Technologies for biomass conversion: an overview and aspects to be developed

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1. Introduction

The purpose of this paper is to highlight, referring to the current European context, some aspects related to the energy use of biomass that may interest the industry of agricultural equipment.

Biomass for energy uses is an important element of the EU policy, despite the current not positive economic situation. In fact, most of the initiatives in this sector need incentives or specific regulations - like the compulsory incorporation of biofuels in the fuels for transport - and this is often seen as a weak point by the traditional investors who don't wish to rely on artificial markets. Moreover, the relevant environmental implications are often source of endless discussions.

However, the development of biomass for energy uses (and in general for non-food applications), supported by a long-term political strategy, has several positive aspects for both the agricultural sector and all the connected industries. More in detail:

- it can generate additional income to farmers[i];
- it can support the development of new technologies and skills[ii];
- if well applied and managed it can lead to important environmental benefits.

In this perspective, therefore, it is believed that the field of biomass should be carefully considered by many players.

2. The role of biomasses in the EU

In recent years the European Union has stepped up efforts to encourage the development of an energy policy increasingly sensitive to environmental issues and has taken a leading role worldwide in the fight against climate change.

In 2009 the Directive 28/EC of the European Parliament on the promotion of energy from renewable sources was published. With this Directive, the Commission established a new framework for the renewable sources: In fact, the rule provides for the raising of the global share of renewable energies in terms of final consumption to 20% from the previous value of 12%. The overall target is divided into specific targets for each Member State and there is also a common obligation for the use of renewable energy in transport of 10%.

The Commission has given the Member States the task of outlining their strategies for achieving the common target through the compilation of National Action Plans, containing information about the identification of national targets and of the measures planned to achieve them. Developed on the basis of a format made available by the Commission, the 27 Action Plans provide today an interesting picture according to two different contexts: *Reference Scenario* (Business As Usual) and *Additional Energy Efficiency Scenario*. The first is based on the assumption that new policies for the reduction of energy consumption are not put in place; the latter considers the adoption of additional measures to reduce energy consumptions.

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The 27 documents show that the *Additional Energy Efficiency Scenario* makes possible to reach the target of 20.7% in 2020. Even the transport sector is expected to exceed the target of 10%, reaching a total contribution of 11.3%.

Most Member States have announced to be able to exceed their targets, making possible to transfer their surplus to deficit States. Among these, Italy and Luxembourg have foreseen the need to develop mechanisms for cooperation with other Member States and/or with third countries to achieve their goals. The mechanisms of cooperation introduced by Directive 28 are favorably considered even by surplus Countries, such as Germany and France.

The greatest contribution in achieving the target of 20% in 2020 will come from the electricity sector, with an estimated 34% use of renewable sources, according to the *Additional Energy Efficiency* view. The contributions of the heating/cooling and transport sectors are estimated respectively at 21.4% and 10.2%.

With regard to the development of the different technologies in the electricity sector, the largest contribution is expected from wind with 40.6%, followed by hydropower (30.4%), biomass (19.1%) and, finally, solar (8.5%). The situation is different for the field of heating/cooling systems where the biomass has the main role with a share of 77.6%.

In transport, finally, the main contribution is expected from biodiesel (64.8%), followed by ethanol (21.7%).

Table 1 and the **Figures 1** and **2** show the situation for 2005 and 2010 and the forecasts for 2020 in terms of contribution of renewable sources and biomass source in the sectors of electricity, heat/cooling and transport: biomass will play a key role in the EU and in all Member States.

Plans similar to that of Europe are being developed in other non-EU countries and even in these cases the role of biomass is always important[iii].

As a conclusion, we can say that the development of renewable energy in Europe relies on the use of biomass in a substantial way.

3. Which biomasses and for what

Biomass is usually widespread at regional level or concentrated in large quantities at processing centers as process by-products or waste materials, collected for disposal. The current discussions about the different types of biomass are on the following issues.

