Regulation of Preschool Education

The goal of this short analysis is to review Georgian legislation in the sphere of preschool education, including kindergarten management, procurement process etc.

Currently there are no separate legislative regulations fully covering legal issues concerning public kindergartens. Despite the fact that according to the article 35 of the Constitution of Georgia “The state guarantees pre-school education in the way, prescribed by law” , there is no law on preschool education in Georgia at the moment.

As a result of local self-governance reform carried out in 2006, preschool education has become the sphere of exclusive responsibility of local municipalities. Accordingly, the issues of arrangement, management and financing of kindergartens are regulated by the local self-governance legislation.

According to the Georgian Law on General Education, article 30, subparagraph j1, local self-governance: “founds preschool care, extracurricular educational and child care establishments as natural and legal non-commercial persons of private law". Besides, from the end of 2012, the Office for Preschool Education was created at the Georgian Ministry for Education and Science .

Article 16 subparagraph I of the Local Self-Governance Code adopted in 2014 defines that the jurisdiction of local self-governance is “to create preschool educational establishments under the municipality management and to provide for their functioning”.

Article 93, subparagraph 4, of the same law states that "it is prohibited to introduce any kind of payment for education, care or catering in public preschool establishments managed by municipalities and located in their area". Accordingly, service by municipal kindergartens is free of charge.

For full review of the legislative norms it should be mentioned that he draft Law on Early Childhood and Preschool Education has been prepared. Its preparation started on the initiative of the Parliament of Georgia in December 2013. The preparation of the draft law is supported by the UNICEF. Also with support of UNICEF the Ministry of the Education and Science is working out a policy and national structure of school readiness education for five-year old children.

8.2. Management systems of kindergartens and day nurseries

In order to provide effective functioning of kindergarten management system self-governance bodies have created non-commercial legal persons – kindergarten unions – main goals of which are following:

- To provide realization of preschool education management policy and internal monitoring;
- To provide sustainable quality of preschool establishments services;
- To provide financial monitoring of preschool establishments;
- To support the process of professional development of preschool establishment employees;
- To support the process of inclusive education in preschool establishments;
- To assist coordinated work of governmental and non-governmental organizations in the sphere of child welfare etc.

On June 27 2011 the government of Tbilisi by decree N 16.67.710 founded the Agency for Management of Tbilisi Kindergartens. The agency is registered as non-commercial, non-profit legal person.

The work of the agency is diverse. According to the statute, its main goals are:

1. To provide realization of preschool management policy approved by the Mayor's Office of Tbilisi and internal monitoring;
2. To provide sustainable quality of preschool establishment services;
3. To carry out financial monitoring of preschool establishments;
4. To support the process of professional development of preschool establishment employees;
5. To support the process of inclusive education in preschool establishments;

6. To assist coordinated work of governmental and non-governmental organizations in the sphere of child welfare

At the moment the agency manages about 160 kindergartens. Its budget exceeds 60 million GEL.

8.3. The rules for arrangement and equipment of kindergartens

In the process of discussing norms of arrangement and equipment of kindergartens, three legislative documents require attention. One of them, the Decree N308/n, year 2001, by the Minister of Labor, Health and Social Protection of Georgia "On Approval of Sanitary Regulations and Norms of Arrangement, Equipment and Working Regime of Preschool and Secondary Education Establishments", regulates following directions of the sphere of preschool care:

- Requirements, concerning plot of land;
- Requirements, concerning buildings;
- Requirements, concerning natural and artificial lighting;
- Recommendations, concerning artificial lighting of preschool establishment buildings;
- Requirements, concerning sanitary and technical arrangement;
- Requirements concerning storage facilities;
- Requirements, concerning sanitary conditions of storage facilities and surrounding area (plot of land);
- Requirements, concerning heating and air quality;
- Requirements, concerning equipment of catering block, food storage and cooking;
- Private hygiene of the personnel;
- Requirements, concerning rules of admission to the preschool establishment;
- Requirements, concerning regime and organization of lessons;
- Requirements, concerning organization of catering;
- Requirements, concerning physical education;
- Types and forms of physical education lessons;
- Requirements, concerning hygienic education of children of preschool age;

- Responsibility for following sanitary regulations.

Second, municipal resolutions on approval of regulations and working regime of united system of preschool establishments, which were passed by municipalities in accordance with legislative changes carried out in 2013.

Third, Decree N78 by the Government of Georgia "On Approval of Technical Regulations and Sanitary Rules and Norms of Catering in Preschool Education Establishments", which, in order to assist protection of child health and in accordance with the article 70 of the Law on Health Care, as well as due to article 103 of the Code on Safety and Free Movement of Goods and article 25 of the Law on Normative Acts, prescribes general requirements to preschool establishments of any organizational and legal form and type.

According to this decree, some parts of the above mentioned one, passed by the Minister of Labor, Health and Social Protection in 2001 are not valid any more, but not all of them.

The absolute majority of technical regulations make main accent on sanitary and hygienic issues. Only the ministry decree from 2001 mentions heating systems. In particular, paragraph 7 of article 8 states that "Buildings of preschool establishments must have central heating and ventilation systems. In agricultural settlements in establishments for not more than 50 persons stoves can be used, but they must shut hermetically. The heating must be switched on 1.5-2 hours before arrival of children. Special committee must check safety of the stoves at least twice a year. For safety of the children it is recommended to have the heating equipment fenced in."

