Micro Combined Heat and Power System for Households

H-CHP PROJECT DELIVERABLE D.T1.3.1

CHP fuels in the NPA region

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1. Abstract

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2. List of Symbols and Abbreviations

AC	Alternating Current
CaPex	Capital Expenditures
CCGT	Combined Cycle Gas Turbine
CHP	Combined Heat and Power
DC	Direct Current
EES	Electrical Energy Storage
FIT	Feed-in-Tariff
IC	Internal Combustion
ICE	Internal Combustion Engine
LPG	Liquefied Petroleum Gas
mCHP	Micro Combined Heat and Power
OFGEM	Office for Gas and Electricity Markets
OpEx	Operational Expenditures
PV	Photovoltaic
RHI	Renewable Heat Incentive
ROI	Return on Investments
SE	Stirling Engine
TES	Thermal Energy Storage

3. List of Tables and Figures

4. Introduction

This chapter covers the fuel supply chain for the NPA area and will primarily focus on biomass fuels.

Any combined heat and power system requires a constant fuel supply. Talking about the bioenergy the raw biomass materials before reaching the end users will pass through a series of processes which known as a biomass supply chain. Each process is associated with the specific sets of knowledge, technology and activity which can also differ from country to country. These processes involve growing, harvesting, transporting, aggregating, storing and converting the biomass may vary depends on the biomass type and the conversion technology used. Pre-processing may also be a necessary step along the pathway from the land to energy use. (Speight et al., 2014)

Fig 1. Biomass Supply Chain.

The larger fraction of cost in biomass energy generation originates from the logistics operations. (Rentizelas et al., 2009) The major issues concerning biomass logistics are its transport, storage and handling which link the processes together or may be a part of each process.

After the available mCHP technologies and the local demand data are known, the next questions should be answered:

- Existence of the biomass market
- Accessibility of the biomass market
- Supply logistics

5. Biomass as a Feedstock

Biomass is an organic matter originally derived from plants or from animals which can be used in order to provide heat or electricity. Biomass is formed through the process of photosynthesis, when the solar energy is used to convert carbon dioxide and water into carbohydrates (sugars, starches, cellulose) and oxygen (Lambers et al, 2008). Thus, the biomass acts as an energy medium in a same way to other fuels such as coal, gas or oil.

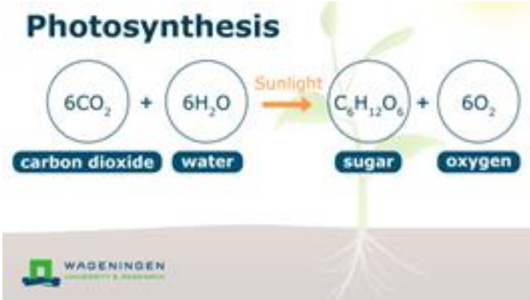

Fig 2. Photosynthesis. (Courtesy of Wageningen University & Research)

During the biomass energy conversion processes (direct combustion, gasification, etc) the carbon is emitted into the atmosphere, but because the plants are consuming the same amount of the carbon during the growth period (photosynthesis) this fuel can be defined as carbon-neutral.

The plant stocks can also be replaced with new growth which makes the biomass renewable fuel.

Two critical elements when assessing biomass usefulness as a fuel is its calorific value and moisture content. Where a fuel calorific value is the rate of its stored energy given in Joules (J) per unit mass (kg) or volume (m^3). The fuel calorific value can be quantified by measuring the heat output during the fuel combustion process at constant pressure and under standard conditions.