- *General environmental aspects*: the most important is probably the subject of the *indirect land use change* (ILUC) that arises when an existing agricultural land is turned to biomass production for energy purposes. In these conditions, probably the agriculture has to expand elsewhere to satisfy the previous demand for crops for food and feed. This can result in GHG emissions increases, especially from the soil and the removed vegetation. Several studies have shown that, in different situations and even considering the long period (more than 10 years), the balance of GHG emissions is not very interesting or even negative[iv];
- *Local environmental aspects*: the local use of biomass is often linked to problems of emissions, particularly PM and VOC. The problem is particularly acute for small devices that cannot afford (from an economic point of view) complex combustion systems to reduce emissions. In this context, it is necessary to propose to the market optimal couplings between the combustion technology and quality of the biofuel (e.g.: BAT boilers or stoves and wood pellet of high quality). This issue is very important, because the attainment of Community objectives for 2020 relies substantially on this solution (e.g.: in Italy for about 25% of the target, equal to about 5 Mtoe/year). The problem now affects also the small and medium-sized combustion plants (e.g.:

small district heating plants) and recently the biogas plants, for the increased sensitivity of the citizens to environmental issues.

- *socio-economic aspects related to the acquisition of farmland and to the competition between food and non food crops*: these issues are linked to the rise in the demand for wood and other biomasses, which could outstrip in some developed countries the domestic supply capacity. Although investors in those countries initially tend to use local resources, in the near future tropics and sub-tropics areas could be considered to fill the gaps, leading to the socio-economic issues on which an endless discussion is currently underway[v].

In addition, a further important aspect, not adequately discussed by the literature, is related to the close relationship between costs of raw biomass and costs of produced energy or biofuels: for example, the conversion of woody biomass in power plants is feasible if the raw material cost less than approximately 40-50 €/t (as received)[vi].

All these issues (which are considered in the concept of *sustainability*[vii]) are convincing the potential investors to put more attention on the use of residual biomass for the production of energy and high quality biofuels. In fact, the use of by-products and wastes poses less environmental and social problems (therefore is frequently considered more *sustainable*), while demand for quality - generally difficult to obtain with residues and waste - is mainly due to the problem of control of gas emissions. In this context, dedicated energy crops should be proposed with caution and only when all the requirements for sustainability are fully met.

Therefore, the residual biomass and a selected number of energy crops are potentially interesting for European operators.

The most attractive solutions for the conversion technologies the market are the following:

- complex systems for the production of raw materials (bio-refineries), biofuels and/or energy to be distributed by networks. Currently, these systems are almost specialized in the production of a single biofuel (e.g.: biodiesel);
- small/medium energy conversion systems based on biochemical or thermochemical processes. Examples: district heating plants with or without cogeneration; power plants and biogas plants connected to the grid, etc.;
- small-scale production of thermal energy for industrial or residential sectors (stoves and small size boilers)[viii].

Real bio-refineries are not yet operational[ix] (except the simplest ones), while the other examples represent real options for the market and already well developed.

Generally speaking, the chain conversion of biomass into energy is shown in **Figure 3.** The most interesting phases for the agricultural sector and for the agricultural machinery industry include the supply and at least part of the conversion.

With regard to the phase of supply, **Figure 4** gives more detail of the critical parameters that actually must be improved in order to make logistic costs more compatible with the possible values of energy, of biofuels and the increasing demand of sustainability.

4. The supply chain: aspects to be studied and developed

Different mechanical operations take place before the energy conversion of residual biomass (e.g.: cereal straw, maize stalks, forest residues, etc.) and of energy crops (e.g.: herbaceous crops, short rotation forestry, etc.). The following are the principal steps: biomass harvest and collection, storage, handling, pretreatment (if deemed necessary for the supply chain), and transportation.

The single phases and the aspects that need a development are described below, with reference to solid biomass.

Harvesting: the operations must be cost effective and make available clean biomass from the field or forest. The harvest schedule may be seasonal, due to harvest timing of primary crop and is dependent on weather conditions. The harvest schedule may affect composition and the structural features of the biomass.

In the case of energy crops and of some residues, the existing machinery is generally unable to harvest the desired components of the cellulosic biomass and doesn't meet the capacity, efficiency required by the new crops and their large yields per hectare.

Handling and transportation: these phases require machinery and plants able to manage high volumes and flow rates of material. As known, the main problem is the low density, fibrous nature and the irregular physical characteristics of the raw biomass. The capital and operating costs for the existing equipment and facilities for handling cellulosic biomass generally are not effective and this is one of the most important problems to be solved.