8.4. Financing and procurement

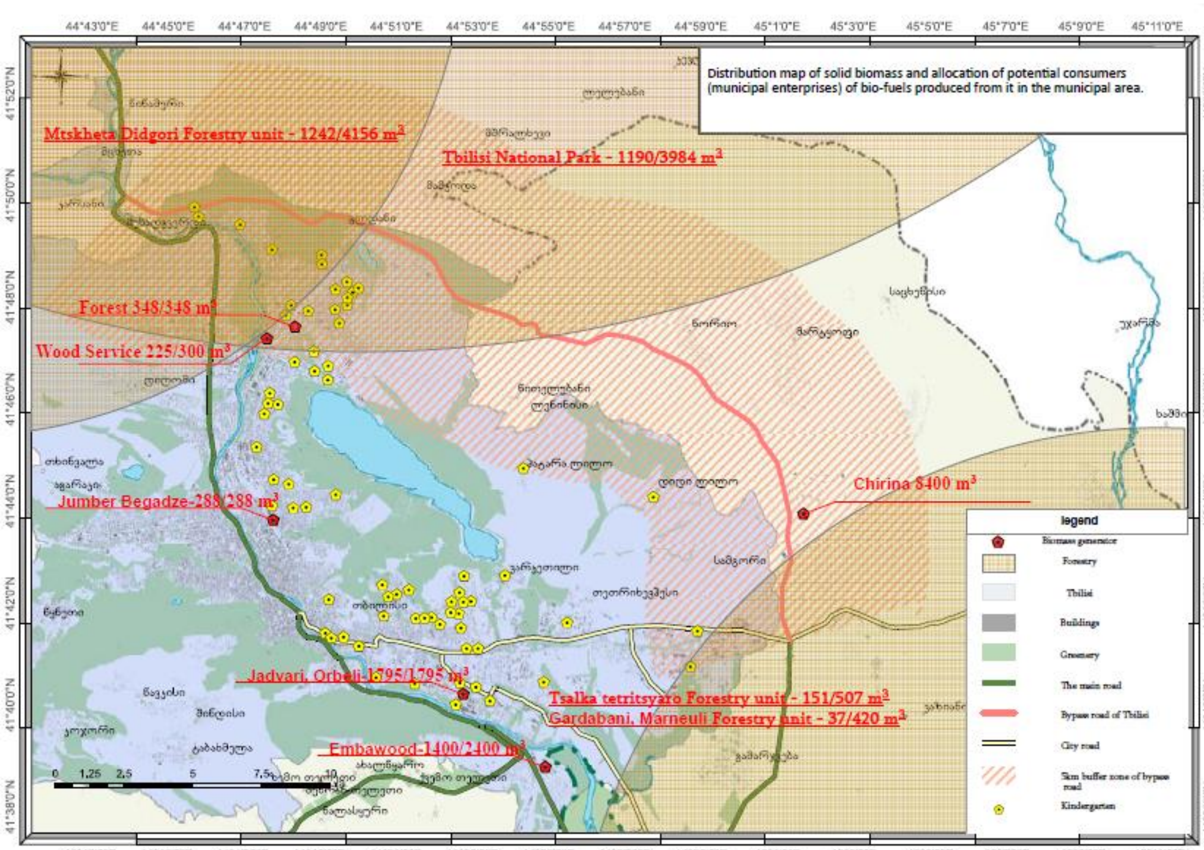
The detailed activities and responsibilities of the kindergarten management agency do not include necessary state procurement for kindergartens and, according to existing practice, kindergartens themselves do not declare public tenders for purchase of goods, services or construction work. This procurement is provided by local self-governance bodies, in case of Tbilisi – Mayor's Office of Tbilisi.

According to existing practice, financing of Tbilisi kindergartens is done through so called "voucher" system. This means that an amount of money is allotted to every child going to a municipal kindergarten and any kindergarten receives financing based on number of children going there. In the beginning of each month administration of a kindergarten submits to the agency accounts according to the needs for the month. Usually this includes salaries, catering expenses, facilities (water, heating, electricity, cleaning) expenses, hygienic equipment, toys, office equipment and other expenses. Often the requested amount exceeds the amount included by voucher (approximately, by 5-10%). After the money is received, kindergarten pays to providers. The purchases are made either from the provider named by the agency, or, in case of cheaper price, the kindergarten can choose one itself.

Currently no kindergarten or other similar establishment in Tbilisi has heating equipment that uses biomass fuel. As to purchasing the fuel and/or special heating equipment, we find no specific limitations or prohibitions in the existing legislation, though the main risk factor is that kindergartens may refuse to use biomass fuel. To solve this problem the persons participating in the project should do everything possible to interest them and to support future use of the fuel. As to the purchase itself, it can be done through tender by the Mayor's Office of Tbilisi (in case of several kindergartens) as well as by kindergartens themselves. This depends on price and amount of the goods.

8.5. Technical Description of Kindergartens

There are 159 preschool education establishments subordinated by Tbilisi Municipality that are scattered around Tbilisi. Below illustrational map provides geographical distribution of kindergartens and biomass sources. Map analysis indicates that optimal location for biomass conversion so that it is close to biofuel utilization would be area adjacent to a detour road of Tbilisi connecting Avchala-Ponichala. 22 kindergartens by its location and technical parameters are adequate for utilization of wood chips. While the rest of establishments are assumed to be pellet utilization entities.



Buildings of kindergartens are constructed with reinforced concrete, belong to low level energy-efficiency group and almost all of them require envelope insulation. Major part of kindergartens is 2 story, with heating area ranging from 1500 to 2500 sq. m. Buildings are 30-40 old, some of them heavily depreciated. Some share of kindergarten buildings have been renovated over the last 3-4 year period and are equipped with natural gas boilers, with capacity of 350-950 kW. Inside network of heating system is designed uneconomically and according to managers of the kindergartens it is impossible to control thermal consumption in various rooms independently. Therefore thermal consumption for 1 sq. m. of area varies from 150-200 W. It is necessary to increase energy-efficiency of these buildings and reduce heating consumption per sq. m. to 40-50 W.

As shown in the below study only if energy-efficiency is increased by substantial level it would be feasible to utilize biofuel for heating of these establishment.

8.6. Technical and Economic Assessment of Equipping Kindergartens with Biofuel Boilers

This Study represents a concept for conversion to biomass of existing heating supply system of the public kindergarten #107 in Tbilisi. It is expected that the approach applied and design solutions proposed will be replicable to similar objects in Tbilisi.

The scope of the Study includes:

- Evaluation of thermal energy demand
- Definition of the principal project concept
- Description of the main equipment components and their dimensioning
- Options for reducing environmental impacts.
- Possibilities for combining various sources of energy to optimize economic effects are reviews.

This report is considered as a basis for the City of Tbilisi for deciding if installation of biomass-fired boiler is feasible for providing heating and hot water services in kindergartens of Tbilisi. In addition, its provisions and recommendations could be used by the City of Tbilisi to apply for financial support for the project development and implementation to UNDP and other donors.

8.6.1. Baseline situation

Kindergarten #107 has been selected as a demonstration site. It is located in Gldani VI microdistrict. This is a 2-storey concrete building constructed in 1977. It serves as many as 386 persons from September to July. The kindergarten is open on Mon-Fri , from 9.00 – 16.00.

Total heated area is 1248 m^2

Heating supply is at present arranged from a gas-fired boiler, which is located in a separate building. The boiler is manufactured in 2007 and has an installed capacity of 950 kW.

Thermal energy is used for heating the radiators only. Hot water is provided by electric heaters.

There is no metering of heating energy supplied, however gas consumption is measured monthly. The following assumptions have been used for deducting thermal energy supply:

- 2013 monthly reports natural gas consumption
- Adjustment factor to consider cooking stoves – natural gas consumption in May;
- Natural gas conversion factor – 9,4 – 9,9 kWh/m^3
- Efficiency of present gas fired boiler, including eventual net losses – 85%

8.6.2. Energy Demand

Assuming energy demand is a starting point for preparation of the project concept. It is important to assess how much energy is needed.