Fuel	Net CV by mass		Bulk density	Energy density by volume	
	GJ/tonne	kWh/kg	kg/m³	MJ/m³	kWh/m³
Wood chips (30% MC)	12.5	3.5	250	3,100	870
Log wood (stacked - air dry: 20% MC)	14.7	4.1	350-500	5,200-7,400	1,400-2,000
Wood (solid - oven dry)	19	5.3	400-600	7,600-11,400	2,100-3,200
Wood pellets (10% MC)	17	4.8	650	11,000	3,100
Miscanthus (bale - 25% MC)	13	3.6	140-180	1,800-2,300	500-650
House coal	27-31	7.5-8.6	850	23,000-26,000	6,400-7,300
Anthracite	33	9.2	1,100	36,300	10,100
Heating oil	42.5	11.8	845	36,000	10,000
Natural gas (NTP)	38.1	10.6	0.9	35.2	9.8
LPG	46.3	12.9	510	23,600	6,600

Fig 3. Typical Calorific Values of Fuels. (Forest Research)

The useful energy will be affected by the amount of water (moisture content) present in the fuel. The moisture within biomass is not just a surface wetness, but it is present within cells and pore spaces (Rollinson, 2016). The moisture will reduce the useful energy of the fuel by lowering the combustion temperature, and the lost heat in the evaporated water. It will also affect the economics of the supply chain if the biomass is sold by weight, as the amount of moisture present will reduce the energy production and increase the transportation costs.

Moreover, biomass chemical composition (the relative amount of the chemical elements in the substance) is important when designing the boiler or gasifier as it will reflect the amount of tar, char and ash produced and will thus affect the efficiency, power output and maintenance intervals.

5.1. Types of Biomass

Primary biomass can be classified into six main categories:

- Forestry (Virgin Wood)

Generally, comes from forestry and arboriculture, and includes any wood untreated with chemicals and finishes. Softwood/hardwood logs.

- Energy Crops

Mostly involves short rotation crops or fast-growing trees such as poplar, sugar and starch crops (beet, wheat, maize) or oil crops like rape and sunflower. This type of fuel requires pre-processing.

- Agricultural Residues (Waste)

E.g. wheat or barley straw, paddy husk, coconut shell, sugarcane top, rise husks etc.

- Food Residues (Waste)

Usually wet and come from almost any food manufacturer in the form of oils, fruit and vegetables, distillery waste, and waste meat and fish.

- Industrial Residues (Waste)

This include treated and untreated wood residues such as sawdust, cardboard, plywood wood chips, paper. A special precaution should be taken as the extremely dry materials can adversely affect a boiler or a gasifier.

- Aquatic Biomass

This refers to any plant or animal material that has formed in water, such as algae and seaweed. Usually with a high moisture content and require drying and pre-processing.

Further classification serves to distinguish between the energy content of the primary biomass, methods for preparing and utilising the biomass for energy production, or the conversion technologies employed for the production of a fuel.

5.2. Most popular types of biomass fuels

5.2.1. Biomass Wood Pellets

Biomass pellets are manufactured from waste wood products. These are small offcuts which are compressed down into pellets along with a binding agent, usually flour or corn starch, to prevent the breakup of individual pellets.

Typical size about 10mm x 30mm.

The pellets can be delivered by specialised pellet trucks or in tankers (if demand is high). However, most popular delivery type is bags with size varying from 10kg to 1000kg.

Wood pellets are a high-density, low moisture content biomass fuel (1000kg of the pellets = 1.5m^3 of space). Because they are of uniform shape and size, they can be automatically fed into the heating system through an attached hopper. This allows pellet fuelled biomass boilers to perform on a timer system, much like traditional boilers.

Disadvantages – fragile when wet and require dry storing facilities. This fuel is not good for use in gasifiers due to its shape and composition.

5.2.2. Wood Chips

This fuel requires minimal processing. Logs are fed into specialised wood chipping machines or drum chippers to produce a wood chips. Then it should be screened to remove either large pieces or fines.

Due to their relatively high moisture content they tend to be less efficient in terms of transportation and storage as wood pellets (1000kg of wood chips = 2m^3).

5.2.3. Wood Logs

Wood logs are the most readily available biomass fuel. After a tree is chopped, minimal processing is required, however, due to a high moisture content, the calorific value is lower compared to either wood chips or biomass wood pellets. To reduce the moisture content a natural or forced drying is required.

The uneven size of the wood logs made impossible to fed it into the boiler automatically. This type of boilers is more maintenance-heavy, as operator will need to put the logs in the burners by hand.