Biomasses may be transported from the field (or the forest) to the conversion plant by truck and/or trains using existing transportation infrastructure. Generally, the transportation infrastructure is one of the least flexible segment of the biomass supply system.

Pre-treatments: these processes should be conceived to improve biomass storability, handling and transport, as well as to prepare the raw material for final conversion into fuels or energy (electricity and/or heat) or, in the case of bio-refineries, chemicals. Pre-treatments could produce materials with characteristics similar to pellets, flours and fluids with different densities, allowing the use of more conventional equipment for handling, transporting and storage. Pre-treatments may include cleaning, separating, sorting; mixing or blending (of different materials); reduction of moisture; increase in density and partial chemical pre-treating. Pretreatments can occur both outside and within the gate of the conversion plant.

Drying is a traditional pre-treatment that offers many advantages in the case of solid biomass but it usually requires high energy consumption. For its minimization, however, driers can be coupled to the plants for energy production (e.g.: using superheated steam drying technology).

Storage: Seasonally available feedstock must be cost effective stockpiled and stored at optimal moisture, minimizing degradation and losses, to provide biomass to the conversion plants during all the year. The analysis and the characterization of the different storage techniques are needed to better define the possible solutions. Important factors are the different physical, chemical and microbiological characteristics of the feedstock (like moisture content), climate, duration of storage and relevant cost. As known, the stored wet biomass is susceptible to spoilage, rotting, spontaneous combustion and odor problems; therefore, the impacts of these post-harvest physiological processes must be controlled for the benefit of the final conversion.

In addition to topics regarding plants and machinery, it should also be pointed out that much remains to be done to increase knowledge about the characteristics of residual biomass and energy crop. For example, important aspects are those related to the possible alteration of the physical state (e.g.: during storage) and to the monitoring of quality.

5. Final remarks

This brief report argues that the interest of agricultural machinery companies should cover the collection, pretreatment, storage, transportation and primary processing of biomass at the conversion plant. All this assuming the necessary political support to the expansion of renewable energies.

Among the various biomass chains mentioned here, in fact, the only one that is expected to expand without special incentives is related to the production of heat for space heating. This is especially true in the case of the small appliances (pellets and wood in logs) and also for the small/medium district heating plants, actually fed with wood chips.

The other chains, based on the creation of medium/large size plants for energy conversion (power plants, simpler bio-refineries), always require incentives or targeted rules. Moreover, to encourage the take-off of investment in larger facilities is necessary to identify the areas with greater availability of biomass, determining the relevant quantity and the quality. In fact, the reliable supply of the biomass at known costs is a strategic aspect for the development of new projects.

6. References

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[i] Farming, especially in some populated countries like Italy, usually accounts for a fairly low or even negligible proportion of the energy consumed. However, many study cases show that it could come to offer a significant contribution to the other sectors by providing renewable energy through the development of energy crops, serving first the civil sector and, where possible, industry. Although the contribution of renewables from agro-forest biomass will always be modest in terms of incidence on overall consumption, biomass production could become a significant production sector, creating new or alternative sources of income for agriculture and other emerging sectors. In the following table the results obtained in Italy from the application of different energy chains based on the use of several types of biomass are summarized.

Biomass chains and their main technical-economic charactieristics (Italian case).

Biomass chain	*Renewable energy yield per surface unit*	*Climate-affecting gases avoided*	*Gross saleable production (GSP)*	*Suitability for local conditions*
Wood energy for heat production by small/medium size boilers	++	++	++	+++
Wood energy for biofuel production (pellet)	++	++	++	+++
Oil energy from small/medium size plants producing • biofuels (oil) • electricity	+	+	++ ++	++ ++
Biogas for electricity production	+++	++	+++	++
Lignocellulosic biomass energy from medium/large size plants for electricity production	++	++	+	++
Oil energy from medium/large size plants for electricity production • seeds only • biofuels (oil) • electricity	+	+	+ ++ ++	++ ++ ++
Oil energy for biofuel production (biodiesel) • seeds only • biofuels (oil)	+	+	+ ++	++ ++
Alcohol energy for biofuel production (ethanol/ETBE)	+	+	+	+