With the reference to gas consumption records available one can assume the following basis requirements for the energy conversion project:

Working hours, apprx.	:	1000 hrs
Thermal Energy produced	:	105 MWh
Maximum energy demand, capacity	:	300 KW

With the reference to available data, we can assume total domestic hot water demand in the kindergarten # 107:

Number of persons	:	386
Norm per person, l/day	:	25 (reference: Azerbaijan Renewable Energy Agency)
Hot water requirement, l/day	:	9 650
Hot Water requirement, KW/day	:	448 kW (assuming standard temperature of potable and domestic hot water)
Assumed hot water demand, kW/hr	:	50 kW

Assuming that the new system will integrate both heating and domestic hot water, we can iterate :

Working hours, apprx.	:	2300 hrs
Total thermal energy produced	:	215 MWh
Maximum energy demand, capacity	:	350 kW

8.6.3. Energy Duration Curve

While domestic hot water demand is more or less stable, the energy demand for heating is not stable. Energy consumption in winter periods represents energy being used both for heating and domestic hot water. Energy consumption in summer periods represents domestic hot water consumption only.

The figure below shows the assumed variation in total thermal energy demand:

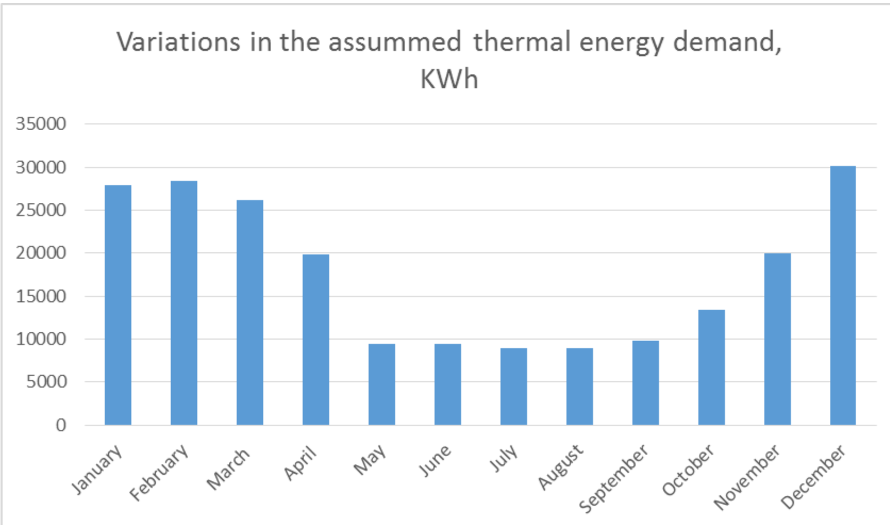


Figure 2: Variations in the assumed thermal energy demand, KWh

When dimensioning heating systems it is a common practice to separate between peak and base loads. Peak loads are normal for short periods in winter time, while base load – summer time. Since efficiency of heating system depends on load of equipment, it is important to receive a true picture of the thermal heating demand.

Normally this is done with using an Energy duration curve, which indicates measured number hours with a specific thermal energy demand (or, % of peak load).

Owing to current gas metering practices, such information is not available for the Study. However, the Consultant has decided to show an example of such curve from its own experience, see below.

The example shows that a boiler will only work very short time at its max. capacity. 90% of the time the heating load will be 60% or less of the peak load.

That means that a boiler sized to cover peak energy demand would most of the time operate at low, below 50% capacity. A boiler sized at 50% of peak load is able to cover heating load during at least 80%

of time. However such a boiler will operate at approximately 40% of the time at less than 50% of load factor, i.e. with suboptimal operational conditions.

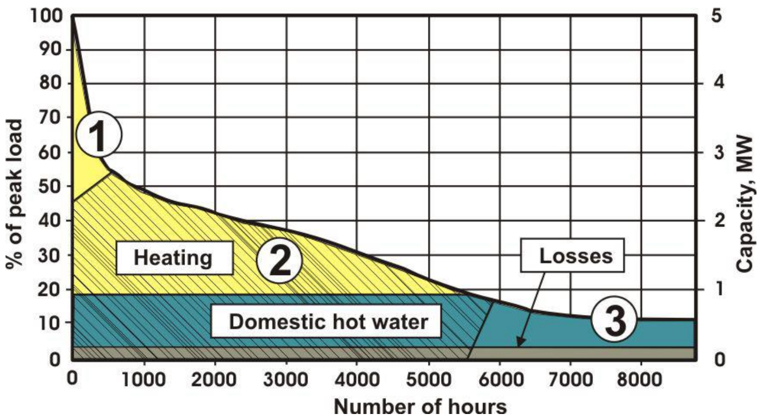


Figure 3: Typical Energy duration curve for a boiler serving public buildings

8.6.4. Type of solid biomass available

The type of boiler and its auxiliary equipment are also dependant on the type of biomass to be used, its properties and economy.

Resulting from the Fuel study, 3 optional sources of fuel are considered:

- Wood pellets
- Wood chips, low moisture content
- Blend of wood chips and manure from poultry farms

The latter cannot be considered as a suitable and safe fuel source for biomass boilers. High alkali content and high content of fine particles, makes operation and maintenance of a biomass boiler challenging. For such type of organic fuel, special boiler technologies suited for combustion of household garbage are used, like fluidized bed furnaces. However, given the size of the system in consideration, such boiler technologies are not feasible. The most suitable way to handle a blend of wood chips and manure from poultry farms is its digestion in biogas reactors.

Therefore, the present Study considers only:

- Wood pellets, heating value – 4,72 MWh/ton
- Dry wood chips, heating value – 4,08 MWh/ton

As mentioned both sources of fuel would have low water content.

Many associate wood chip quality with moisture content, but the quality of the fuel depends on things other than the moisture.

The main factors that control biomass quality is ash ratio and proportion of fine particles. Both of these are independent of the moisture of the fuel, i.e. if the ash percentage is high and the proportion of fines is high, drying will not improve the quality of the biomass significantly.

The following qualities of the proposed fuels could be considered as appropriate:

- Normal moisture - 20- 30% of the total weight
- Maximum content of particles <3 mm - 10% of of the total weight
- Bulk density, pellets - 650 kg/m^3
- Bulk density, woodchips - 270 kg/m^3
- Content of woodchip>100 mm - 7% of the total weight
- Maximum length of pellets - 5 cm
- Ash melting point - >1100 °C

It is important to avoid high content of bark in the biomass in consideration, as it gives high ash content and considerable operational problems.

With an annual demand for thermal energy of 215 MWh and the expected total efficiency of the heating system of 90%, it will be needed to procure the following quantities of biomass:

Alternative 1: 51 ton/year, or 78 m^3/ year of wood pellets

Alternative 2: 60 ton/year, or 222 m^3/ year of wood chips

8.6.5. System's concept

Dimensioning a biomass boiler is a point of departure for the system's concept development. The optimum plant sizing approach tries to achieve a balance between CAPEX investment and operational costs.

The following choice shall be made when dimensioning a biomass boiler:

- Base-load sizing – minimizing total CAPEX
- Peak-load sizing – maximizing the fossil fuel displacement

It is important to keep in mind that a biomass boiler cannot be regulated further down than 25-30% of the maximum boiler output. Therefore, if one chooses too large a biomass boiler compared to the energy requirement, there is the risk of having to shut down the boiler large parts of spring / fall in addition to summer.

