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Technical status of biomass co-firing

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SUMMARY

The biggest share of electricity and heat is still generated by combustion of fossil fuels like coal, oil and gas today. However, renewables become more important in the production of electricity and heat all over the world. Probably the fastest and easiest way to replace large amounts of fossil fuel based electricity by sustainable electricity is to replace the combusted fossil fuels by biomass. Co-firing of biomass fuels in mainly coal-fired units, and thereby replacing part of the coal, has been adopted all over the world the last decennium. This is seen as a short-term solution to exchange traditional fossil fuels such as coal and fuel oil, with a sustainable large scale of solid and liquid biomass types, like wood pellets or palm oil, in order to reach environmental incentives.

Worldwide, about 40% of electricity is produced using coal, and each percent of coal that could be substituted with biomass in all coal fired power plants results in a biomass capacity of 8 GW_e, and a yearly reduction of approximately 60 Mton of CO_2. If only 5% of coal energy could be replaced by biomass in all coal-fired power plants, this would result in a fossil CO_2 emission reduction of around 300 Mton CO_2/year.

The last decade significant progress has been made in the utilization of biomass in coal-fired power stations. Currently, over 234 units have either tested or demonstrated co-firing of biomass or are currently co-firing on a commercial basis. Coal is often replaced by biomass in pulverized coal plants up to 30% biomass, as in Belgium, Canada, Denmark, Finland, The Netherlands, Sweden, United Kingdom and the United States, to mention a few. Some countries adopt a mixture of biomass and fossil fuel in dedicated boilers. Blends of biomass and fossil fuels are utilized commercially in bubbling and circulating fluidized beds in countries as for example Austria, Finland, Sweden and the United States.

Co-firing has expanded in existing pulverized fuel power stations during the last decade, and it is expected that the challenges of the next decade will be to further increase co-firing percentages and fuel flexibility. Whereas, today 30% co-firing is the maximum, the aim of many new and existing coal fired power stations will be to increase the co-firing percentage, in some cases up to 50% or higher. Technical issues such as fuel handling, combustion, corrosion, slagging and fouling, flue gas cleaning, ash handling and health and safety issues will then become more demanding. As a result, these power plants will have to be designed, modified or completely retrofitted such that they are capable to combust high percentages of selected types of biomass fuels together with the coal. Additionally, fuel availability, security of supply and fuel flexibility will emerge more upfront. Sustainability criteria and legislation with respect to ash utilization will be important tools for selecting biomass fuels and co-firing

percentages. Finally, there is a clear trend towards development of methods to produce high quality commodity fuels from a wide feed stock, enhancing flexibility of adopted biomass feed stock at preferably lower costs.

In order to achieve these future goals various co-firing strategies can be followed, such as low percentage co-firing of specific fuel types, retrofitting existing installations for increasing co-firing percentages, or enhancing the input of a wider range of coal and biomass types in specific new or retrofitted boilers. On demand fuel specifications through applying pre-treatment technologies is an alternative route. When designed properly, co-firing of biomass is a short term, flexible solution to significantly reduce fossil CO_2 emissions in many countries.

1 INTRODUCTION

The role of renewables in the electricity and heat production continues to increase on a worldwide basis. Specific policy targets for renewable energy exist in many countries and states worldwide, including all 27 European Union countries, 29 U.S. states (and D.C.), and 10 Canadian provinces [1]. In March 2007, the European Commission published a roadmap with a binding target of a 20% share of renewables in the energy consumption by 2020, and other countries are introducing similar targets.

In the electricity supply industry, more than 60 countries—37 developed and transition countries and 23 developing countries— have some type of policy to promote renewable power generation [1]. At least 44 states, provinces and countries have enacted renewable portfolio standards (RPS), also called renewable obligations or quota policies.

The evolution of electricity production in IEA countries from the 1970s to 2005 is presented in Figure 1. It is clear that the contribution of renewables was still very modest. The biggest share is by far still combustion of fossil fuels like coal, oil and gas. One of the fastest and easiest ways to increase the share of renewables is by replacing fossil fuels with biomass, and the co-firing of biomass fuels in mainly large coal-fired units, and thereby replacing part of the coal, has been adopted all over the world over the past few years. This is a relatively quick method to exchange traditional fossil fuels such as coal and fuel oil, with a sustainable large scale of solid and liquid biomass types, like wood pellets or palm oil, in order to reach environmental incentives.

In the absence of advanced but sensitive flue gas cleaning systems commonly used in industrialized countries, co-firing biomass in traditional coal based power stations will typically result in lower emissions of dust, NO_x and SO_2 due to the lower concentrations of fuel components (ash, sulphur and nitrogen) that cause these emissions. The lower ash content also results in lower quantities of solid residues from the plant.

Worldwide, about 40% of electricity is produced using coal, and each percent of coal that could be substituted with biomass in all coal fired power plants results in a biomass capacity of 8 GW_e, and a reduction of approximately 60 Mton of CO_2 per year. If only 5% of coal energy could be replaced by biomass in all coal-fired power plants, this would result in an emission reduction of around 300 Mton CO_2/year. Co-firing percentages in conventional pulverized coal fired power plants have increased from roughly 1-10% of energy input, to well over 20% over the past decade. In some specific pulverized coal fired installations, 100% conversion from coal to biomass has been demonstrated.

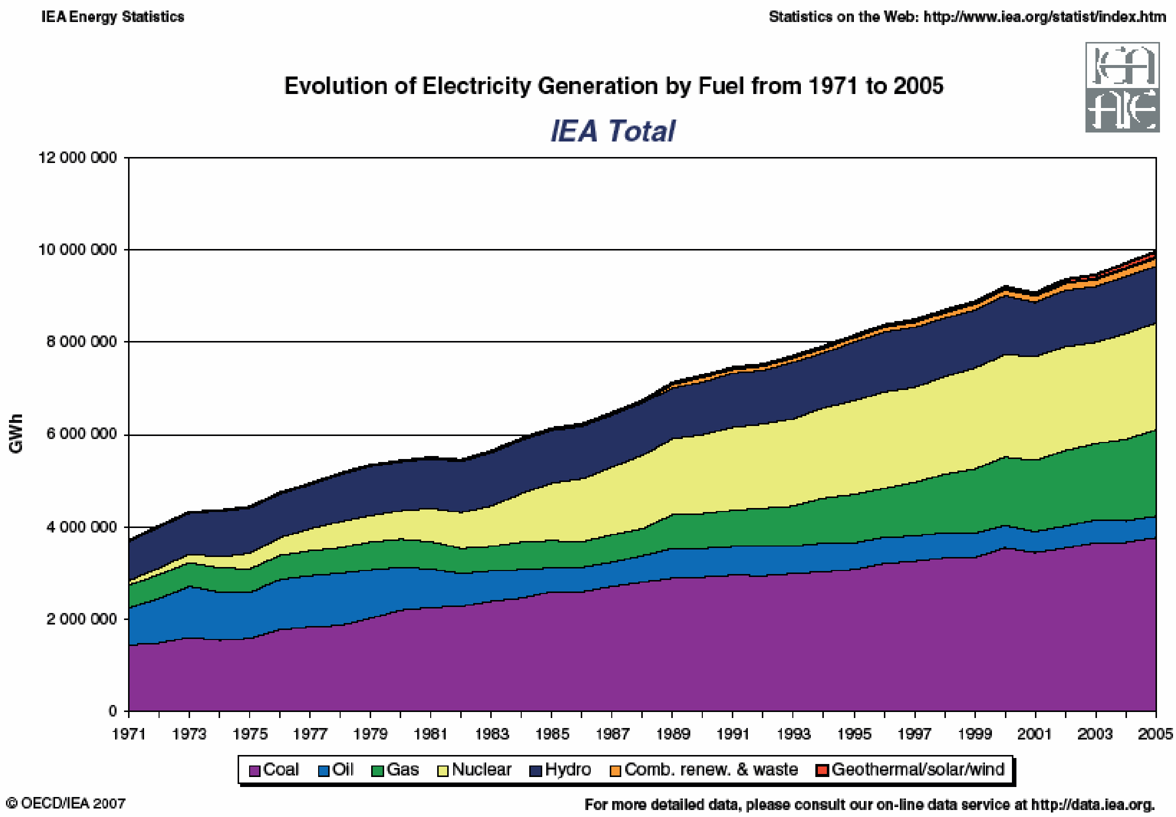

Figure 1 Evolution of electricity generation by fuel in the total of IEA countries [2]

Furthermore, the biomass used in this process would be approximately twice as effective in reducing CO_2 emissions as it would be in any other process, including dedicated biomass power plants. About two-thirds of global coal consumption worldwide is for power generation, and this demand for coal is rapidly increasing, particularly in Asian developing countries.

Biomass co-firing has additional benefits that are of particular interest to many developing countries. Co-firing forest products and agricultural residues adds economic values to these industries, which are commonly the backbone of rural economies in developing countries. Co-firing also provides significant environmental relief from field/forest burning of residues that represent the most common processing for residues. All of these benefits exist for both developed and developing countries, but the agriculture and forest product industries commonly represent larger fractions of developing economies and the incremental value added to the residues from such industries generally represents a more significant marginal increase in income for people in developing countries. Many developing countries are located in climate regions where biomass yields are high and/or large amounts of residues are available. In countries that primarily import coal, increased use of biomass residues also represents a favorable shift in the trade balance. There is experience with co-processing several types of biomass and waste in cement kilns in developing countries, which may, in addition to the above mentioned benefits contribute to improved waste management.

An overview of biomass combustion and co-firing technologies currently available can be found in the ‘Handbook of Biomass Combustion and Co-Firing’ [3], whereas this report serves as an update, specifically to biomass co-firing. Furthermore, the report presents some topics regarding fuel processing as in torrefaction, combustion related problems, gas cleaning and ash handling. Finally, a number of IEA Bioenergy Task 32 members elaborate on the various experiences in their country [4].