Legend

Renewable energy produced: up to 2 toe/ha: +; 2–4 toe/ha: ++; > 4 toe/ha: +++	GSP: up to 500 €/ha: +; 500 – 1000 €/ha: ++;> 1000 €/ha: +++
CO_2 saved: up to 5 t/ha: +; 5 – 10 t/ha: ++; > 10 t/ha: +++	Suitability for local context: plains, hills, mountains: for 1 context ; +; for 2 contexts: ++; for 3 contexts: +++

[ii] A successful example is energy development from biogas in Germany. Originally conceived to provide an alternative to the poorly competitive livestock farms in post-reunification Eastern Germany, biogas generation from farm crops has promoted the development both of the relevant technology and of a vital industry[ii] [Möller 2009], as summarized in the following Table.

Highlights of the development of the German biogas industry (adapted from Möller 2009).

Item/Year	*2005*	*2006*	*2007*	*2008*	*2009*
No. of plants	2,600	3,500	3,710	4,000	4,700
Electrical capacity installed (megawatt, MW)	650	1,100	1,270	1,200	1,400
Electrical energy produced (Terawatt/hour/year, TWh/y)	2.8	>5	7.4	8.2	10.8
Proportion of national electricity production (%)	0.5	>1	1.4	1.6	2
Turnover of the industry (billion €)	0.5	1	0.65	0.6	1.05
Turnover of operators (million €)	360	650	750	800	1,000
Jobs	5,000	10,000	10,000	10,000	10,500
CO_2 reduction (million tonnes/y)	2.5	5	6.4	7	9.3

[iii] For example: In South Korea, the recently approved Renewable Portfolio Standard requires utilities to source ten per cent of their electricity supplies from new and renewable sources, including biomass, by 2022. In the United States, legislation has been passed requiring a quarter of all national energy to be supplied from renewable sources, including biomass, by 2025.

[iv] Generally, the following aspects should be considered:
Displacement effects act across national border. Commodities such as palm oil, soy oil and sugarcane are traded on a global scale. Therefore, displacement effects act across borders. Achieving effective national land-use planning in some producing countries should therefore not be taken as full protection against indirect effects. If, for example, Indonesia were to prevent further deforestation through effective land-use planning, sourcing increasing amounts of palm oil from Indonesia for the energy sector may still cause indirect land-use change in other producing countries such as Malaysia.
Displacement effects act across substituting crops. This is caused by the fact that different crops can substitute each other to some extent. For example, if the EU diverts more rapeseed oil production from food to feed then it is likely to increase its imports of vegetable oils. Rapeseed oil or different vegetable oil, as different vegetable oils are to some degree substituting products. Thoenes (2007) states that "*EU palm oil imports have already doubled during the 2000-2006 period, mostly to substitute for rapeseed oil diverted from food to fuel uses*."
Competition for land connects also non-substituting crops. Another reason why displacement effects act across crops is that different (non-substituting) crops can compete for the same agricultural land. A recent example of this occurred in 2008 when high maize prices led farmers in the US to plant more maize and less soy (USDA 2010), which could trigger soy expansion in other world regions.

[v] According to a number of reports, there is already evidence of foreign investors acquiring land in Africa, South America and Southeast Asia to Establish crop plantations for biomass energy. For many experts, this trend, if left unchecked, could increase pressures on land access and food security in some of the world's poorest Countries and communities.

[vi] Relationship between the value of electricity and the cost of biomass for a steam power plant installed in Italy (15 MWe). The following figure shows some parallel straight lines with constant values of IRR (0, 10%,15%, 20% and 25%). Calculations were made without considering depreciation, inflation and taxes. With these simplifications, it is believed that the plant is economically attractive if the IRR is between 15 and 20%. The diamond represents the actual Italian situation for this type of plants (corresponding to a value of 180 €/MWh – sum of the value of the electricity and the average value of green certificates - and to a cost of the biomass of about 45 € /t - 45-50% moisture content w.b.-), situation that could be considered satisfactory. The rectangle represents the range of possible variation of parameters. Note that the cost of the biomass strongly influences the economic performance of the system. The safe supply of biomass at stable costs is therefore a strategic aspect.