It is therefore important that the boiler is not over-dimensioned in relation to its demand base. Meanwhile it should be large enough to avoid a need to invest in new base load after a few years, if energy demand rises.

As a general rule of thumb, sizing the biomass plant in this scenario at between 45 and 65% of the peak load can in fact deliver 80-90% of the annual heat demand for the site.

With the reference to this and to the assumed energy duration curve, it is hereby proposed to size a base boiler at approximately 50% of the total heating load – or 180 kW.

Approximately 15% of time, the actual heating load will exceed the available capacity of the biomass boiler. In this case, the biomass boiler should be turned-off. The old gas-fired boiler shall be put on operation. The capacity of this reserve boiler is enough to cover peak loads and it has short start-up time.

Approximately 50% of the time – heating is off and only domestic hot water is supplied. During these periods the biomass boiler would be operating at low capacity, which is inefficient and brings to operational problems. It is therefore proposed to use heat storage, namely accumulator tank.

Such a situation will mainly happen during summer season. At that time, a biomass boiler shall start up approximately once a day for a short period to heat up water in the accumulator tank. Accumulator tank shall be dimensioned to accumulate approximately daily demand in domestic hot water. With the reference to the estimates of domestic hot water demand, the required volume of this tank is 10 m^3. It shall be provided with proper insulation.

To avoid pressure drops in the system caused by circulation pumps with electronic speed control system, a design engineer may consider a low loss header prior to entering into the distribution system as well as heat an exchanger or thermal regulator for the domestic hot water circuit.

Principal flow-sheet of the proposed system is indicated below:

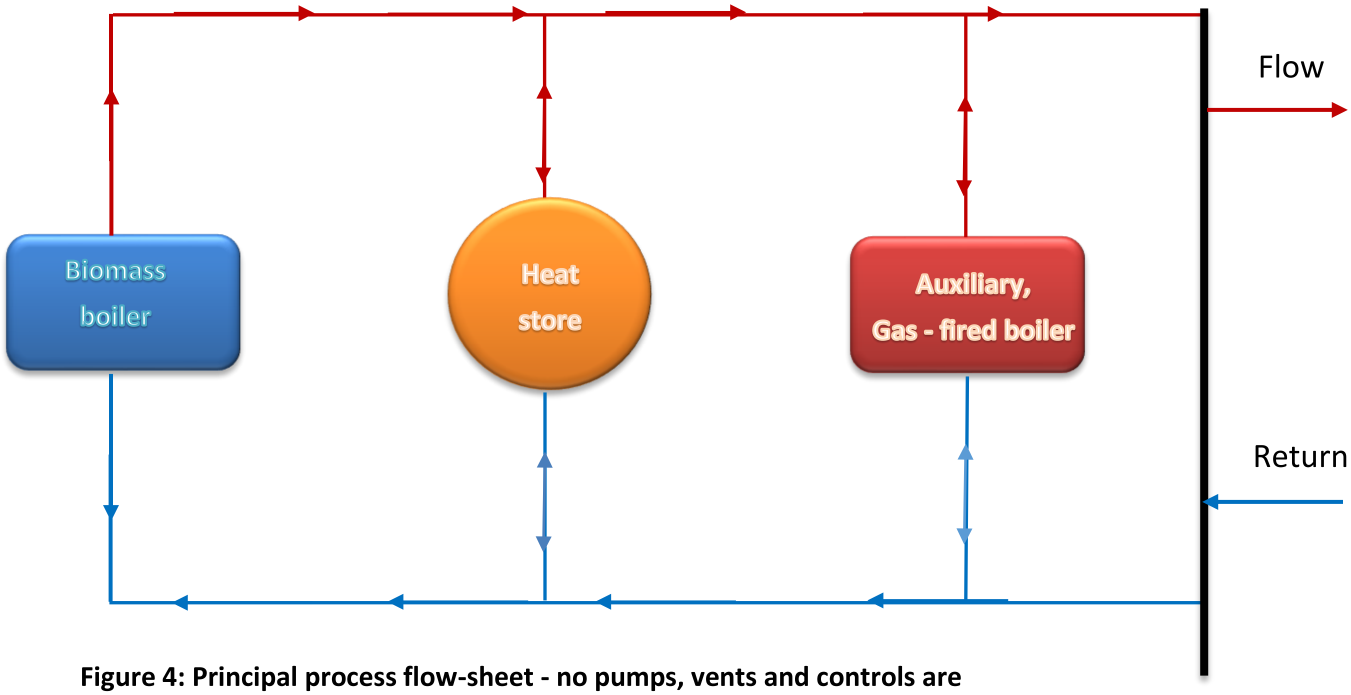


Figure 4: Principal process flow-sheet - no pumps, vents and controls are indicated

8.6.6. Boilerhouse

Selection of boiler type is determined by the type of fuel, fuel flexibility and requirements for combustion, automation and economy. This is a trade-off between convenience and cost.

Effective combustion can be achieved if:

- Combustion temperature is within correct range (>850 ^{o}C)
- Retention time (sufficient time in combustion chamber)
- Turbulence (blending of air/combustion gases)
- Sufficient feed of oxygen (excess of air)

For burning biomass with between 15% and 30% moisture, a solid grate burner system having a relatively small grate attached directly to the end of the feed screw is often used. The fuel is fed directly into the combustion chamber by the fuel feed mechanism, rather than being dried first as in the case of the inclined grate plants.

The grates will be mounted in the burner under an angle, which provides the fuel falling under gravity. The solid grates were developed from designs commonly used in coal plants, and are widely used for the combustion of drier fuel, (e.g. joinery waste), good quality woodchip, and wood pellets. They can burn wood pellets and wood chips up to 30% moisture content. The potential for burn-back along the screw or auger is high, requiring the feed mechanism to be emptied on boiler shut down.

Solid grate systems tend to be most common in the 50-300KW range (up to 500kW on pellets), and can use both pellets and woodchips (a change of grate with time may be required in some models).

An alternative is stoker burner systems - often a cheaper alternative to solid grate options because they are generally less sophisticated, but they offer less opportunity for automatic control and therefore such systems require that fuel quality is consistent. They are most common for wood chips in the size range 30-500 KW.

Pellet and dry wood-chip systems biomass boilers are generally responsive and they may have good control possibilities and are the closest to fossil fuelled boilers in terms of maintenance and operation, although there can be large variations between systems from different manufacturers in terms of sophistication.

Figure 5: The Swedish EcoTec 300 kW pellets boiler system

The proposed system shall be automatically fed via screw and rotary systems similar to those used for conveying feed and grain on farms. Automatic feed is optimal for biomass fuels having a moisture content 20 – 25%. From the fuel hopper, pellets or wood chips will get into the boiler at a rate that shall be determined by control system.