2 CO-FIRING GENERAL OPERATIONAL EXPERIENCE

Over the past 10 years a lot of progress has been made in the utilization of biomass in coal-fired power stations. Currently, over 234 units have either tested or demonstrated co-firing of biomass or are currently co-firing on a commercial basis. An overview of the type of installations where this happened is shown in Table 1.

Table 1 Power plants with experience in co-firing combinations of biomass and fossil fuels (derived from Task 32 database, 2009 [4])

country	BFB	CFB	CFB, BFB	Grate	PF	unknown	Total
Australia					8		8
Austria		3		1	1		5
Belgium					1		1
Canada					7		7
Denmark		1		4	7		12
Finland	42	13	6	4	10	6	81
Germany				1	4	22	27
Indonesia	2						2
Italy					6	1	7
Netherlands					6		6
Norway		1					1
Spain		1				1	2
Sweden	3	7		2	3		15
Taiwan		1					1
Thailand		1					1
UK		2			16		18
USA	1	5		5	29		40
Total	48	35	6	17	98	30	234

One of the major applications of co-firing blends of biomass and fossil fuels has been the utilization of fluid beds in pulp- and paper mills and the forestry sector in Scandinavia. This also appears from Table 1. In these installations, ‘reverse co-firing’ is often applied; in this concept relatively small amounts of fossil fuels are added to biomass fuels to improve

combustion conditions (e.g. sulphur rich coal is added to a chloride rich biomass type to avoid corrosion by formation of alkali chlorides on super heater tubes).
More recently, the interest and experience has rapidly grown in introducing biomass in combustion plants that were originally designed to burn fossil fuels. These are predominantly pulverized coal (PC) fired units. Since the potential for utilizing additional biomass for electricity generation is by far the largest in these PC units, this report focuses on this application.

Co-firing biomass residues with coal in traditional coal-fired boilers for electricity production generally represents the most cost effective and efficient renewable energy and climate change technology, with investment costs commonly ranging from 100-600 USD/kW_e depending on the fuel and technical option chosen. The main reasons for such low investment costs and high efficiencies are optimal use of existing coal infrastructure associated with large coal-based power plants, and high power generation efficiencies generally not achievable in smaller-scale, dedicated biomass facilities. For most regions that have access to both power facilities and biomass, this results in electricity generation costs that are lower than any other available renewable energy option and biomass conversion efficiency that is higher than any proven dedicated biomass facility.

A wide range of biomass fuels have been adopted in various co-firing programmes, and even in single installations, trials have been performed with many biomass types. There are however some issues that should be carefully considered. It has been demonstrated that co-firing woody biomass may result in a decrease of boiler efficiency, depending on mainly the boiler type and fuel types used. To be able to fire a diversity of fuel types without influencing the boiler efficiency or capacity and not leading to unwanted effects such as slagging, fouling and corrosion will be an important topic of the near future. In that respect the production and utilization of torrefied biomass will most probably become an important issue on the co-firing agenda.

3 CO-FIRING CONCEPTS

Biomass thermo chemical conversion is achieved by means of combustion, gasification, pyrolysis or liquefaction. Of all these thermo chemical conversion techniques, combustion is by far the most broadly applied, and is in an advanced stage of development, reaching overall plant net electric efficiencies of nearly or over 40% on lower heating value basis.

When biomass is introduced in an existing pulverized coal unit, advantage can be taken of the economies of scale and energetic efficiency of the unit. Commercial availability and plant flexibility are high and investment costs are relatively low.

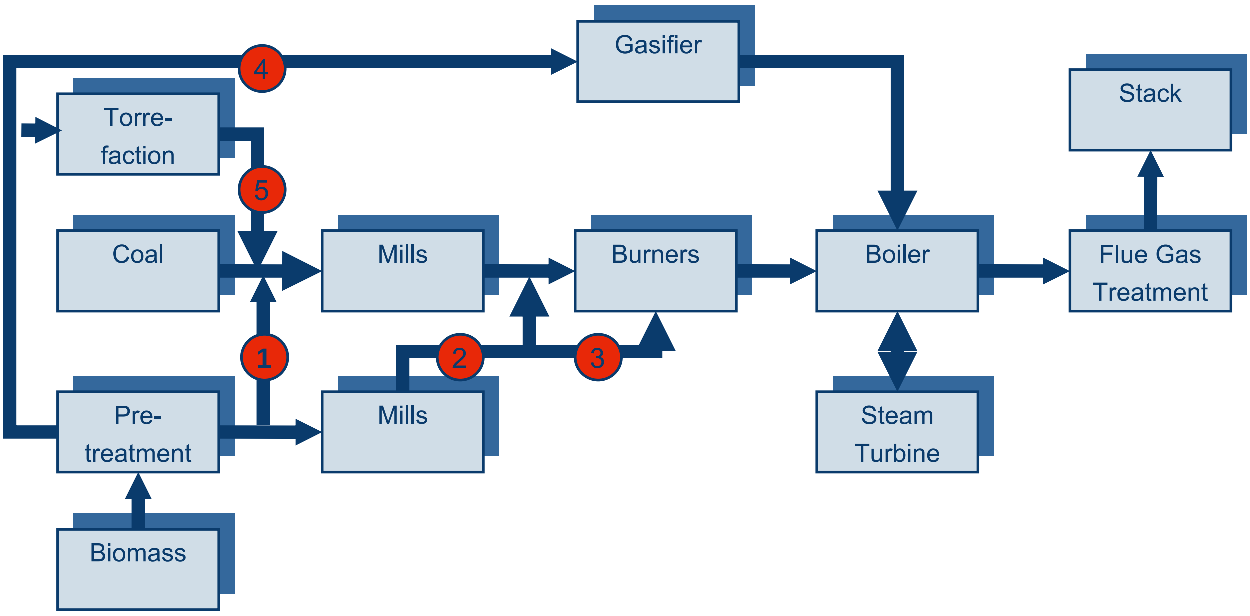

Figure 2 The principal direct and indirect co-firing routes [5]

The great majority of biomass co-firing projects worldwide have involved the utilization of solid biomass materials and have been as retrofits to existing pulverized coal-fired power stations. The options for co-firing in this type of plant can be categorized as follows, and as illustrated in Figure 2 [3]:

– direct co-firing: co-firing by pre-mixing the biomass with the coal and co-milling, i.e. route 1 and 5 in Figure 2
– direct co-firing: co-firing of pre-milled biomass to the coal firing system or furnace, route 2 and 3 in Figure 2

- indirect co-firing: involves the gasification of the biomass and the combustion of the product fuel gas in the furnace, as indicated by route 4 in Figure 2
- parallel co-firing: involves the combustion of the biomass in a separate combustor and boiler and the utilization of the steam produced within the coal-fired steam and power generation systems.

All of the key co-firing options in Figure 2 have been successfully applied at least at demonstration scale, apart from route 5 which involves the utilization of torrefied biomass materials. These are not yet available in industrial quantities.

4 BIOMASS SUPPLY AND DISTRIBUTION

4.1 Biomass fuel characteristics

The principal types of biomass and biomass-based waste materials utilised in domestic, commercial and industrial applications in significant quantities are listed in Table 2. The majority are relatively clean waste and residue materials from agricultural and forestry, and from activities associated with the processing of agricultural and forestry products.

Table 2 The major solid biomass materials of industrial interest on a worldwide basis (Courtesy; Bill Livingston)

Agricultural products	Forestry products	Domestic and municipal wastes	Energy crops
Harvesting Residues	**Harvesting residues**	**Domestic/industrial**	**Wood**
Cereal straws Oil seed rape and linseed oil straws Flax straw Corn stalks	Forestry residues	Municipal solid waste (MSW) Refuse-derived fuels Construction and demolition wood wastes Scrap tyres Waste pallets	Willow Poplar Cottonwood
Processing residues	**Primary processing wastes**	**Urban green wastes**	**Grasses and other crops**
Rice husks Sugarcane bagasse Olive residues Palm oil residues Citrus fruit residues	Sawdusts Bark Offcuts	Leaves Grass and hedge cuttings	Switchgrass Reed canary grass Miscanthus
Animal wastes	**Secondary processing wastes**		
Poultry litter Tallow Meat/bone meal	Sawdusts Offcuts		

A high variety of fuels have been tested during one-day tests or trials including wood pellets, demolition wood, sawdust, paper sludge, switchgrass, straw, meat and bone meal, olive cake, sheanut scraps, citrus pellets, rice pellets, soya hulls, cereal residues and rapeseed scraps. Among the fuel types that are used on a commercial basis as co-firing fuel for coal-fired power stations are wood pellets and wood waste, straw, peat, bark and olive waste. Table 3 presents value ranges of a number of properties for common co-fired biomass types.

Table 3 Properties of solid fuels [3]

	Net calorific value (MJ/kg, as received)	**Moisture (wt%, as received)**	**Ash (wt%, dry)**	**Cl (g/kg, dry)**	**S (g/kg, dry)**
Soft wood chips (spruce)	8	50	0,8-1,4	0,05-0,06	0,07-1
Bark	8,2	50	5-8	0,1-0,4	0,1-2
Straw (winter wheat)	14,5	15	4-12	1-7	0,5-1,1
Grass	13,7	18	n/a	2.6-20	0,8-7
Olive residues (from 3-phase production)	8,5	53	2-4	1-3,3	0,9-1,2

4.2 Storage/handling and pre-processing of biomass fuels

Biomass fuels are often difficult to process and handle. Especially when going to high percentages co-firing, a number of aspects has to be taken into account. For example, the reception and storage of the biomass fuel should not be underestimated. Most biomass fuels have a lower calorific value than coal and therefore require larger specific storage place.

Also environmental, health and safety aspects shall be taken into account. This includes the emission of dust mainly in case of open yards and conveyors.

In all organic matters a relative high moisture content promotes micro biotic activity. This micro biotic activity is mostly exothermal under influence of oxygen, leading to the heating of the biomass material. If the temperature rise is too high, it leads to significant degradation of the biomass, or there may even be a risk of self-ignition of the biomass pile.