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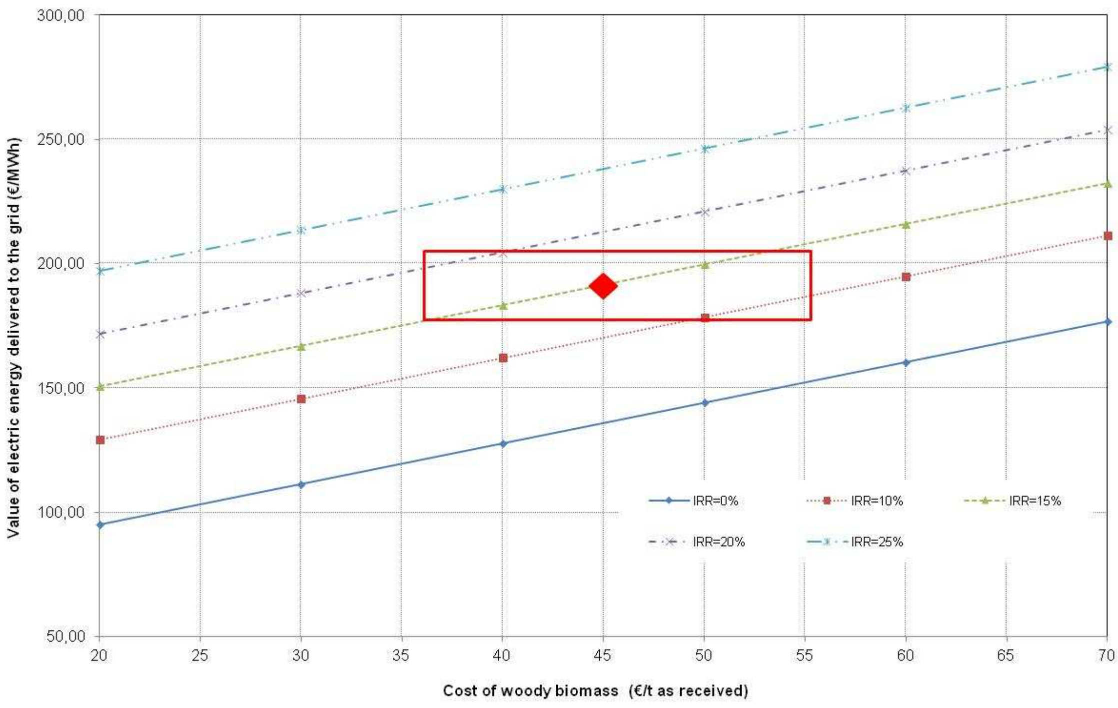


[vii] CEN is developing some technical standards to better define, for biomass, the concept of sustainability, according to the Directive 28/2009/EC. The reason for this work came from the observation that although the biomass has a “green” image, an increasing concern arises about the sustainability of produced biomass (e.g. including impacts on biodiversity, displacement of food production but also the effectiveness in GHG reduction). These concerns have been not only expressed by NGOs, but also by spokespersons in the UN, WTO and EC.
The CEN/TC 383 is preparing a set of principles and criteria, that can be used to establish the sustainability of the biomass produced for monitoring the EU targets and for granting financial support. These standards will allow users to check for the sustainability themes as laid down by the European authorities. This means inclusion of:

- definitions, basic requirements, principles, criteria, indicators and evaluation methods to assess compliance of biomass products to RED (Directive 28/2009/EC) criteria, and
- evaluation methods to assess the capacity of certification schemes and standards to guarantee the conformity of biomass product to the RED criteria.

The actual status of the work is summarized the following table.

Project code	*Title*	*Status*	*Pubblica-tion*
prEN 16214-4	Sustainability criteria for the production of biofuels and bioliquids for energy applications - Part 4: Calculation methods of the greenhouse gas emission balance using a life cycle analysis	Under Approval	2013-03
prEN 16214-3	Sustainability criteria for the production of biofuels and bioliquids for energy applications - Part 3: Biodiversity and environmental aspects	Under Approval	2013-03
prEN 16214-2	Sustainability criteria for the production of biofuels and bioliquids for energy applications - Part 2: Conformity assessment including chain of custody and mass balance	Under Approval	2013-03
FprCEN/ TR 16214-5	Sustainability criteria for the production of biofuels and bioliquids for energy applications - Principles, criteria, indicators and verifiers - Part 5: Guidance towards definition of residue and waste via a positive list	Under Approval	2012-03