5.2.4. Peat for energy

While commercial exploitation is not sustainable, some domestic peat banks cut for fuel are decades old and are managed to minimize erosion. Peat stacks are a familiar sight in parts of the far north and west. (SNH, 2015)

Scottish Environment Protection Agency (SEPA) states: "Peat is a body of sedimentary material, usually dark brown or black in colour, comprising the partially decomposed remains of plants and organic matter that is preserved in anaerobic conditions within an essentially waterlogged environment." (SEPA, 2010)

There are two principal types of peat:

- The upper (acrotelm) layer which is quite fibrous and contain plant roots etc. Acrotelmic peat is relatively dry and has some tensile strength.
- The lower (catotelm) layers are highly amorphous, with very high water content and tend to have very low tensile strength. The structure of catotelmic peat tends to disrupt completely on excavation and handling.

Peat lands hold large stocks of poorly protected carbon and excavation of peat will result in large carbon losses from the excavated peat and also the areas affected by drainage. Minimising peat excavation will reduce these potential carbon losses and consequently reduce the carbon payback period associated with developments on peat.

Peat as a fuel can be delivered in three forms:

- Sod peat

  Chunks of peat, hand- or machine-cut, and dried in the open air. Usually used as a household fuel;

- Milled peat

  Granulated peat, mass-produced by special machines. Can be used either as a power station fuel or as a raw material for peat briquettes production;

- Peat briquettes

  Blocks of dried, highly compressed peat. Used as a household fuel.

5.3. Biomass by Region

Seven different ecological regions can be found in the Nordic Periphery and Baltic countries. They range from Scandinavian montane birch forest and grassland in northern Norway, Sweden and Finland (especially at higher altitudes) to Central European mixed forests in Lithuania. Finland and most parts of Sweden are within the boreal forest or taiga region, where pine, spruce and birch dominate the forests. Spruce and pine also dominate the forests in much of Norway with Scandinavian coastal coniferous forests being found along Norway's west coast. (Roser et al, 2008)

Sarmatic mixed forests dominate in the southern parts of Sweden, Norway and Finland. Baltic mixed forests and Scandinavian coastal coniferous forests are commonly found in Denmark. The most notable change when moving south is the increasing share of hardwood species such as birch, alder, beech, oak, ash and aspen (European Environmental Agency 2006).

Due to the great ecological diversity within the NPA region, the biofuel feedstock types can vary significantly.

In Scotland forests currently cover around 17% of land area and produce around 7 million m^3 of timber a year, with this production set to increase over the coming decade. (Scottish Government, 2007)

The Scottish Government identifies that forestry can be of critical importance in mitigating climate change through development of a strong biomass market. The production forecast for Scotland's forests estimated available volumes of 6.9 million m^3, peaking at 8.9 million m^3 in 2017-2021. Meanwhile a large amount of this material is exported to other markets, there are underused materials which could be available as biomass fuel. The total potentially available volume of virgin biomass (i.e. wood plus brash) is approximately 323,000 odt (appx 650,000 m^3).

Short rotation coppice (SRC) and short rotation forestry (SRF) cover around 200ha and spread geographically from the Scottish Borders to Orkney islands. More proposals are submitted; however, it will be a minimum of 3 years before a harvest can be achieved. (Scot.gov, 2007)

6. Biomass Conversion Technologies

Biomass can be combusted directly to provide the energy or can undergo a conversion process to produce a higher energy density fuel in solid (torrefaction), liquid or gaseous (gasification) form. Three main methods for converting of the primary biomass to a higher value fuel are:

1. Thermo-chemical conversion (Combustion, pyrolysis, gasification, torrefaction, hydrothermal upgrading)
2. Enzymatic conversion (Anaerobic digestion, fermentation)
3. Chemical conversion (Esterification)