Biomass pre-processing prior to firing in pulverised fuel-fired furnaces, usually involves comminution, generally to provide a milled product with a topsize of 1-2 mm. Besides, biomass materials mostly have a fibrous structure, which makes them generally unsuitable for milling in conventional coal pulverizers. Especially when milled together with coal, one has to be careful. That is why biomass particles are mostly larger than coal particles (<100 μm). This may result in incomplete combustion of the biomass particles.

Woody biomasses can be milled together with coal, but co-milling percentages have to be low, with a maximum of approximately 10 wt-% [5]. If a too high percentage is co-milled this may even lead to a significant reduction of the milling performance. Increase in blending ratio reduces particle fineness of the milled material. Often the Hardgrove Grindability Index (HGI) is taken as an indication for milling performance [6]. When considering wet coal or biomass types, the HGI is not a reliable index to predict the milling performance. The milling performance is in general negatively influenced by blending coal with biomass. HGI values of straight coals are lowered by 3 points at 5 wt% blending and 5-8 points at 10 wt% blending [6].

Abrasive wear rates of the mills are also affected by coal-biomass blends. All hardwood blends reduce the wear rate of straight coal. On the other hand, biomass that contains a significant amount of soil and dirt has a negative influence on the wear rate.

The main biomass commodities are:

- untreated, the biomass is only dried and/or chipped
- pelletized, after drying, chipping and/or milling the biomass is compressed in pellets
- thermally pre-treated

4.3 Pretreatment or upgrading technologies for raw biomass

There has been an increase in the interest in the thermal pre-treatment of biomass materials for combustion and co-combustion applications in recent years. These pre-treatment techniques of interest include pyrolysis, steam explosion and torrefaction.

4.3.1 Steam explosion

Steam explosion is a pre-treatment process to separate lignocellulosic materials into their three main components: hemicellulose, cellulose and lignin [7]. Basically, the process involves treating the biomass with steam at elevated pressures for a few minutes and then suddenly reducing the pressure. The term explosion refers to this second step. Due to the mechanical forces of the explosion, the biomass structures break down, and degrade the hemicellulose and lignine components. Steam explosion is thought to be advantageous for hardwoods, however, high pressure and high temperature reactors are needed. The process economics are currently unlikely to be particularly attractive. It is fair to say that this pre-treatment option is still at the development stage.

4.3.2 Pyrolysis

A technology that is already commercially used, is pyrolysis. Pyrolysis processes involve the thermal treatment of the biomass at modest temperatures, generally in the range 400-1000ºC and at oxygen partial pressures below those necessary for appreciable gasification reactions to occur. Pyrolysis of biomass generates three different products in variable quantities: char, gas and oil (tar). Flash pyrolysis gives high specific oil yields, but the technical efforts needed to process pyrolytic oil are challenging at the present stage of development. The liquid that is produced during this process is an emulsion in water, it is corrosive and contains PAC’s which makes it unattractive for storage and handling.

Pyrolysis technologies for biomass materials have not, as yet, achieved full scale commercialisation and that there is little or no practical experience of the long-term operation of industrial scale pyrolysis processes. The majority of the development work on the test rigs and pilot plants has been concerned with the basic performance of the reactors over relatively short operating campaigns, and with the quantification and characterisation of the principal pyrolysis products.

Pyrolysis as a first stage in a two-stage gasification plant for straw and other agricultural materials does deserve consideration [8]. Hamm Uentrop Power Station in Dortmund has installed a pyrolysis unit connected to a main coal-fired boiler, as illustrated in Figure 3. The products from the pyrolysis process are gas, char, metals and other inserts. The pyrolysis gas is injected directly into the boiler, whereas the char is milled in the existing coal mills and is injected in the boiler together with the coal.

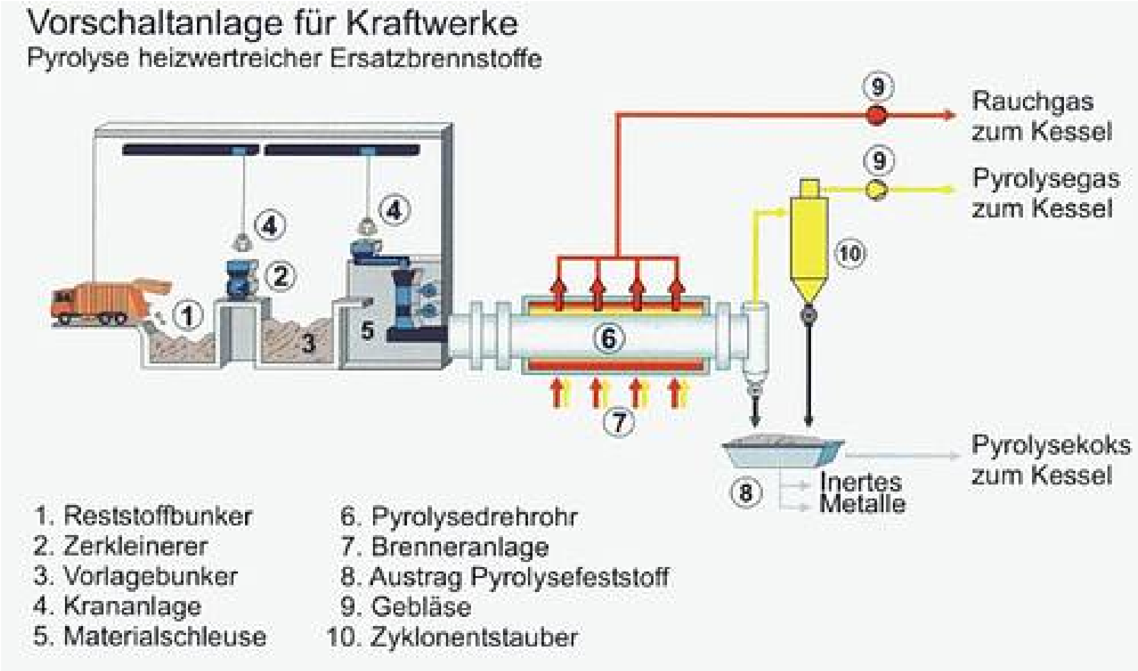

Figure 3 Upfront pyrolysis unit of Hamm Power Station [9]

4.3.3 **Torrefaction**

Torrefaction is gaining interest world wide. Torrefaction of biomass results in a fuel more similar to coal. It is a feasible method for improvement of the properties of biomass as a fuel [10]. The process consists of heating biomass in an inert atmosphere to a maximum temperature of 300 °C. The treatment yields a solid uniform product with lower moisture content and higher energy content compared to those in the biomass feedstock.

Furthermore, completely torrefied biomass has lost its original fiber structure which makes it very suitable to be pulverized in coal mills. It remains to be investigated what the size of the particles should be in order to realize complete combustion during the short residence time in the pulverized coal furnace. Apart from the size of the biomass particles, the burnout time also depends on other properties (density, moisture content, reactivity, et cetera) and the gas phase temperature and composition..

This gives the opportunity for a further increase of the biomass/coal-ratio in power plants. Although torrefaction is an additional pre-treatment step in the biomass value chain, it needs approximately the same energy as an alternative pelletization + transportation route. This can be explained by the fact that the torrefaction gaseous by-product is combusted and the generated heat is used in the process itself. Furthermore the energy density of the torrefied pellets is higher resulting in more efficient transportation. Pellets of torrefied material contain a low moisture content while normal wood pellets contain 10-12% moisture. Most torrefaction concepts also efficiently use the heat from cooling the torrefied material. In this way, torrefaction can be applied with a net efficiency ranging between 70% - 90% depending on the moisture content of the untreated biomass. Only a small fraction of the energy needed for the torrefaction process will come from external energy sources like natural gas and electricity. A net efficiency of 70-90% is comparable to the efficiency of drying and pelletizing of untorrefied wood pellets.

5 COMBUSTION

Many biomass or biomass-derived fuel types have chemical and physical properties that deviate significantly from the properties of coal. The key differences include:

- some biomass materials can have very high moisture contents and may need dewatering or drying prior to combustion
- the majority of biomass materials have lower ash contents than most coals
- the calorific value of most biomass materials on a dry basis is lower than those of most coals
- the volatile matter content of most biomass materials is relatively high compared to those of most coals. This means that biomass materials are more reactive to combustion processes than are most coals. They are easier to ignite, produce a smaller quantity of char and the char particles are more reactive then coal chars
- this means that larger biomass particles, up to 1 mm or so in diameter, can be fired efficiently in pulverized fuel flames
- most biomass materials have significantly lower nitrogen contents than most coals, and this means that the NO_x emission levels from biomass combustion tend to be lower than from coal combustion.

Not only biomass fuels often have a completely different character than coal, but the differences between various biomass types may be just as large. The physical structure, chemical composition and calorific value of the fuel will influence the combustion process in the boiler. Therefore co-firing certain types of biomasses may result in several challenges. Figure 4 presents how these properties affect design, operation and performance of co-firing systems.

When going to direct co-firing percentages of approximately up to 10% (thermal), it is often chosen to inject the biomass in the existing coal firing system. This is a relatively simple solution. The biomass fuel is milled in dedicated mills, and the milled biomass is then injected in the pulverized coal lines. The preferred injection locations are at the mill outlet or close to the burners [13].