A typical boiler system shall include the following components:

- Reception facility
- Storage silo
- Fuel feed/ Screw system
- Fuel Hopper
- Combustion System (Boiler)
- Refractory materials/fire brick (optional for dry fuels)
- Air feed system (primary/secondary air)
- Electronic Controls
- Connection to Chimney/flue gas fans
- High Temperature Chimney (if there is not an existing chimney to connect to)
- Plumbing Connections (to the building’s hot water heat distribution system)
- Exhaust gas treatment/Cyclone (optional)

- Bottom ash container and ash removal system with screw (optional)
- Internal piping and electrical connections
- Expansion vessel
- Control and safety system
- "As-built" documentation, installation and connection design

The choice and sizing of auxiliary equipment (such as the flue/chimney) and ash handling is mostly determined by the type and size of the boiler, while the need for thermal stores and fossil fuel stand-by is determined by the site heat load and reaction times required.

It is important to keep in mind that biomass-boilers require significantly more space than a gas boiler. It will be needed to install several components additional to an ordinary gas-fired system. It will be needed to install storage, fuel, ash handling system, and perhaps even other equipment. It will be therefore necessary to arrange additional facilities.

For the boiler house of such capacity it is recommended to put boiler in a container/module. They are, essentially 'plug and play' options that offer several advantages such as minimising disruption to existing buildings, speed of installations and simplicity. Such boiler systems shall normally be delivered assembled. This will ensure fast conversion of energy supply to biomass. In the right circumstances, they can be very cost-effective solutions.

8.6.7. Fuel storage and feed

For a small boiler house and with the location close to the kindergarten it is proposed that the fuel is stored in a silo or container. The various vendors have different design of silo solutions.

Standard designs for boiler houses of such capacity are:

- Vertical silo standing on the ground
- Container standing on the ground or semi-buried with direct fuel feeding system
- Container standing on the roof of the boiler house

A solution with digging down silos may require earthworks and incur additional costs. Availability of an area around the kindergarten suggests the use of silo solution in the form of containers that is connected to the biofuel plant through the feed system. This solution offers easier access for maintenance.

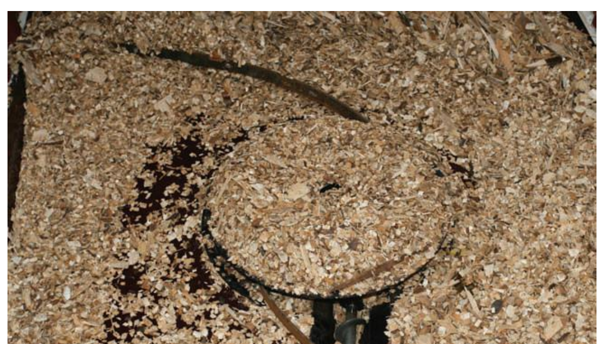


Figure 6: Extraction of wood chips - a screw with agitator arms

Fuel storage volume and shape determined by fuel, production and desired capacity. As a rule, storage capacity should be a 5 days operational capacity.

The storage volumes required at a minimum are shown below:

- Wood pellets - 3 m^3
- Wood chips - 7 m^3

Storage for wood chips would require larger volume and bigger investment.

To achieve the most favorable energy price of biofuel and reduce transport cost the storage volume should be having a capacity that can cover an entire truckload.

It is normal to have about 15 – 30 m^3 storage, dependent on the trucksload and area available for area for parking of trucks. This is especially important for storing wood chips.

In this case, biomass will be delivered 3-5 times a year, which is a usual practice for small scale biomass boilers. A supplier of biomass should be consulted to see what transport will be used to deliver the fuel and whether they can deliver only a partial load.

Screw, hydro-rotary feed mechanisms or vibration systems (push-floor) are the most common feed systems in use on automatic feed biomass boilers. Screw can be configured into a series of chains (chain scrapper) to allow fuel to be moved between levels and around corners. Screw feed generally is cheaper than hydraulic feeds, but it will not work well with large and thick chips, more than 8-10 mm in length. If woodchips vary in properties it is advisable to add agitator arms to a screw.

The different physical properties of the two main sources of biomass fuel for heating (pellets and chips) necessitate specific considerations that shall be taken into account at arranging the fuel storage:

Wood pellets:

If blower delivery is used, the storage unit will need the appropriate couplings to allow connection to the pellet blower hose and its end will need to be within the reach of the truck driver. The storage unit will need an exit port to allow the release of blowing air when the delivery takes place. If there need to be bends in the delivery pipework, large bends (e.g., a 90^{O} angle) could cause damage to pellets during delivery. The floors of the storage unit will need a slope of at least 40° towards the feed mechanism to ensure pellets can flow into it.

Woodchips:

Ideally, a woodchip storage should be designed to allow the delivery of a fuel load with as little manual intervention from the site owner/operator as possible. Woodchips do not flow as pellets do. The supplier of storage will need to carefully design it to avoid blockages of fuel and thus jams.

As both wood pellets and wood chips are reasonably dry, less than 30% moisture content, they will not degrade in storage and lose their heating value.

Conversion of energy supply to biomass boiler will require organizing the delivery of fuel. Since biomass is brought by truck, a design engineer shall make sure that for them there is easy access and the ability required maneuvers and unloading.

8.6.8. Control equipment

Combustion process shall be controlled automatically with the use of flue gas oxygen sensor, adaptive fuel feed control mechanism and automatic control of boiler in-flow and return temperatures.

An automatic boiler house would need one operator to monitor the performance and ensure the continued availability of wood chips or wood pellets in stock, as well as visual control of the boiler.

Figur 7: O_2 sensor at the exhaust of a biomass boiler

The control unit shall allow an operator to control the flow of wood pellets or wood chips and combustion air flow into the boiler based on temperature settings. The unit shall give readings on boiler and exhaust temperatures.

A control device, such as temperature sensor and flap valve with water supply shall be used the primary burn-back measure.

The Accumulator tank shall be supplied with simple control system based on two temperature sensors, one near the top of the buffer vessel and the other near the bottom. The boiler shall ceases firing when the hot water interface has reached the bottom sensor when charging and firing re-commences when the accumulator tank has discharged to the level of the upper sensor.

8.6.9. Emissions abatement and ash handling

There are no specific regulations for abatement of air emissions from the boilers of such capacity. However, given the location of the facility it would not be uncommon to place a cyclone or multi-cyclone to take out most particulates down to about PM20.

Ash is a by-product of wood combustion, the quantity produced varying from 0.5% to 2% or more of the dry weight of wood chip or wood pellet burned, the exact proportion being dependent on the chemical composition of the fuel. Around 98% of this is bottom ash from the grate and the remaining 2% is fly ash. Restrictions for its disposal may apply. Emptying ash collection containers shall be a part of regular maintenance of the boiler.

The volume of flue gases from the solid fuel is higher than that of natural gas. Therefore, it is necessary to evaluate the capacity of the existing chimney. When transferring the existing boilers to biomass burning may be necessary to increase the height of the chimney to ensure adequate dispersion of pollutants. Different countries may have various regulations on the chimney height and an equipment supplier shall ensure that the chimney proposed has right dimensions, in compliance with local legislation.