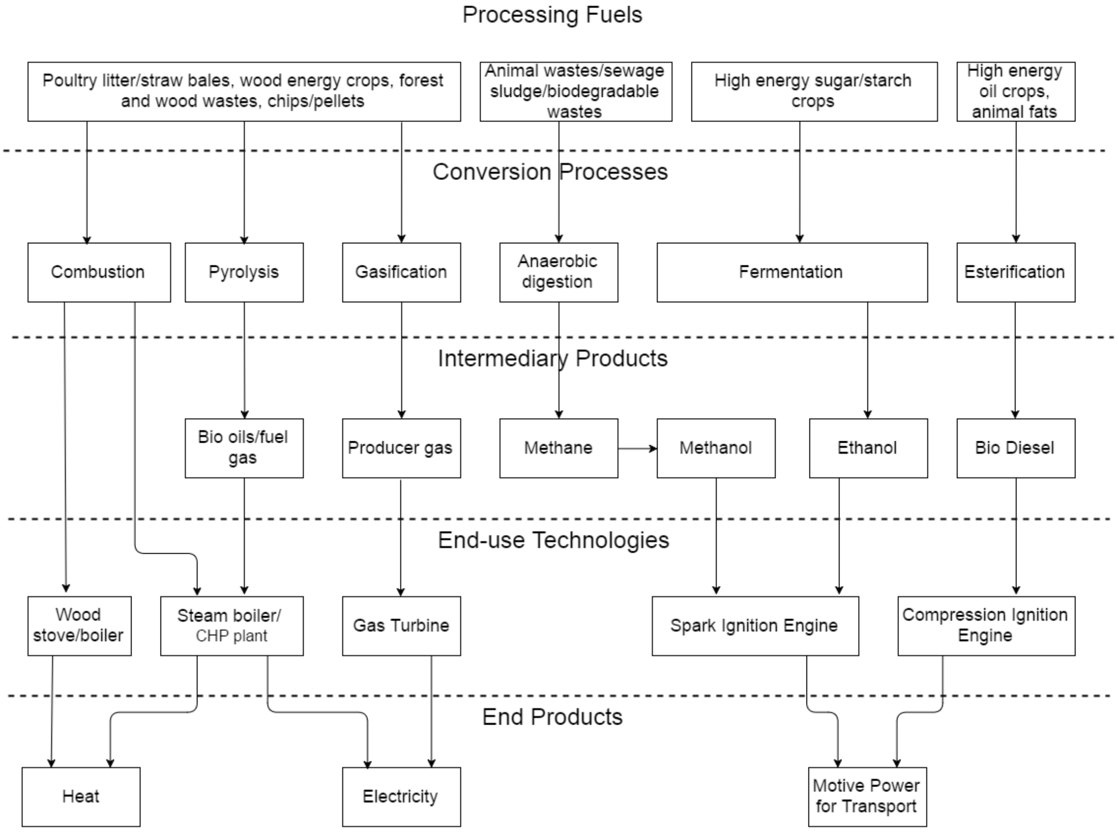

Fig 4. Biomass Conversion Processes.

We are merely interested in a direct combustion of the primary biomass fuel (wood chips/logs/pellets, peat, waste) or its gasification where producer gas can be used to power up the internal combustion engines, microturbines or Stirling engines.

6.1. Direct Combustion

Combustion is an exothermal reaction between fuel and oxygen with a resultant output being mainly carbon dioxide and water vapour. However, a thermal decomposition of any material is a very complex process including a large number of chemical reactions and producing a blend of solid (soot), condensable (bio-oil, tar) and gaseous constituents in different variations. (Rollinson, 2016).

The thermal energy released can be used directly for heating purposes or to produce electricity via Stirling engine or Rankine cycle machines. Combustion properties, condition and composition of the fuel that is to be burned, defines the furnace designs and firing parameters to ensure the optimal efficiency or uptime. (Mando, 2013). The generation of electricity from the biomass powered combined heat and power units delivers a stable and predictable power supply compare to other renewable technologies such as wind or solar.