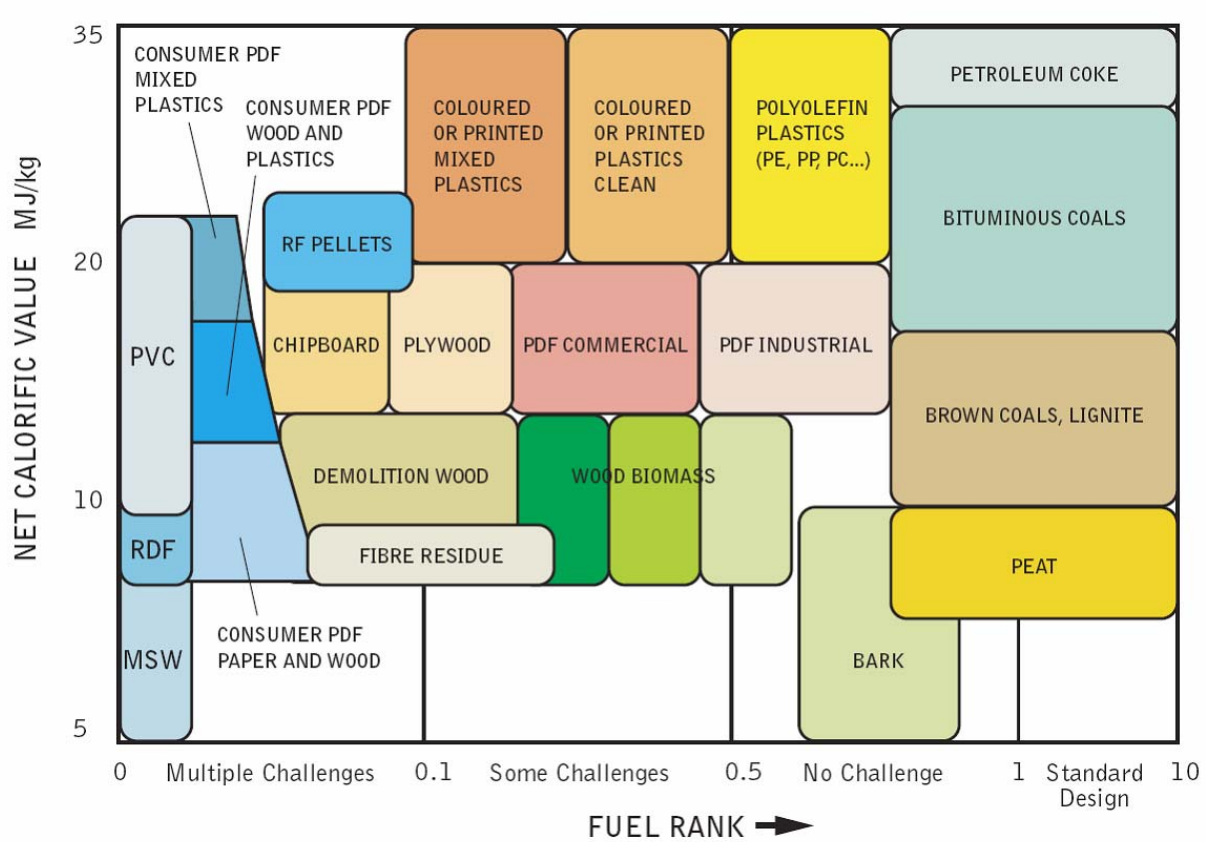

Figure 4 Influence of fuel characteristics on boiler design [11]

An alternative way to enhance co-firing percentages is by using dedicated biomass burners. However, depending on boiler design, modifications in and around the boiler may be necessary, making it a more challenging option.

As a general guideline for measures that have to be taken to the burner system [5]:

0-10 wt-%	in general no or minimal measures have to be taken with respect to burner settings
10-50 wt-%	possible modification of the pre-processing is necessary and also adaptation of the burner settings, e.g. with respect to combustion air. Possible limitations on the types of biomass that can be co-fired using the original burners
50-100 wt-%	adaptation of the burner settings or complete replacement of the current burners by new ones.

6 GAS CLEANING AND ASH HANDLING

6.1 Slagging, fouling and corrosion

With fouling and slagging the fly ash is attached to the boiler wall and the heaters (super heater, reheater and economizer). In the furnace section, slagging is the dominant mechanism, while in the convection section fouling is the dominant mechanism. Due to slagging and fouling heat transfer is reduced, which reduces the overall plant efficiency, and the risk of corrosion increases. It is difficult to predict slagging and fouling, and several formulas for specific installations have been derived.

Slagging and fouling experiences are available for individual biomass types, for example in the U.S., or for coal blends, for example in the Netherlands [5]. When considering a blend of coal and biomass, it is not possible to treat the blend as the weighted average of its components. Therefore it is important to monitor slagging and fouling inside the boiler until enough experience is obtained.

The ash deposition layer on the boiler wall or heater tubes may lead to corrosion. In general it can be said that high chlorine content promotes the risk of corrosion, while high sulphur/chlorine-ratios reduces the risk of corrosion. This is a further factor which may, in some circumstances, tend to limit the acceptable maximum co-firing ratio for specific biomass types.

As a result, the increased risk of slagging and fouling and possible boiler tube corrosion may limit co-firing levels. Therefore, it is important to know the combustion conditions inside the boiler, and to be careful with high chlorine-content biomass types.

6.2 Ash quality

In traditional pulverized fuel boilers, two types of ashes are identified: bottom ash and fly ash. The bottom ash consists mainly of ash in the flue gas that is condensed on the super heaters and builds up until it drops to the boiler hopper due to its weight. It also consists of particles that are injected in the boiler that are too heavy to be lifted by the flue gas flow. Fly ash is the ash that exits the boiler with the flue gas. It can be captured by flue gas cleaning equipment or may leave the stack as dust.

Most IEA countries have strict limitations on dust emission. For example, the European Directive on the limitation of emissions of certain pollutants into the atmosphere from large combustion plants (LCPD) states emission limit values of 100, 50 or even 30 mg/m_0^3 (at 6% O_2, dry in the flue gas) for solid fuels. National governments may even apply lower emission limit. Therefore, most large scale (> 50 MW_{th}) solid fuel power generators contain dust collectors. The most commonly applied types of collectors are fabric filters and electrostatic precipitators.

Most governments encourage utilization of ashes instead of landfill. Ashes from dry and wet bottom boilers are interesting materials to be utilized in building industry and civil engineering. An important and high-grade utilization of fly ash is as pozzolanic addition in concrete and cement. The current European standard "Fly ash for concrete" (EN 450) allows that fly ash may originate from co-combustion up to 20% (mass) fuel based and 10% (mass) ash based (the type of biomass that may be co-fired is also defined). However, the ASTM standard (C-618) on the utilization of fly ash in the concrete industry states that the fly ash shall be completely originate from coal.

Most biomass types are much lower in ash content than coal. As a result, co-firing a significant amount of biomass may lead to a reduction of the amount of fly ash.

6.3 Atmospheric emissions

The effect of co-firing on the emissions can be seen two-fold:

- co-firing influences the actual emissions of certain components to the atmosphere. In most cases, emissions of pollutant elements are reduced due to co-firing. This is mainly due to the low concentrations of these elements in the secondary fuel. Elements such as sulphur, nitrogen and mercury are in general present in a lower content in biomass than in coal, even when compared on heat input basis. However, experimental characterization of NO_x-emissions during combustion of coal, biomass and various blends of the two fuels, particularly at low co-firing ratios, has resulted in NO_x-emissions from biomass-coal blends both greater and less than those from coal alone [3]. Some secondary fuel streams contain a relatively high concentration of Cl. As a result, the emission of HCl may increase. In some cases, demolition wood is used as secondary fuel. When co-firing demolition wood there is a risk of increased emission of heavy metals such as lead and zinc. There are no clear indications that the emissions of polycyclic aromatic hydrocarbons (PAH) and dioxins are increased by co-firing
- based on the secondary fuel type (such as some types of demolition wood), the unit may not be regarded as a large scale combustion plant, but as a waste incinerator. In that case, the emission limit values do no longer have to comply with the LCPD, but to the

emission limit values according to the Waste Incineration Directive (WID). The consequence of this should not be underestimated, because the WID emission limit values are in general more stringent than the LCPD emission limit values. As a result, a plant compliant to LCPD emission limit values when running on coal only, may not be compliant to the WID emission limit values when a mixture of coal and secondary fuel is used:

- in case the mixing rule applies the emission limit value results from a corresponding mix of the individual emission limit values for combustion plants and waste incinerators. Then, co-firing these types of biomass are often feasible, especially when co-fired at small percentages
- in case the mixing rule does not apply, it may occur that the unit is considered as a waste incinerator. Then, co-firing these types of biomass may not be feasible.

7 CARBON FOOTPRINT AND SUSTAINABILITY

An increasing number of different biomass fuel types is commercially used in co-firing installations. Often these fuels have to be transported over tens to hundreds of kilometers by truck, train or barge, or even thousands of kilometers by ocean freight carriers. In that respect it is of major importance to be able to classify each fuel type on sustainability. In the Netherlands a governmental project group complemented by stakeholders from industry, trade and banks developed criteria for the sustainable use of biomass. These are called the Cramer criteria.

It is undeniable that current firing of biomass materials, especially for the use of mobility, has resulted in a local increase of the price of crops. Therefore, in some other countries in Europe (Germany and the UK) there was a food versus fuel discussion which resulted in several initiatives in the EU.

Currently, the EU is working on the revision of the Renewable Energy Directive (RED) of 2005, and it is expected that in 2009 a revised version will be available. As a consequence standards for the sustainability of biomass will be developed by CENELEC. For this purpose a CEN TC 383 working group is formed who will develop the standards based on the RED the coming three years. These standards will be applicable in all European countries. A number of countries will incorporate the standards in their national law. Important features of the standards will be the Greenhouse Gas Emission Balance, calculations and fossil fuel balance (over the whole biomass chain, LCA, CO_2 footprint) with a minimum overall CO_2 efficiency 35-40%. in 2011 and 50% in 2017 (proposal). Other aspects to be discussed are; competition with food or other local applications, biodiversity, environmental issues, economic and social aspects, verification and auditing and macro economic effects.
In the Netherlands a technical agreement on these issues based on the Cramer criteria (NTA 8080) is in place from January 2009. The greenhouse gas balance for co-firing biomass in coal-fired units is 70%, for gas-fired stations this is 50% as it is for transport fuels.