[viii] As an example of a chain for the recovery and the local use of biomass, is presented an experience performed within the project *Mixbiopells* (http://www.mixbiopells.eu) partially funded by the EC in the framework of Intelligent Energy Program and performed, among the different partners, by the CTI (Italian Thermotechnical Committee; www.cti2000.it) in co-operation with the *Biomass Laboratory* of the Polytechnic University of Marche (www.biomasslab.it).
The basic idea is to recover the pruning of the vines to produce pellets characterized by an acceptable quality with a set of mobile machines. More in detail:

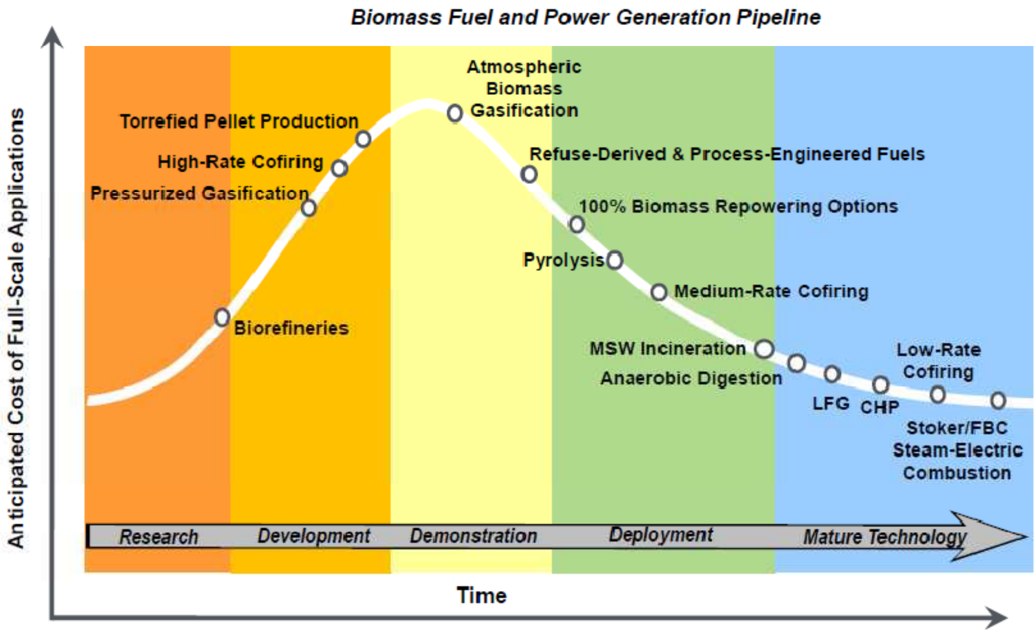
- an machine for collection and chopping of pruning, in order to obtain rapid natural drying;
- a mill for grinding pruning, driven by PTO of a tractor;
- an extruder for pellets driven by PTO of a tractor;
- a burner suitable for this type of pellets and adaptable to different types of boilers.

The industries involved are: MAREV for the collection machine (http://www.marev.it/), MIFEMA, for the mobile milling machine (http://www.mifema.it/it/); GENERAL DIES for the mobile pellet mill (http://www.generaldies.com/index.php) and TERMOCABI for the pellet burner (www.termocabi.it/).
A working group established to discuss the chain stated as follows:

- the costs of production of the solid biofuel produced with a mobile mill is competitive. A first assessment shows costs in the region of 100-120 €/t of pellet;
- the quality of the pellet is acceptable for the use in rural environment (the same farms that have the pruning available or users in the vicinity);
- the chain is quite interesting for contractors.

The following figure from the project documentation illustrating some aspects of the whole chain (Clockwise from bottom: collection machine - *Marev* -; drying phase; milling and refining - *Mifema* -; pelletizing - *General Dies* -; energy conversion - demonstrative burner not coupled with a boiler, *Termocabi* -).

[ix] Construction and implementation of chemical biorefineries will unlikely be immediate, but will probably be a natural progression of existing biomass processing plants, like biofuels. The following image gives a glance on the current positioning of the stage of development of biorefineries in comparison with other processes for the production of energy from biomass (Levine E., 2011. *Utility-scale biomass: cofiring and densification*, DOE).