The combustion process for any biomass fuel consists of three stages:

1. Drying
2. Pyrolysis
3. Oxidation

The impact of each stage on the total efficiency of the combustion process will depend on the:

- Moisture content
- Calorific value of dry matter
- Content of volatile matter
- Ash content
- Ash melting point
- Particle size and variation

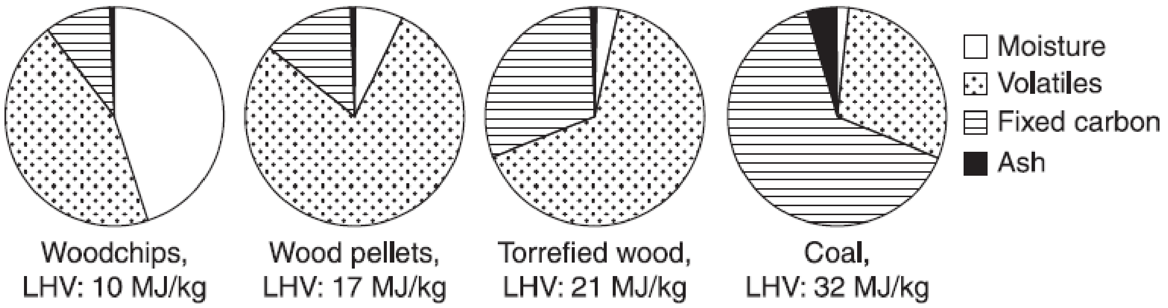

Fig 5. Composition of typical woody fuel and coal (Rosendahl, 2013).

The first stage of the process – Drying – is the evaporation of moisture from the fuel. The moisture content and chunk size of the biomass are considered at this stage. E.g. large wood logs with high moisture content require longer time for drying than fine wood chips. The heat for drying is supplied by radiation from the flames or by convection from a preheated air (directly or via heat exchanger).

As the biomass gets close to being fully dry the temperature increases until at around 200^{0}C second stage – Pyrolysis – starts. During this stage the volatile matter (vaporised tars and oils) starts to be released.

With further increase of temperature above 400^{0}C, the Oxidation stage along with combustion of solid material begins. From this point, the heat is supplied from the combustion itself. As a consequence, the temperature will rise above the fuel bed igniting the volatiles. This usually can be seen as the yellow flame above the fuel.

The final stages of combustion associated with arising of the char particles due to the biomass decomposition. The maximum combustion intensity and temperature are achieved here. Char is composed mainly of carbon which produce carbon dioxide when burns in air (with oxygen).

$$C + O_2 \rightarrow CO_2 \text{ (Eq. 1)}$$

The inert matter is non-combustible and consists of slag and ashes. (Fig 6)

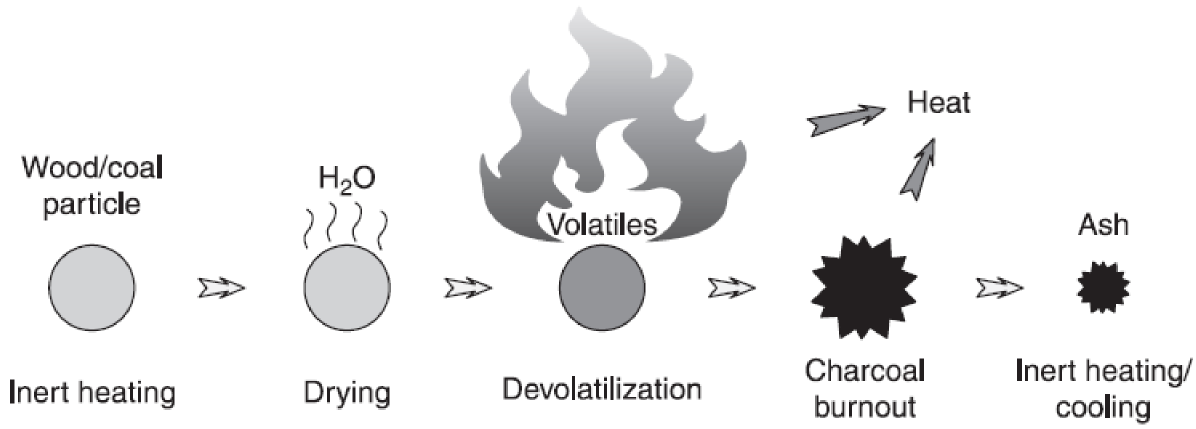

Fig 6. Particle combustion route (Rosendahl, 2013)

From Figure 5 (The composition of typical woody fuel and coal) can be seen that for wood pellets three quarters of the energy is in the volatile matter in contrast to only one third for coal. Therefore, any boilers or stoves should be designed to ensure that these volatiles burn. It is also important that air must reach all of the char for its complete combustion. To ensure this the thorough airflow control must be deployed. Incorrect amount of air can lead to incomplete combustion resulting in low efficiency and high emissions of pollutants such as CO, smoke and other particulates.