The Belgium green certificate (including a CO_2 calculation) is in place and verification is performed by SGS for the Belgian Government.

The CO_2 footprint consists of a CO_2 calculation over the whole biomass chain and includes fertilizers used for energy crop and emissions thereof, emissions evolved during harvesting, treatment (for example chipping and pelletizing), transport, and replacement of CO_2 from fossil fuels.

8 STATUS OF CO-FIRING IN IEA COUNTRIES

This section discusses the status of co-firing in a number of IEA countries.

8.1 Austria

Gerold Thek, Ingwald Obernberger, BIOS Bioenergiesysteme GmbH, Austria.

In the mid nineties a big Austrian utility started co-firing of biomass in two coal fired power plants. However, both of them have been phased out in 2001 and 2004, respectively. Moreover, several co-firing plants are running in the pulp and paper industry as well as in the chemical industry. A selection of Austrian co-firing plants is shown in Table 4.

Table 4 Selected co-firing plants in Austria (status May 2009)

Plant	Owner	Plant output (MWe)	Plant output (MWth)	Direct co-firing percentage (NCV)
Zeltweg	Verbund Austrian Hydropower AG	137	330	3
St. Andrä	Verbund Austrian Hydropower AG	124	284	3
Lenzing	Lenzing AG	40	108	64,6
Frantschach	Patria Papier & Zellstoff	17	61	99

The technology, which has been realised in large-scale by the Austrian utility company VERBUND in the pulverised coal combustion power plant in Zeltweg in 1997 in the framework of the EU Thermie project BioCoComb [17] was biomass gasification and utilisation of the product gas as fuel in a coal combustion system. This technological approach foresees the gasification of biomass in a CFB reactor. The product gas is fed to a coal combustion power plant where complete burn-out of gas and char particles takes place [18]. Due to the liberalisation of the European electricity market, the whole power plant Zeltweg was shutdown in 2001.

In another power plant of the Austrian utility company VERBUND (coal-fired power plant in St. Andrä) the technology of co-firing of biomass on a separate grate directly under the coal-fired boiler [19] has been applied from 1995 till 2004. In 2004 the power plant was shut down. This concept is based on the combustion of biomass on a grate which is directly integrated in the coal-fired boiler at the bottom end of the boiler hopper. On this grate biomass combustion as well as the burn-out of coal ash particles takes place. The flue gas produced is mixed with the flue gas of the coal burners.

Moreover, in Austria biomass co-firing in circulating fluidised bed (CFB) and bubbling fluid bed (BFB) combustion systems is applied in several CHP plants in the pulp and paper industry. A wide variety of biomass fuels are used (bark, wood residues, black liquor, sewage sludge) in BFB or CFB furnaces. The biomass fuel fraction in the feed varies between 5 and 99%. A selection of plants in this sector is shown in Table 4.

The current economic framework conditions in Austria are not as good as they should be in the point of view of renewable energy usage. This situation becomes evident when looking at the plants in operation. Co-firing in Austria only takes place in industries where biomass fuels are available as residues, e.g. in the pulp and paper industry. The only two coal fired power plants operated from utilities, which ever have applied biomass co-firing, have been shut down. This is mainly due to the low feed-in tariff for electricity from co-firing plants, which amounts to 6.28 €Cent/kWh$_e$, when untreated biomass like forest wood chips is used. This tariff decreases in case of use of by-products from sawmills by 25% and in case of use of demolition wood by 40% [20]. Compared to the market price for base load (see Figure 4) it can be seen, that only the feed-in tariff for co-firing forest wood chips is usually higher than the market price (except in 2008) and that co-firing with other biomass fuels like by-products from sawmills or demolition wood would not be beneficial.

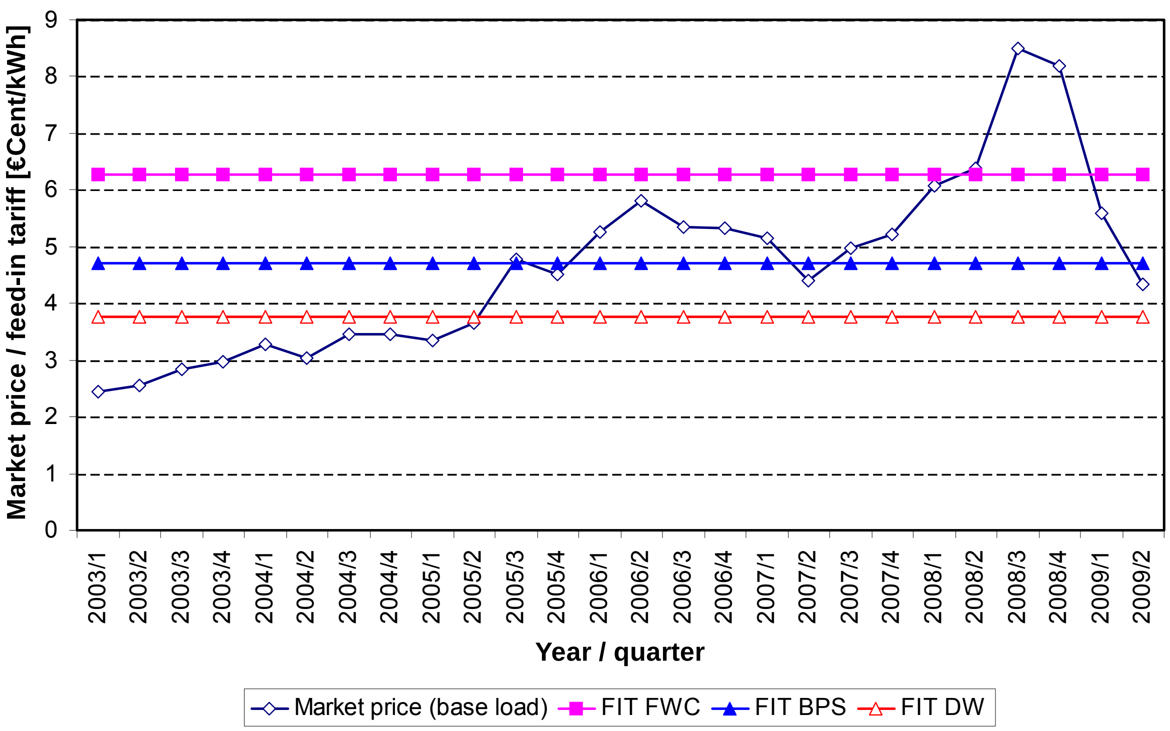

Figure 4 Market price for base load electricity compared to Austrian feed-in tariffs for co-firing plants (FIT: feed-in tariff, FWC : forest wood chips, BPS : by-products from sawmills, DW : demolition wood) [21]

In order to support electricity generation from biomass by co-firing in coal fired power plants in Austria the support regime would have to be changed appropriately in order to make it financially attractive. Austria is mainly focusing on decentralised pure biomass applications. Biomass co-firing is not major objective at present.

8.2 Belgium

Michaël Temmerman, Département Génie rural Centre Wallon de Recherches agronomiques, Belgium.

In Belgium, the take off for co-firing and biomass utilization to produce electricity has started after the “green certificate” system implementation, which was decided by government decree in 2001.

At the end of year 2007, Electrabel, the Belgian historical electricity producer, produces in Belgium electricity from renewable energies at a capacity of 402.7 MW_e. The objective of the company is to double this capacity by 2015. Among these renewables, biomass accounts for 78% and 314 MW_e.

Small scale cogeneration units and biogas production from waste are responsible for a total power output of around 10 MW_e. Another 300 MW_e is produced by 5 power plants. The Les Awirs power plant is fed by 100% biomass, has a power output of 80 MW_e, and needs 1000 tons/day. The 4 remaining power plants have 220 MW_e power all together and use wood and olive residues as biomass fuels for co-firing.

Due to the green certificate context, a biomass certification procedure is applied to imported biomass. This procedure controls a set of criteria related to sustainable development of the supply chain of the biofuel power plants. As a consequence, sustainable resource management, for example for forest, is controlled in regard to national and international laws. The traceability of the product from resource to final product use at the power plant has to be shown. Finally the energy and carbon efficiency of the supply chain has to be calculated and is taken into account for green certificate attribution

8.3 Canada

Sebnem Madrali, Department of Natural Resources, Canada.

Canada is made up of ten provinces and three territories. Each of these jurisdictions have significant influence over the electricity sector. There is also a wide diversity of prime energy sources by province/territory. Figure 5 shows the Canadian energy supply distribution. Therefore the opportunity and business case for biomass to electricity conversion varies across these jurisdictions and is not accurately presented in that fashion.

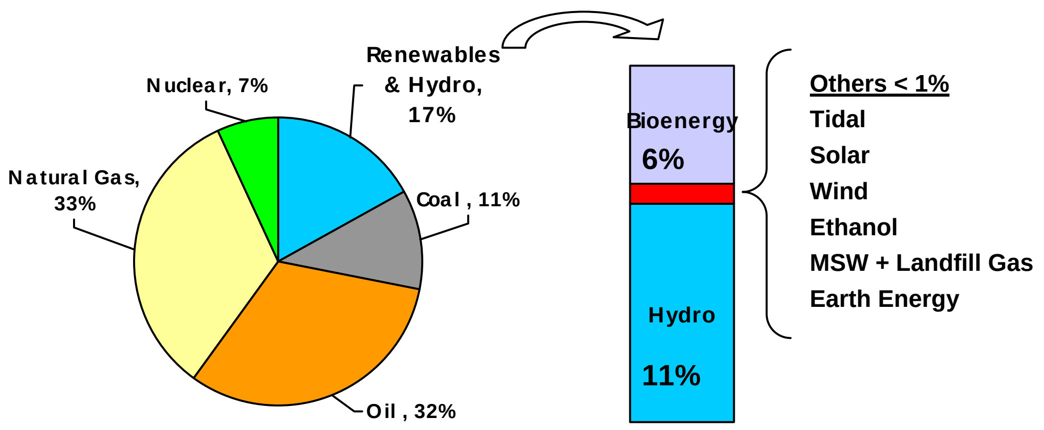

Figure 5 Canadian energy supply distribution.