Figure 8: Example of an operational routine at one of the biomass boilers in Norway

For reference, a rule of thumb is:

- A chimney shall be minimum times two of the height of a tallest building in the area of 500 m.

Therefore the recommended height of a chimney is – 20 m.

8.6.10. Operation and Maintenance Requirements

Small-scale automatic biomass boiler systems will normally require limited operation and maintenance. However, the equipment supplier shall provide operation and maintenance manual in Georgian with explicit description of regular operation and maintenance and list of spares required.

Normal routines for the system proposed may include:

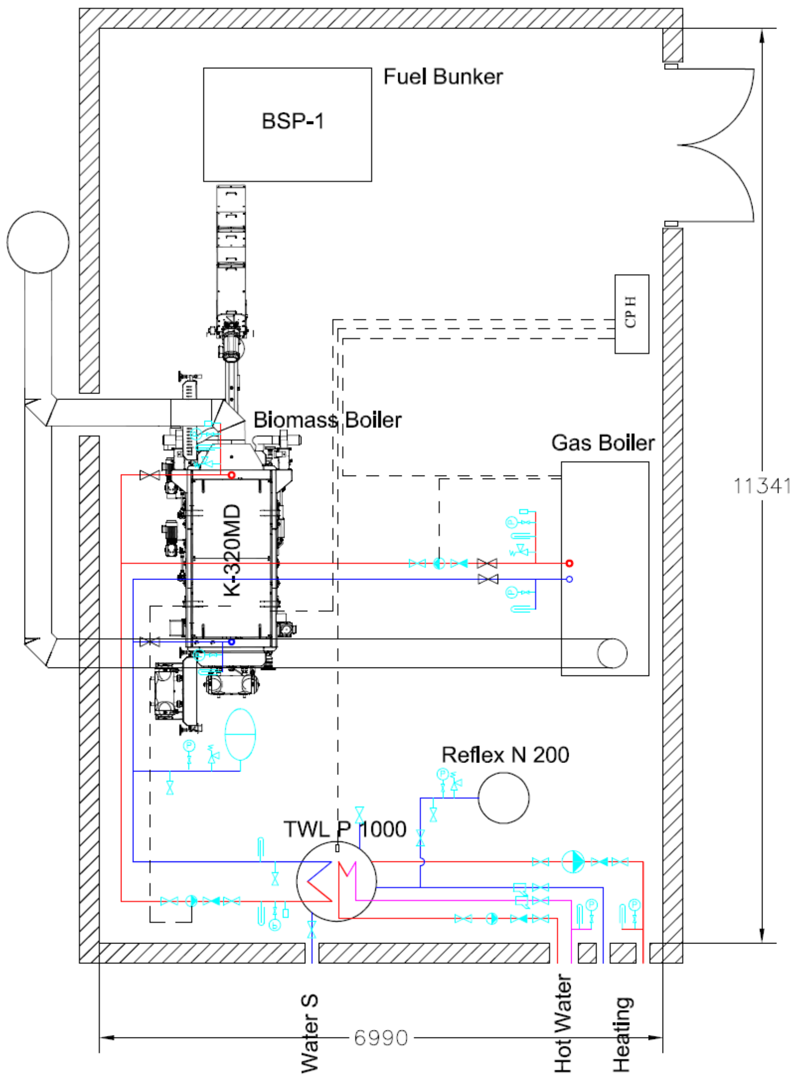
- Control of important operational parameters (pressure, temperature, levels,
- Temperature of flue gas is around 200 ^{o}C and getting lower with low operational load
- Cleaning of boiler surfaces
- Visual control of combustion (feed of fuel, stock in silo, combustion check via sight-glass, control of ash level, weight and percentage of fuel

8.6.11. Summary of recommended specifications

Technical requirements	Wood Chips Boiler	Wood Pellets Boiler
Design peak load, KW	350	
Design thermal power demand, MWh	215	
Operating temperature of heat carrier	80 (+/- 5%)	
Efficiency, not less than,%	90(+/- 5%)	
Nominal capacity, KW	180(+/- 10%)	

Working pressure, bars	1	
Volume of heat carrier in accumulator tank, m^3	10	
Insulation of accumulator tank	Primer coated outside surface, removable high efficiency insulation with thickness of 100 mm	
Auxillary boiler	Existing gas-fired boiler	
Type of connection	Parallel	
Annual fuel requirement, m^3	222	78
Boiler installation	Container/module	
Moisture of fuel, %	20(+/- 5%)	
Maximum length, cm	10	5
Density, kg/m^3	270	650
Burner system	Solid grates	
Fuel feed and combustion	Automatically controlled	
Volume fuel storage, m^3	20(+/- 10%)	
Warranty, months	12	
Spares availability, years	5	
Documentation	Operation and maintenance manual in Georgian	
Auxiliary equipment	Circulation pumps, flow-in and return pipelines, fire and explosion prevention controls and valves, area for loading and unloading	
Controls	Flue oxygen sensor, air flow sensors, temperature sensors at a boiler and accumulation tank, adaptive fuel feed mechanism, heating meter	

BOILER PLANT LAYOUT



- Room thermostat for floor heating control
- Towel dryer tan with thermostat
- Radiator thermostat
- Return line
- Supply line
- Circulation line
- Circulation pump
- Safety valve
- Filter
- Back way valve
- Close valve
- Thermometer
- Manomether
- Air valve
- Drain valve
- Two way valve
- Flow meter
- Gravitational valve
- Expansion Tank
- Balance valve
- Three way valve
- Automatic pressure valve

DESIGN:

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PROJECT: KINDERGARTEN #107

ARCHITECT:

ENGINEERING: V.Puodziunas

STATUS: Concept

DRAWING: Architectural Layout

FORMAT:	A3	br-con-1
SCALE:		
DATE:	2014-12-12	

8.6.12. Bill of Quantity

KINDERGARTEN #107 TBILISI, GEORGIA HEATING WORKS PACKAGE - BOILER ROOM	Bill No: KG-1		Page No: KG-1/1	
ITEM DESCRIPTION	Q-NTITY	UNIT	UNIT RATE	TOTAL PRICE in Euro
The Contractor is referred to the specification and drawings for all details related to this Section of Works and is to include for complying with all the requirements contained therein.				
Boilerhouse and infrastructure construction	1	Nos.	9,958.51	9,958.51
Supply and installation of Biomass boiler 350kW with ball valves, back valves, circuilation pumps, with air and drain vent, with support elements, with thermometer and manometer, piping, and accessories				
Biomass boiler 350kW K-320MD or analogic	1	Nos.	71,012.45	71,012.45
Fuel bunker BSP-1	1	Nos.	6,224.07	6,224.07
IS-1 membrane tank for heating system, 250ltr, 2.5bar	1	Nos.	331.95	331.95
IS-2 membrane tank for hot water system, 50ltr, 2.5bar	1	Nos.	178.42	178.42
Heating circulation pump	1	Nos.	1,327.80	1,327.80
Hot water tank circulation pump	1	Nos.	746.89	746.89
Piping	1	Set.	1,161.83	1,161.83
Insulation	1	Set.	410.79	410.79
Valve package	1	Set.	1,742.74	1,742.74
Automation set, including detectors, cables, courugated pipe and other accessories	1	Nos.	954.36	954.36
Accessories	1	Set	497.93	497.93
Installation works	1	Set.	4,149.38	4,149.38
Total				98,697.10

8.7. Economic assessment of Utilization

Economic analysis of scenarios discussed in previous chapters is not allowing for adequate comparison and assessment due to the following circumstances:

1. Current energy parameters of building (without taking any energy-efficiency measures) do not provide any economic gains by installing biomass boiler;

2. Currently installed natural gas boiler was selected due the abovementioned qualities of building and is designed inefficiently; therefore it is necessary to not only improvement of energy-efficiency of building but complete upgrade heating system.