The air to fuel ratio – shows the relationship between the amount of air (kg) and the amount of fuel (kg). This may vary according to the fuel type being used.

For the efficient completion of all reactions during the direct combustion process the Temperature, Time and Turbulence are of paramount importance. For example, to obtain the full oxidation of the fuel requires the matter to be exposed to a minimum temperature for sufficient time to ensure that drying and pyrolysis stages are completed efficiently.

6.2. Gasification

Gasification is the chemical conversion process of biomass to a gaseous fuel. "Unlike combustion where oxidation is substantially complete in one process (Eq.1), gasification converts the intrinsic chemical energy of the carbon in the biomass into a combustible gas in two stages. The gas produced can be standardised in its quality and is easier and more versatile to use than the original biomass e.g. it be used to power gas engines and gas turbines, or used as a chemical feedstock to produce liquid fuels." (McKendry, 2002)

With a limitation of the oxygen supply, additional reactions occur during gasification:

- Partial oxidation $C + \frac{1}{2}O_2 \leftrightarrow CO$ (Eq. 2)

- Water gas reaction $C + H_2O \leftrightarrow CO + H_2$ (Eq. 3)

Compare to the direct combustion with complete oxidation that produces only a hot CO_2 gas product, the gases produced during the gasification are carbon monoxide, hydrogen and steam, which can undergo further reactions:

- Water gas shift reaction $CO + H_2O \leftrightarrow CO_2 + H_2$ (Eq. 4)
- Methane formation $CO + 3H_2 \leftrightarrow CH_4 + H_2O$ (Eq. 5)

It is possible to get more energy out of a ton of wood via gasification compare to the direct combustion due to the more efficient chemical reactions chain. Non-combustible carbon dioxide is a by-product of the direct combustion, and its chemical bonds cannot be broken, which means its energy cannot be recovered. With gasification, one of the by-products in producer gas is carbon monoxide, which chemical bond can be broken and releases additional energy.

In comparison to direct combustion, gasification of small-scale biomass emits much fewer airborne pollutants such as NOx, SOx, CO and other particulates.

If gasifier is used as a part of the Stirling engine based combined heat and power unit, it is possible to increase the efficiency of the Stirling engine. As producer gas having a higher combustion temperature, the higher temperature differential between hot and cold pistons can be achieved.

However, this more complicated system requires higher initial costs, operating costs, extensive maintenance and special provisions for a feedstock. The efficient gasifiers can be designed for a narrow range of feedstock only, where the primary biomass composition, size and shape, will have a detrimental effect on a temperature inside the reactor and all chemical processes in general.

7. Biomass Supply Chain

7.1. Issues and factors to suggest when assessing a biofuel supply chain

With the seasonality of biomass supply and a great variability in sources, supply chains play a key role in cost-effective delivery of bioenergy (Henkel, 2015). There are few potential difficulties related to bioenergy supply chains:

- **Technical issues**
  - Inefficiencies of the conversion processes
  - Storage methods for seasonal availability
  - High water content of the biomass feedstock
  - Conflicting decisions (technologies, locations and routes)
  - Complex location analysis (source points, inventory facilities and production plants)
- **Financial issues**
  - The limits for the economy of scale which focuses on maximizing single facility size
  - Unavailability and complexity of life cycle costing data
  - Lack of required transport infrastructure
  - Limited flexibility or inflexibility to energy demand
  - Risks associated with new technologies (insurability, performance, rate of return)
  - Extended market volatilities (conflicts with alternative markets for biomass)
  - Difficult or impossible to use financial hedging methods to control cost
- **Social issues**
  - Lack of participatory decision making
  - Lack of public/community awareness
  - Local supply chain impacts against global benefits
  - Health and safety risks
  - Extra pressure on transport sector
  - Decreasing the aesthetics of rural areas
- **Policy and regulatory issues**
  - Impact of fossil fuel tax on biomass transport
  - Lack of incentives to create competition among bioenergy producers
  - Focus on technology options and less attention to selection of biomass materials
  - Lack of support for sustainable supply chain solutions
- **Institutional and organizational issues**
  - Varied ownership arrangements and priorities among supply chain parties
  - Lack of supply chain standards
  - Impact of organizational norms and rules on decision making and supply chain coordination
  - Immaturity of change management practices in biomass supply chains

7.2. Example Calculations for Biomass Supply (Western Isles)

The process of the Biomass Supply Chain analysis is illustrated with the Western Isles example which highlights the challenges in this region. Over the next phase of the project, the supply chain will be analysed for all regions of NPA.

7.2.1. Supplier comparison

Supplier comparison was done to identify possible routes of the biofuel delivery for the end users on the Western Isles.

	Supplyer 1	Supplier 2	Supplier 3	Supplier 4	Supplier 5
	Angus Biofuels	**Glenskinno Biofuels**	**Forest Fuels**	**New Fuel**	**HW Energy**
Available fuel types (CV, MC)	· G50 dry/wet wood chips (unscreened) · cut and split softwood/hardwood	· G50 dry/wet wood chips (unscreened and screened) · cut and split softwood/ hardwood	· G30, G50, G100/P16, P31, P45 Wood Chips (MC 20%-30%) · Wood Pellets (ENplusA1) with MC<10%	· G30-G50 dry/wet wood chips (unscreened and screened)	· G30-G50 dry wood chips (MC 20%-30%) (screened) · Wood Pellets (ENplusA1) with MC<10%
Capacity (Production Rate)	440 (m^3/h)	12000 tonnes per annum	On request, No limitations	15-20 tonnes per hour	25000 tonnes per annum
Price range	£	£	££	££	££
Distance from end users	240 miles	224 miles	380 miles	186 miles	188 miles
Delivery costs	£1200 per 24tonnes	£1000-£1200	N/A	N/A	£1000-£1500
Delivery time	1 week	1 week	N/A	10 days	10 days
Other comments	Bulk deliveries by sea available	Bulk deliveries by sea available	Don't deliver to the Western Isles		Specialist blower lorry, walking floor articulated lorry or tipping trailer (max delivery 27t)

Fig 7. Biomass fuel supplier comparison (Western Isles, UK).

Fig 8. Biofuel suppliers' location.

Based on the price information from the local suppliers the cheapest fuel can be delivered by the Glenskinno Biofuels. They have drying and screening facilities and are able to supply the G50 size wood chips with moisture content less than 10%. However, due to a long distance from the end user and necessity of crossing the sea channel, delivery price of the fuel will be increased significantly. The estimated delivery cost will be £1200 per 24 tonnes of wood chips, which will boost the price of the single tonne of fuel by £50. Where original price per tonne of G50M10 wood chips is £100, and total price with delivery £150.

Depends on the number of the end users the bulk deliveries by sea might be an option. In this case, a large storage facility with a good ventilation and moisture control is required. Although this will also affect the total price of the biomass fuel.

7.2.2. Annual Fuel Requirements

Annual biomass fuel requirements for each household depend on the CHP system specifications, energy demand, average outdoor temperature and other factors. Detailed analysis can be obtained from the Deliverable T1_4 "Optimal micro-CHP configuration". According to the simulation model, for the micro-CHP system with the power output of 0.6kW electrical and 9kW thermal, the annual fuel requirements are 21842kWh or 4748 kg. This numbers are valid if we're considering the biomass wood pellets as a feedstock.

7.2.3. The Future Prospects for Western Isles Biofuels

To assess the future prospects for the Western Isles Biofuels we need to identify the potential difficulties related to bioenergy supply chains (see Chapter 7.1).