Source: EPRI Biopower Generation White Paper, February 2010

Figure 1 - Electricity from biomass in the different member States according to the National Plans (source: Beurskens et al, 2011)

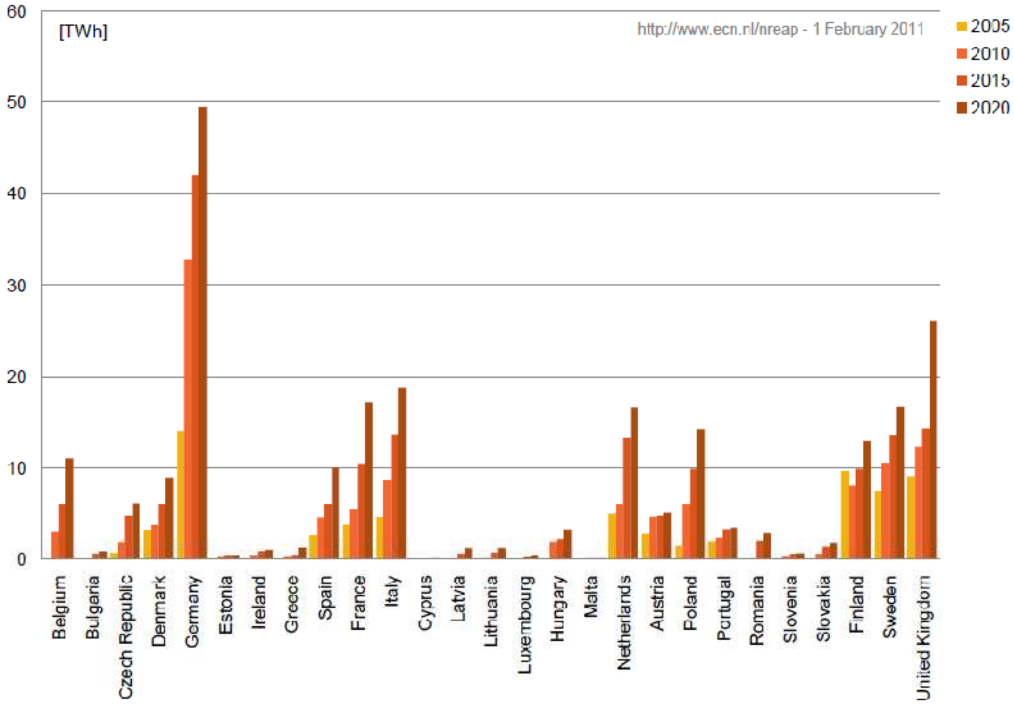


Figure 2 - Heat from biomass in the different member States according to the National Plans (source: Beurskens et al, 2011)