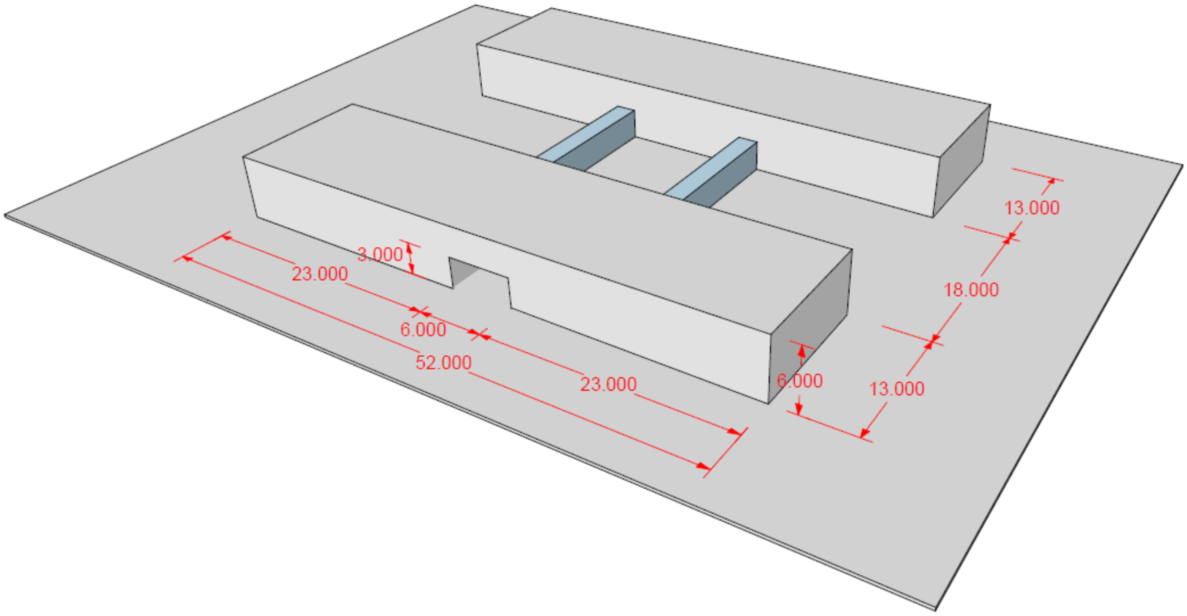
Hence, economic comparison can only be meaningful if natural gas boiler and biomass boiler operate in equally improved conditions that involve improvement of energy-efficiency, installation of adequate capacity boilers and respective infrastructure. Below is provided economic comparison for selected kindergarten that illustrated relevancy of biomass boiler to gas boiler for various prices of biomass as of discount to gas equivalent:

	% by which biomass price is lower than gas	New Gas boiler (80kW), infrastructure scenario and accessories in Euro	New Biomass boiler (80kW), infrastructure scenario and accessories in Euro	Economy After years
Installation and Equipment		54,000	58,000	
Annual Fuel Cost for various scenarios of prices	10	1,432	1,288.38	27.94
	20	1,432	1,145.23	13.97
	30	1,432	1,002.07	9.31
	40	1,432	858.92	6.99
	50	1,432	715.77	5.59
	60	1,432	572.61	4.66
	70	1,432	429.46	3.99
	80	1,432	286.31	3.49
	90	1,432	143.15	3.10

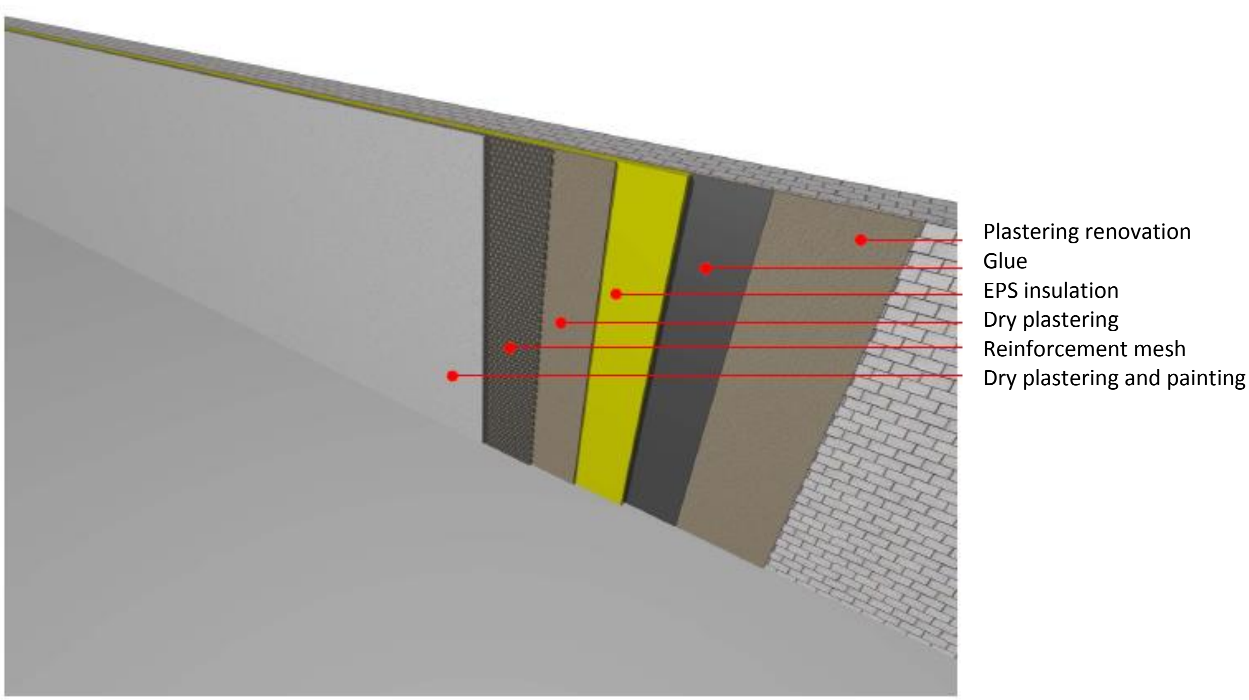
8.8. Conceptual Project of Energy-Efficiency Advancement for Selected Kindergarten

Due to the fact that most kindergarten buildings do not satisfy minimal norms of energy-efficiency, that in turn leads to inadequate capacity of boiler and increased consumption and costs, below is provided a list of measures required for advancement of energy-efficiency and approximate budget for kindergarten #107.