In addition to the current NPA research for the single household's biomass opportunities, the Western Isles Biomass project which will cover medium scale biomass systems was initiated by the Comhairle nan Eilean Siar (CnES - the Local Authority with responsibility for the Western Isles of Scotland). There were identified 15 potential sites across Western Isles for biomass boilers/CHP system installation and performed feasibility analysis for each site. The total installed capacity of such systems might be of up to 1.8MW (Mabbett, 2015). Together with the mCHP system installation for the single households, these figures could be notably higher.

According to the Comhairle nan Eilean Siar, there are 12780 households in the Outer Hebrides. Even the retrofitting of 10% of the current households with individual mCHP system will increase the biomass system's installed capacity by another 1.9MW reaching in total of 3.7MW.

The main issue is that the local supply market of biomass fuel is limited and is generally in emergent stages to meet the requirements of current low volume domestic demand (CnES, 2015). To address the increasing demand, a local Biofuel hub will be required. This hub should consider the import routine of the raw material, processing the biomass, storing the biofuels and supplying the biofuels to the end users.

Other issues such as social, policy/regulatory and institutional/organizational are actively worked on by the local council and the UK government and support mechanisms are provided in most cases. This includes RHI support, participatory decisions, public/community awareness, environmental impact.

8. Conclusion

Biomass is an organic matter originally derived from plants or from animals and acts as an energy medium in a same way to other fuels such as coal, gas or oil. The plant stocks can also be replaced with new growth which makes the biomass renewable fuel.

Two critical elements when assessing biomass usefulness as a fuel is its calorific value and moisture content. The moisture will reduce the useful energy and will affect the economics of the supply chain if the biomass is sold by weight, as the amount of moisture present will reduce the energy production and increase the transportation costs.

The Primary biomass can be classified into six main categories such as forestry, energy crops, agricultural residues, food residues, industrial waste and aquatic biomass. Further classification depends on the energy content, methods for preparing and conversion technologies employed for the biofuel production.

Most popular types of biomass fuels are wood pellets, wood chips and wood logs, also peat can be used for energy production for domestic purposes.

There are seven different ecological regions can be found in the Nordic Periphery and Arctic countries, and this biodiversity is leading to great variations for forest energy utilisation. In some regions such as southern parts of Sweden, Norway and Finland the sarmatic mixed forests are dominating, whereas the central and some northern parts are covered with the boreal forests, where pine, spruce and birch are more common. In contrast, the peat bogs and grasslands are dominating in the Scottish islands, Faroe Islands and northern parts of Norway and Sweden. Availability of the primary biomass resources should be considered when assessing the biofuel supply chain or choosing the system design and biomass conversion technologies.

Biomass can be combusted directly to provide the energy or can undergo a conversion process to produce a higher energy density fuel in solid, liquid or gaseous form. Three main methods for converting the primary biomass to a higher value fuel are thermo-chemical conversion, enzymatic conversion and chemical conversion.

While direct combustion is of main interest for this project, the biomass gasification could bring additional benefits. In comparison to a direct combustion, gasification of small-scale biomass emits much fewer airborne pollutants such as NOx, SOx, CO and other particulates. If gasifier is used as a part of the Stirling engine-based CHP unit, it is possible to increase the efficiency of the prime mover. As producer gas having a higher combustion temperature, the higher temperature differential between hot and cold pistons can be achieved. However, the more complex system will have more limitations and will require higher initial and operating costs.

Any CHP system requires a constant fuel supply. The raw biomass materials before reaching the end users should pass through a series of processes known as a biomass supply chain. Each process is associated with the specific sets of knowledge, technology and activity which can also differ from country to country. There will also be potential difficulties related to bioenergy supply chain which may be technical, financial, social, policy and regulatory or institutional and organizational.

The process of the Biomass Supply Chain analysis is illustrated with the Western Isles example which highlights the challenges in this region. It showed supplier comparison, annual fuel requirements and the future prospect for the Western Isles biofuels

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