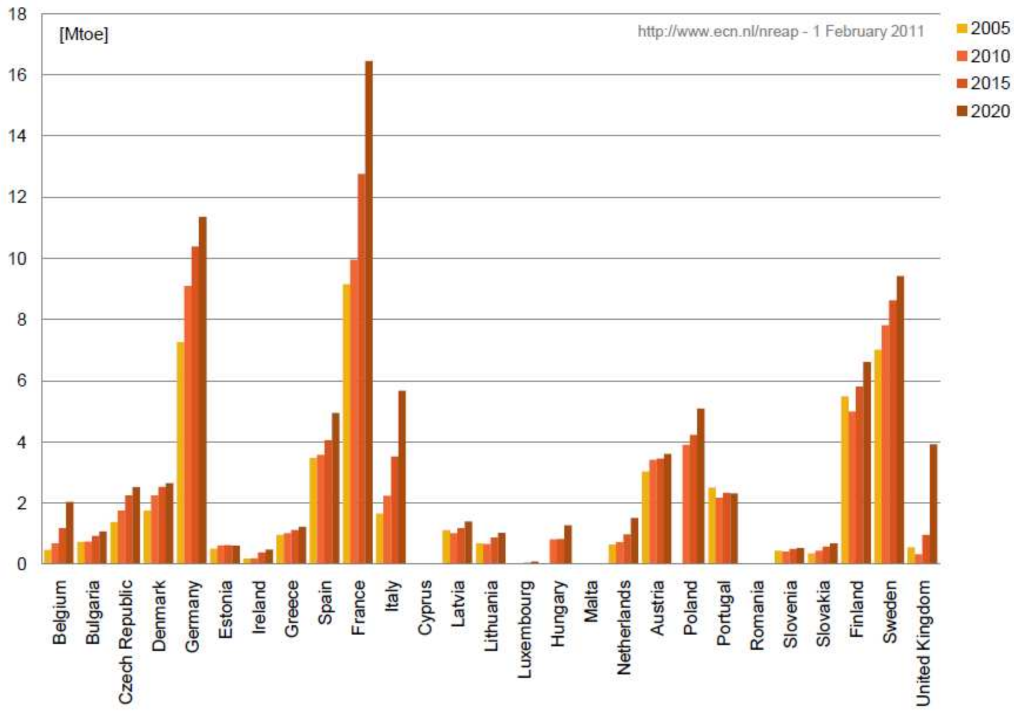


Figure 3 – Main steps of the biomass energy chain

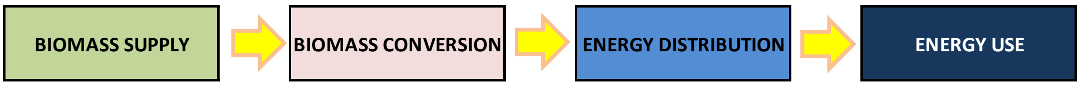


Figure 4 – The supply chain and relevant aspects to be improved (Source: Fraunhofer IML, 2011)

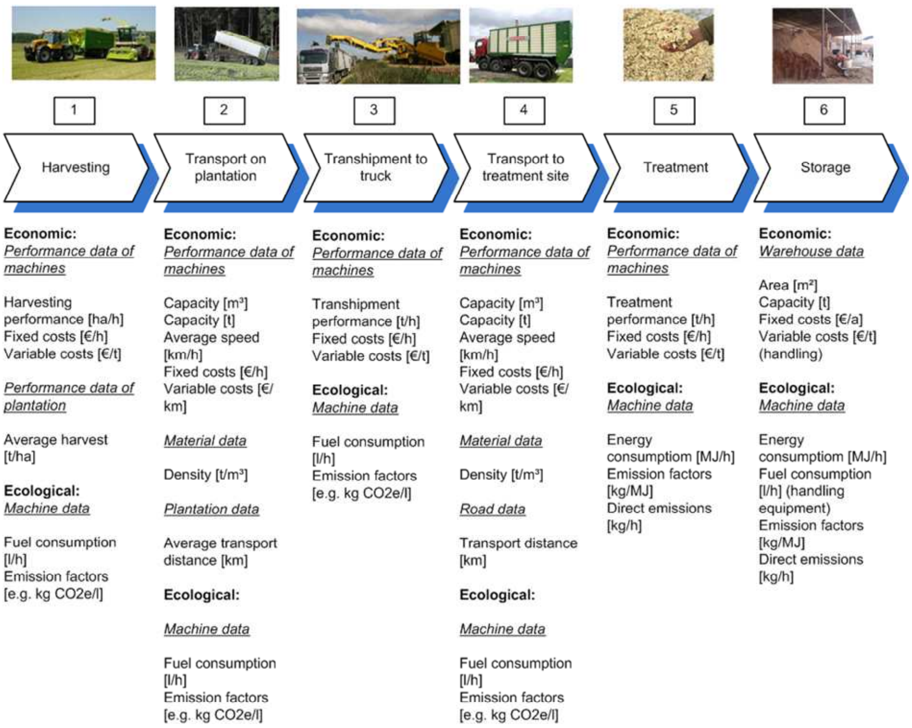


Table 1- Total contribution from renewable energy sources (RES) for all 27 European Union Member States and the role of biomass in the achievement of targets. Note that the latter is predominant over the whole arena of renewable sources

	RES Total (Mtoe)		*Biomass (Mtoe)*		*Biomass / RES Total*	
	2005	*2020*	*2005*	*2020*	*2005*	*2010*
RES – Electricity	41.1	103.1	5.8	19.9	14%	19%
RES - Heating/Cooling	54.7	111.6	49.4	86.5	90%	78%
RES – Transport	3.9	32.0	2.9	28.4	74%	89%