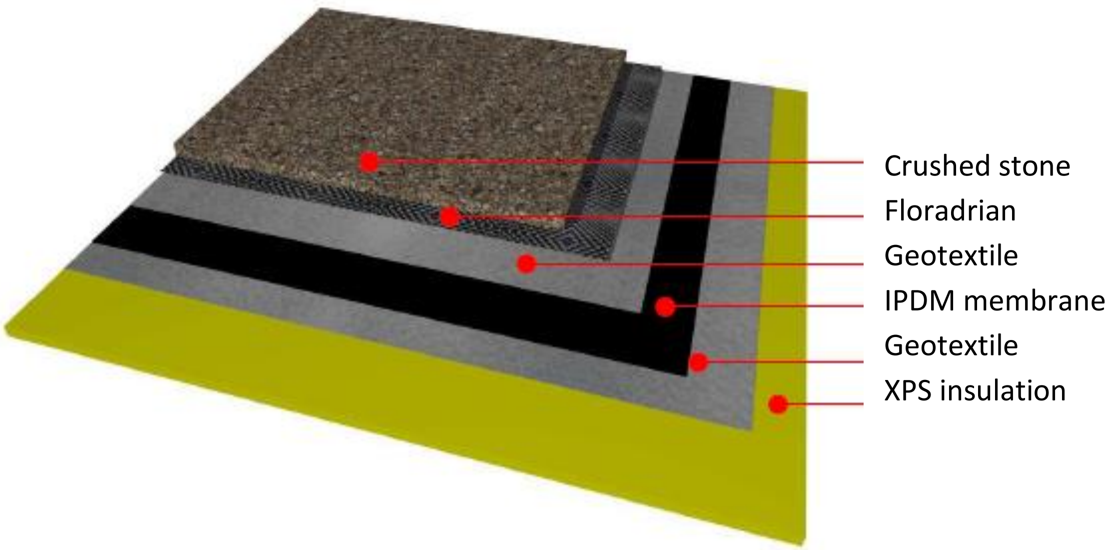
Volume of Kindergarten building:



Cross-section of wall after insulating:



Cross-section of roof after insulating:



Approximate budget of insulating building envelope:

#	Title	Unit	Quantity	Unit price in Euro	Total Price in Euro
1	Heating audit and design of technological project	Sq. m.	2,000	8	16,000
2	XPS Insulation (50mm)	Sq. m.	568	25	14,202
3	Geotextile 2 layers	Sq. m.	1,136	4.5	5,113
4	IPDM membrane with accessories	Sq. m.	568	35	19,882
6	Crushed stone	cb. m.	57	60	3,408
6	Installation (water proof inverse roof)	Sq. m.	568	20	11,361
7	**Total:**				**69,966**
8	**Renovation of existing entrance**	Sq. m.	798	8	**6,387**

9	**Glues for EPS**	Sq. m.	798	3	**2,395**
10	**EPS Insulation (50mm)**	Sq. m.	798	15	**11,975**
10	**Dry plastering**	Sq. m.	798	5	**3,992**
11	**Mesh**	Sq. m.	798	2.5	**1,996**
12	**Dry plastering and paint**	Sq. m.	798	18	**14,370**
13	**Installation (facade insulation)**	Sq. m.	798	15	**11,975**
14	**Total:**				**53,088**
	Window replacement*	Sq. m.	261	150	**39,139**
	Door replacement*	Sq. m.	86	150	**12,920**
	Total:				**52,059**
	Grand total:				**175,113**

* Budget includes window and door replacement, that is not required for building of kindergarten #107, however may be required for other kindergarten buildings.

Chapter 9: Conclusions and Recommendations

Analysis of various scenarios of production that involves conversion of wood residues into pellets and wood chips shows that:

- Easily available (free/cheap) biomass resources in Tbilisi Municipality enable production of 2000 tons per year that despite various mitigation measures cannot compete adequately (with proper profit margin, taxes, etc.) with natural gas
- Assigned task is feasible in case of increasing production to 4000 ton per year. Such capacity to obtain necessary input will requires collection of biomass from not only wood residue biomass but firewood that is distributed to local population. Considering commercial prices of firewood in Tbilisi this scenario can only be profitable if production has substantial mitigation measures (more than 40% of grant component in capital investments, low interest rate, and subsidized raw materials - firewood for low prices to be used as biomass). This means that this size of production is feasible if established as municipal organization or given subsidies and preferences (zero rate VAT and other taxes) and in addition does not have to purchase land for establishment of production, obtains wood residues and firewood for no substantial cost by state subsidies and is supported by international donor organizations (adequate mitigation measures can be selected from production feasibility assessment chapter). However output (4000 tons) of such production requires adequate utilization of biofuel that would be more than 100 kindergartens. Which in turn leads to limited use of wood chips as only a share of kindergartens has enough area for wood chip boiler infrastructure therefore pellets would be the only feasible selection.
- It is feasible to conduct fundraising to integrate other projects into biofuel production to achieve efficient synergy. For example instead in settlements of internally displaced persons that are supplied with firewood free of charge 5-10 kW energy-efficient stoves operating on pellets can be installed. This will result in switching from firewood to pellets.
- As in the area of Tbilisi municipality, near to Norio/Markthopi there are large resources of wood chips enriched with poultry manure and there is Norio landfill solid biofuel production can aided by integrating it to other facilities like: biogas production and cogeneration plant described in scenario 3 or other large-scale production facilities that involve similar inputs (wood) or outputs (thermal, electrical and other energy). Wood processing industrial zone establishment with some preferences would enable reduction of pellet production by 10-20%. It is reasonable to conduct detailed technical and economic analysis for this scenario.
- Based on detailed investigation and study of energy parameters of building of kindergarten #107 it can be confirmed that input parameters as 950 kW capacity boiler that this kindergarten is

equipped with is inadequate for such building. Building requires taking energy saving improvement measures that involve upgrading of network of thermal consumption and development of technical qualities of building (envelope insulation, adjustment of characteristic of windows and thermal bridges to European norms – see 8.8 Conceptual Project of Energy-Efficiency Advancement for Selected Kindergarten). In this case heat input required for this building, namely capacity of boiler can be substantially decreased – from 350 kW to 80 kW as such buildings require no more than 40 W per heated sq. m. In turn this will also provide considerable reduction in cost of pellet boiler and its infrastructure.

- In this case it is feasible to switch this building to consumption of pellets by installation of proper capacity pellet boiler.