8.3.1 Nova Scotia

Nova Scotia is a small province of under 1 million people on the eastern coast of Canada. It has indigenous coal reserves and though the majority of mining operations have shut down, the legacy of using coal lives on with over 70% of electrical energy being produced by coal or petroleum coke. The majority of the solid fuel is imported from South America and the US.

Nova Scotia also has an established biomass sector with supply and demand maintaining a balance of about 1 million tons per year. The market is large paper mills (in province), pellet export and small independent power producers (IPP's).

The regulated electric utility, Nova Scotia Power (NSP), is interested in adding biomass to its fuel portfolio by both adding new energy sources by small IPP's and co-fire in the existing solid fuel fired thermal generating units.

One of the eight solid fuel units (Point Aconi, 183 MW_e) has a circulating fluidized bed (CFB) combustor. NSPI has successfully demonstrated co-firing varying percentages of hog fuel milled to minus 6 mm. Based on the testing, NSPI intends to issue a Request for Expression of Interest (RFEI) for a multi-year hog fuel supply of up to 50,000 tons per year.

The Trenton 6 generating unit was designed to burn lower grade bituminous coals and as such has some capacity to co-fire biomass at higher blends. Plans are proceeding for co-firing demonstrations at that unit. NSPI would then continue demonstrations with the remaining thermal units.

NSPI's other area of work is establishing a sustainable supply and growing the industry rather than competing for the existing market. The major opportunity exists on land that had been previously farmed and now is grown over with under utilized species. Putting some of that 400,000 ha back to work would mean substantial economic growth in rural Nova Scotia.

8.3.2 **Ontario**

As one of the largest producers of electricity in North America, Ontario Power Generation (OPG) operates 64 hydroelectric, 5 fossil and 3 nuclear stations with a capacity of more than 22,000 megawatts of electricity. OPG has over 8,500 MW_e of fossil generation capacity including four coal-fired plants (6400 MW_e) and one dual fuelled by oil and natural gas (2100 MW_e).

The Ontario government has implemented a phase-out date of 2014 for all coal use in Ontario. Converting its existing coal-fired generating capacity to biomass firing/co-firing would allow OPG to maintain and utilize infrastructure. Encouraged with the results obtained during test trials with variety of biomass materials, OPG currently focuses on addressing technical issues in transforming its coal-fired plants and systems to biomass, including a supply chain for the feedstock. The biomass sources considered as fuel include wood and agricultural pellets and agricultural by-products.

OPG's Nanticoke Generating Station (generating capacity of about 4000 MW_e) on Lake Erie has been running test burns on a regular basis that adds biomass in the form of wheat shorts, grain screenings and wood pellet to the coal mix since 2006. The future phase of the test program plans longer duration burns and has completed a short 100% biomass test on one of the plants eight generating units. OPG's Thunder Bay Generating Station (306 MW_e) has conducted test burn using pelletized grain screenings. More intensive testing is planned later this year. The Atikokan Generating Station (211 MW_e) has been testing wood pellets with considerable success including 100% biomass fuel in the summer of 2008. The program will include longer duration tests to determine the sustainability of using biomass fuel over an extended period of time. The Lambton Generating Station (1976 MW_e) on the St.Clair River has also completed a short test co-firing with agri products. OPG is completing a detailed Health and Safety Review at all plants before it resumes testing.

Utilizing biomass in power generation offers a great potential to create opportunities for Ontario's agricultural and forest industries that grow and make biomass products; however, it also creates challenges. Technical and non-technical issues to consider and must taken into account include the effect of biomass on the equipment and operation, sustainable supply with minimal impact on other resource users, processing, transportation, storage and pricing of both the biomass fuel and the renewable electricity produced. OPG currently works with many stakeholders to resolve these issues to determine whether or not it is feasible to pursue the biomass option on a commercial scale.

8.4 Denmark

Anders Evald, Force Technology, Denmark.

Biomass for power production was introduced in different sectors in Denmark since the 1980'ies. Co-firing is just one out of several technologies implemented; on a broad term these technologies include:

- co-firing wood or straw in medium to large scale power plants (large boilers, steam technology)
- dedicated biomass fired combined heat and power plants (smaller boilers, steam technology)
- dedicated biomass fired boilers coupled to the steam cycle of a larger coal-fired power plant (large boilers, steam technology)
- pilot and demonstration plants for dedicated biomass power in small scale (small systems, gasification, stirling engines and other new technologies).

Table 5 Current status of co-firing in Denmark

Power station	Unit	Owner	Plant output (MW_e)	Plant output (MW_{th})	Direct co-firing percentage (heat)
Studstrupværket	4	DONG Energy	350	455	7
Studstrupværket	3	DONG Energy	350	455	7
Amager	1	Vattenfall	80	250	0 to 100
Avedøre main boiler	2	DONG Energy	365	480	70
Avedøre straw boiler	2	DONG Energy	1)	1)	100
Grenaa Co-Generation Plant	1	DONG Energy	19	60	50
Herningværket	1	DONG Energy	95	174	70
Randers Co-Generation Plant	1	Energi Randers	52	112	35
Ensted biomass boilers	3	DONG Energy	630 2)	95 2)	100

1) capacity is included in the figure for the main boiler

2) biomass boilers supplies steam corresponding to 40 MW_e out of block unit total 630 MW_e

Studstrupværket are two identical coal-fired block units equipped with facilities to handle and co-fire 10% on energy basis straw. On an annual average, 7% is reached. Whole Hesston bales of straw each about 500 kg are received in the plant. The two units together use 100,000 to 150,000 ton/year of straw.

The new Amager unit 1 is a new block unit retrofitted into the building of the old unit no.1. It is a suspension fired power boiler with very large fuel flexibility; among others solid biomass fuels, straw and wood can be co-fired from 35 to 100% of block unit capacity along with coal (only 90% percent capacity can be reached during straw-only operation). Also fuel flexibility exists to co-fire biomass with fuel oil. Wood and straw are both supplied as pellets. Annual consumption is not yet known, and will depend on fuel prices in the future.

The plants Ensted 3 and the biomass boiler in Avedøre 2 are dedicated, grate fired biomass boilers supplying steam to the main block unit.

The straw boiler in Ensted 3 uses about 150,000 ton/year of straw received in Hesston bales, while the wood chips consumption is about 30,000 ton/year in a boiler, which operates as a super heater using the steam from the straw boiler.

The straw boiler in Avedøre 2 uses about 150,000 ton/year of straw, received as Hesston bales. The Avedøre main boiler can burn a mixture of wood in suspension firing along with natural gas and/or fuel oil. Typically wood supplies 70% of fuel on heat basis, but the unit can operate very flexible from this point, up and down. Wood is supplied as wood pellets, annual consumption between 150.000 and 300.000 ton/year.

The Grenaa unit is a CFB boiler designed for a 50/50 (energy basis) mixture of straw and coal. Annual straw consumption is about 50,000 ton/year, received as Hesston bales.

Herningværket was recently retrofitted for larger biomass fractions, currently about 70% on heat basis; fossil fuel is natural gas and fuel oil. Biomass is forest wood chips; the annual consumption is in the order of 230,000 ton/year.

The Randers co-generation plant was recently retrofitted for wood chip combustion in co-firing with coal. The boiler is fed by spreader stokers, and the boiler is equipped with a grate. Expected consumption of forest wood chips is about 65,000 ton/year, representing about 1/3 of the plant annual fuel consumption on an energy basis.

Driver for the majority - in terms of volume - of biomass power in Denmark is a specific scheme set up by the Folketinget (parliament) in the early 1990'ies. This scheme requires power plants to use a certain amount of biomass annually, total currently 1.4 million ton/year.

In early 2008 this figure was increased with an additional 0.7 million ton/year as part of a political agreement that opens for increased coal use in power plants earlier restricted through legislation.

Added to the political pressure in this kind-of quota system, power companies also receive up to 3 different bonuses for using biomass for electricity production:

1. A fixed/guaranteed minimum tariff for renewable electricity, which includes the market value of electricity (the actual wholesale price) as well as a subsidy element up to the fixed minimum tariff in the case where market value is less than the fixed guaranteed tariff. Biomass electricity is eligible to this bonus for 100 % of the biomass based kWh determined through allocation of the total fuel consumption on an energy basis.

2. A Renewable Electricity bonus of 0.10 DKK/kWh (for newer plants 0.15 DKK/kWh). Biomass electricity is eligible to this bonus for 100% of the biomass based kWh determined through allocation of the total fuel consumption on an energy basis.

3. A subsidy per ton on biomass used, between 0 DKK and 100 DKK per ton, distributed to eligible power plants and calculated from a need-principle based on the economic

performance of the individual plant (biomass type and price, installation type, electric efficiency et cetera).

All costs associated with these schemes are part of the utilities' common Public Service Obligations, PSO. This way the costs are distributed to the electricity consumers in Denmark.

Further the EU carbon dioxide quota system adds value to electricity produced from renewables, further enhancing the incentives for power production in co-firing and dedicated biomass plants.

8.5 Finland

Janne Kärki, VTT-Energy, Finland.

The Finnish bioenergy market has developed over the decades from small-scale local utilization of wood fuels to large-scale combined heat and power (CHP) production. Finland's experience is based on efficient use of biomass for large-scale energy production in municipalities and at pulp and paper mills. Globally, Finnish biofuelled combined heat and power production plants represent the leading edge of technological development. Wood is the major biofuel for large-scale energy production. Peat is another important indigenous fuel, covering nearly 10% of energy consumption. The use of agricultural biomass, residues or energy crops for energy production is limited in Finland.

Finnish energy production has high overall efficiency, since about one third of electricity is produced at combined heat and power plants (CHP). Half of the CHP plants are connected to district heating systems and the other half supply process heat and steam to industry. The overall thermal efficiency of large-scale co-generation plants varies between 85 and 90 per cent. Without CHP plants, the carbon dioxide (CO_2) emissions in energy production in Finland would be about 50 per cent higher than the current emissions.

Renewable energy – hydropower, bioenergy and wind – generated 25% of Finland's electricity in 2007 (in total 90.3 TWh). Biomass produced more than 10%. About 30% of Finnish net supplies of electricity is generated from combined heat and power production. Electricity is generated at about 400 power plants that utilize varying fuels and production technologies.

In 2006, industrial heat production was 228 PJ (63 TWh), of which as much as 79% was produced at CHP plants. District heating totaled 121 PJ (37 GWh), of which 77% was from

CHP plants. 15% of district heating was generated by renewable energy sources and 18% by peat. However, as much as 60% of industrial heat production was from renewable fuels.

Modern boilers allow the efficient use of wood fuels and co-combustion with other fuels. Traditional grate combustion is still competitive when boiler capacity is under 20 MW_e. Larger plants employ fluidized bed combustion (FBC) technology that originally developed for non-homogeneous solid biofuels that are difficult to use. Biomass co-firing is an effective way to introduce biomass to large scale power plants to reduce their greenhouse gas emissions. Of the various industrial sectors, the paper and board making processes of the forest industry are the largest consumer of heat generated by CHP and co-firing.

Different types of biomass residues can be co-combusted by various combustion and gasification technologies and configurations. Today, direct co-firing is the most commonly applied configuration. In applications that range from 20-310 MW_{th} the typical technology is fluidized bed combustion where different biomass residues from forest industries are directly co-fired with peat, sludge, coal and oil.

There are over 50 biomass co-firing plants (> 20 MW_{th}) in operation with years of experience in Finland (see Table 6). The total fuel capacity of these plants is 11,1 GW_{th}. Three-quarters of the co-firing plants are equipped with bubbling fluidized bed boilers. The plants can be categorized as follows:

- 6 plants in which coal is the main fuel and in which wood fuels are co-fired
- 24 CHP plants in which peat is the main fuel and the proportion of different wood fuels are important (mainly co-firing plants in municipalities)
- 28 CHP co-firing plants in which the proportion of biomass is higher than peat and the other fuels (mainly forest industry plants).

Table 6 Current status of co-firing in Finland (boilers > 20 MWth)

City	Name of the Company	Co-firing		Main fuel I	Main fuel II	Other fuels
		Boiler	**MW_{th}**			
Main fuel: Coal						
Naantali	Fortum Power and Heat Oy	PF	945	coal	biomass	WSTGAS/HFO/LFO
Lahti	Lahti Energia Oy	PF	514	coal	NG	biomass/REF/HFO/LFO/peat
Turku	Oy Turku Energia Ab	PF	363	coal	HFO	LFO/biomass
Pori	Porin Prosessivoima Oy	CFB	199	coal	biomass	HFO/LFO/others
Salo	Voimavasu Oy	BFB	127	coal	biomass	peat/REF/HFO/LFO/BGAS
Lohja	Fortum Power and Heat Oy	BFB	80	coal	biomass	REF/HFO
			2228			
Main fuel: Peat						
Oulu	Oulun Energia	CFB, BFB	295/315	peat	biomass	coal/HFO/LFO

Kuopio	Kuopion Energia	PF	245/131	peat	biomass	HFO/LFO
Pietarsaari	Oy Alholmens Kraft Ab	CFB/BFB	592	peat	biomass	coal/REF/HFO
Haapavesi	Kanteleen Voima Oy	PF	390	peat	biomass	HFO
Seinäjoki	Vaskiluodon Voima Oy	CFB	325	peat	biomass	coal/HFO/LFO
Jyväskylä	Jyväskylän Energiantuotanto Oy	BFB	265	peat	biomass	coal/HFO
Kajaani	Kainuun Voima Oy	CFB	240	peat	biomass	sludge/REF/coal/HFO/LFO
Mikkeli	Etelä-Savon Energia Oy	CFB/BFB	224	peat	biomass	REF/HFO/LFO
Pori	Pori Energia Oy	BFB	206	peat	biomass	REF/HFO/LFO
Joensuu	Fortum Power and Heat Oy	BFB	200	peat	biomass	HFO
Tampere	Tampereen Sähkölaitos	BFB	200	peat	biomass	NG/LFO
Tornio	Tornion Voima Oy	CFB	145	peat	biomass	REF/coal/HFO
Rovaniemi	Rovaniemen Energia Oy	CFB/BFB	136	peat	biomass	coal/LFO
Eura	Fortum Power and Heat Oy	CFB	121	peat	biomass	coal/REF/HFO/LFO
Kokkola	Fortum Power and Heat Oy	CFB	98	peat	biomass	REF/LFO/coal
Kokkola	Kokkolan Voima Oy	BFB	80	peat	biomass	
Forssa	Vapo Oy	BFB	70	peat	biomass	HFO/LFO
Kotka	Kotkan Energia Oy	BFB	66	peat	biomass	REF/LFO
Hämeenlinna	Vattenfall Kaukolämpö Oy	BFB	59	peat	biomass	coal/LFO
Valkeakoski	Fortum Power and Heat Oy	BFB	50	peat	biomass	coal/REF/HFO/LFO/sludge/others
Iisalmi	Savon Voima Lämpö Oy	BFB	48	peat	biomass	HFO/LFO
Haapavesi	Vapo Oy	CFB	40	peat	biomass	Sludge/WSTGAS/LFO/HFO
Pieksämäki	Savon Voima Lämpö Oy	BFB	35	peat	biomass	coal/REF/HFO/LFO
			4576			
Main fuel: Biomass						
Kuusankoski	Kymin Voima Oy	BFB	285	biomass	peat	REF/sludge/HFO/NG
Anjalankoski	Stora Enso Publication Papers Oy	BFB	250	biomass	peat	REF/coal/HFO/NG
Rauma	UPM-Kymmene Oyj	CFB/BFB	220	biomass	peat	REF/HFO/coal/sludge
Jämsänkoski	UPM-Kymmene Oyj	BFB	185	biomass	peat	REF/sludge/HFO
Äänekoski	Äänevoima Oy	BFB	173	biomass	peat	sludge/HFO
Hamina	Stora Enso Publication Papers Oy Ltd	BFB	161	biomass	sludge	NG/peat/HFO
Ristiina	Järvi-Suomen Voima Oy	BFB	146	biomass	peat	HFO/LFO/REF
Rauma	Rauman Voima Oy	BFB	120	biomass	peat	sludge/REF/HFO
Rautjärvi	M-real Oyj	BFB	113	biomass	peat	sludge/REF/HFO/LPG/LGAS
Kuopio	Powerflute Oy		112	biomass	peat	coal/HFO/LFO/sludge/REF
Jämsä	UPM-Kymmene Oyj	BFB	104	biomass	peat	HFO/sludge/coal
Mänttä	Mäntän Energia Oy	BFB	94	biomass	peat	coal/HFO/sludge
Oulu	Laanilan Voima Oy	CFB/ BFB	87	biomass	peat	REF/coal/HFO/LFO/WSTGAS
Savonlinna	Järvi-Suomen Voima Oy	BFB	75	biomass	peat	REF/HFO/LFO/coal
Heinola	Lahti Energia Oy	PF	42	biomass	peat	HFO
Joensuu	UPM-Kymmene Wood Oy	Grate	33	biomass	peat	HFO
Lieksa	Vapo Oy	CFB	32	biomass	peat	HFO/LFO
Kuusamo	Fortum Power and Heat Oy	BFB	29	biomass	peat	HFO
Kankaanpää	Vatajankosken Sähkö Oy	BFB	24	biomass	peat	HFO/LFO
Ylivieska	Vieskan Voima Oy	BFB	24	biomass	peat	REF/HFO/LFO
Anjalankoski	Myllykoski Paper Oy	BFB		biomass		
			2308			
Pulp mills, boiler of solid fuels:						
Lappeenranta	UPM-Kymmene Oyj	BFB	792	biomass	peat	sludge/HFO/LFO/WSTGAS/ Methanol/other
Oulu	Stora Enso Oyj	BFB	246	biomass	peat	sludge/LFO/methanol/hydrogen

Kemi	Stora Enso Oyj	BFB	246	biomass	peat	sludge/LFO/methanol/hydrogen
Imatra	Stora Enso Oyj	BFB	235	biomass	peat	NG/Sludge/HFO/WSTGAS/Methanol
Varkaus	Stora Enso Oyj	CFB	150	biomass	peat, coal	REF/sludge/HFO/LFO/WSTGAS
Heinola	Stora Enso Oyj	BFB	120	peat	biomass	coal/sludge/HFO
Kemi	Oy Metsä-Botnia Ab	BFB	115	biomass	peat	HFO/WSTGAS/Methanol
Valkeakoski	UPM-Kymmene Oyj	BFB	78	boimass	peat	REF/sludge/WSTGAS/HFO
			1982			
		Total	**11094**			

8.6 Netherlands

The Netherlands has a rich history when it comes to co-firing. The first large scale co-firing project started as early as in 1995. By that time 240,000 tons of waste and demolition wood was sent for landfill disposal. In order to use this wood environmentally beneficial it was decided upon co-firing 60,000 tons per annum of processed waste wood in Centrale Gelderland in Nijmegen.

Today, the Netherlands has 7 coal-fired units, divided over 5 locations. All of these units have experience with co-firing biomass. Of these 7 units, 6 units are co-firing on a commercial basis. These units consist of tangentially-fired or opposed wall-fired boilers. Percentages of co-firing up to 15% (heat) are common, and even higher co-firing percentages have been reached.

Trials have been performed with relatively low percentages (up to 5% co-firing) co-milling the biomass with the coal. It can be said that co-firing is common business in the Netherlands today, and is in commercial operation year through. The biomass is milled separately, and often by separate milling equipment on-site. The pulverized biomass is either injected in the coal lines, or injected in separate feeding lines.

Table 7 Current status of co-firing in the Netherlands

Power station	Unit	Owner	Plant output (MW_e)	Plant output (MW_{th})	Direct co-firing percentage (heat)
Amer Centrale	8	Essent	600	250	10 - 12%
Amer Centrale	9	Essent	600	350	27 + 5%[1)]
Borssele	12	EPZ	403	-	10 - 15%
Gelderland	13	Electrabel	602	-	5 – 8%
Maasvlakte	1+2	E.ON	2 x 531	-	6%

1) 27% direct co-fring and 5% indirect co-firing

Many fuels have been adopted, including wood based materials as wood pellets and waste and demolition wood. Furthermore, materials as paper sludge pellets, meat and bone meal, and a high variety of agricultural rest products have been applied. This was especially the case until 2006.

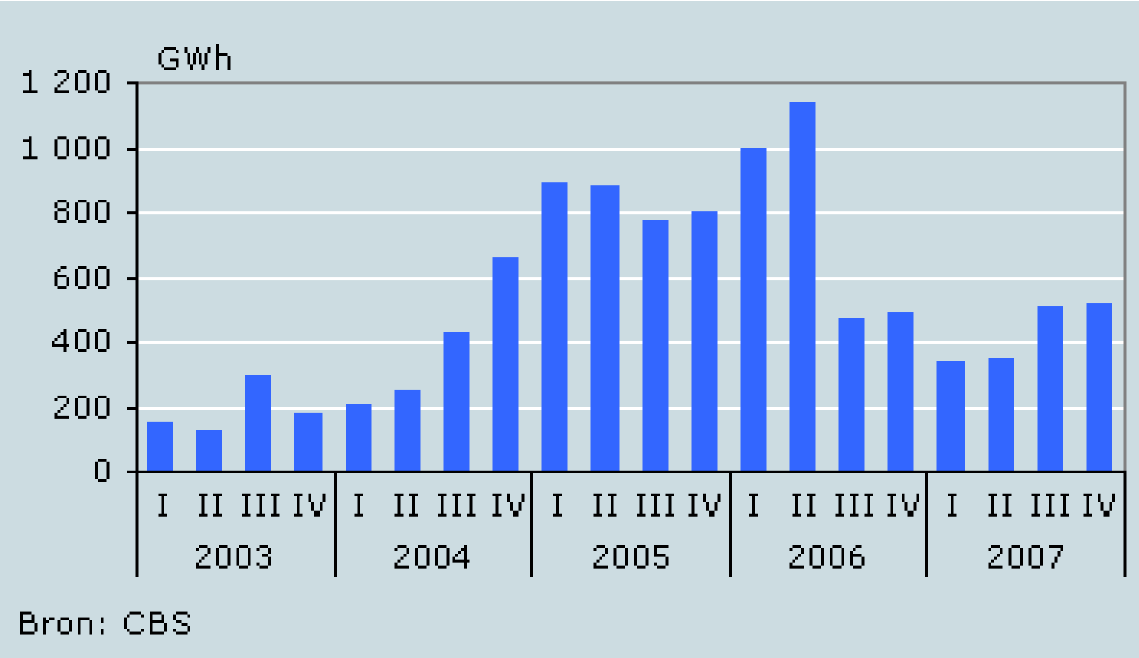

Figure 6 State of affairs of co-firing for electricity generation in the Netherlands from 2003-2007. Shown is the electricity production by secondary fuels (Source: CBS).

Figure 6 shows the electricity production by co-fired biomass fuels by Dutch electricity generators in the period of 2003-2007. Biomass combustion and co-firing plays an important role in the total sustainable energy production, especially in the period from 2000 until 2006. When comparing 2005 figures with 2003 figures, the total electricity generation by co-firing fuels quadrupled. However, the electricity production from biomass as co-firing fuel has reduced significantly in 2007 [20]. The reason for this decline mainly resulted from a change in subsidy programmes in July 2006. Then, the subsidized co-combustion of bio-oil was not allowed anymore, and firing palm oil at Essent's Claus power station was stopped. Also some units have been out of service for a longer period in 2007. The last reason for the decline was that subsidies for co-firing certain types of polluted solid biomass were lowered significantly, which at that point had a marginal effect on co-firing.

Until 2007 co-firing was subsidized by the Dutch MEP-subsidy programme. This programme was stopped in 2006 and succeeded by the SDE subsidy programme in 2008. Although co-firing was included in the MEP programme, it was not included in the SDE programme. The

MEP programme, however, still holds for the power stations that were included in the pre-2007 MEP-programme, and therefore relates to the existing co-firing projects. The subsidy tariffs for co-firing according to the MEP were determined in 2007 for the last time. The figures are presented in Table 8.

Table 8 Subsidy tariffs (as addition to the whole sale electricity price) as given by the MEP subsidy programme in 2007, and still applicable for existing projects, in EURct/kWhe [22].

Subject	**subsidy (EURct/kWh$_e$)**
co-combustion of wood pellets	6.5
co-combustion of agro residues	3.8
co-gasification of mixed biomass	3.8

All current coal-fired power stations, excluding Hemweg 8 power station, have a MEP disposition, and therefore receive the MEP subsidy when they co-fire.

Ashes derived from co-fired boilers are regularly utilized in building industry and civil engineering. The ashes are fully accepted by the market due to stringent quality criteria and good public relations.

Table 9 New-to-build initiatives in the Netherlands with application for co-firing (status: first half 2009).

initiative	location	fuel[a)]	type[b)]	power (MW_e)[c)]	year into operation	Co-fring[d)]	status/ background
Nuon / Magnum	Eemshaven	coal / petcokes / biomass / natural gas	IGCC	1200	2012 (gas) 2014 (coal)	30% m/m	permit application
Electrabel	Maasvlakte	coal / biomass	USC	800	2013	60% e/e	none irrevocable permits
E.ON/ MPP3	Maasvlakte	coal / sec. fuels (incl. biomass)	USC	1100	2012	20% m/m	none irrevocable permits
RWE	Eemshaven	coal / biomass	USC	2x800	2013	10% e/e	none irrevocable permits
C.gen	Europoort Rotterdam	coal / petcokes / biomass / natural gas	IGCC	450	2014	30% e/e	notification of intent, September 2008

a) As a guideline with biomass is meant wood pellets and wood derived fuels, while secondary fuels also incorporate other derived fuels
b) IGCC : integrated gasification combined cycle power plant / USC : direct injection ultra supercritical boiler
c) Gross
d) m/m : mass based, e/e : energy based

Table 9 presents initiatives in the Netherlands for new-to-build coal fired units. Some of those units are direct injection ultra supercritical boilers with the possibility for biomass co-firing. Other units are of the IGCC type. All units are planned to be built either in the Rotterdam harbor area or in the Eemshaven (North of the Netherlands) area. All units are in the process of acquiring a permit for co-firing up to a certain percentage of biomass fuels with the permission limits indicated in Table 9.

8.7 Sweden

Claes Tullin, SP Technical Research Institute of Sweden, Sweden.

Although co-firing was extensively practiced in the 80´s, the use of coal for heat and power production in Sweden is very limited today. Of the total amount of coal used (Figure 7), only about 1/3 is used in CHP plants. The main reason for the limited use of coal is the tax on CO_2 for heat production which was introduced in 1991. This means that co-firing in Sweden usually means biomass combustion with a smaller amount of coal in principle corresponding to the production of electricity which is excluded from the tax.

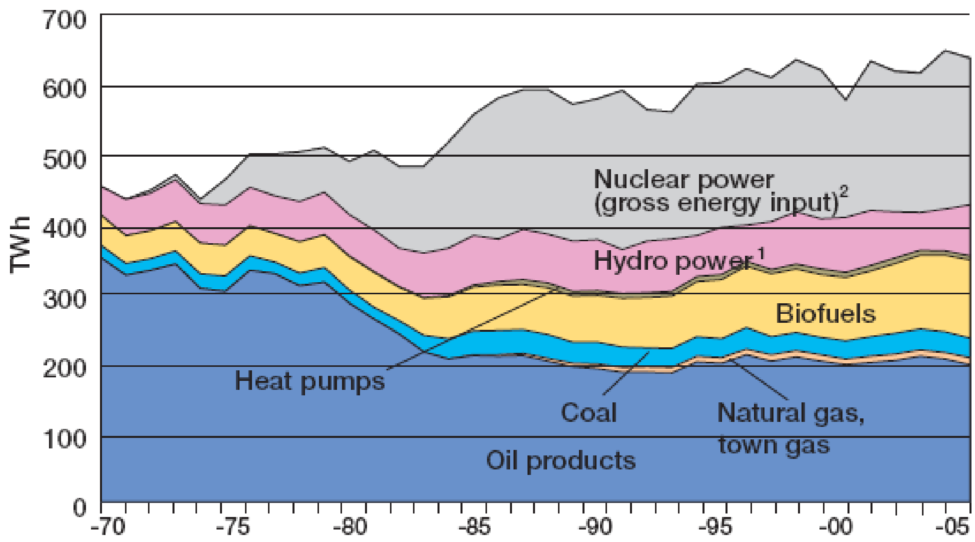

Figure 7 Energy supply in Sweden 1970-2005 excluding net electricity export (Energy in Sweden 2006, Swedish Energy Agency).

Although the use of coal is limited, there are some interesting advantages with co-firing that deserve to be pointed out. Biomass fuels contain an unfavorable ash composition which results in deposit formation and corrosion on super heaters mainly due to the content of alkali and a low sulphur to chlorine ratio. By co-combustion of a sulphur containing fuel such as coal or peat, it is possible to change the ash chemistry and avoid troublesome deposits. Indeed, also addition of pure sulphur has been found to be beneficial and a commercial technique for simultaneous sulphur addition and de-NOx has been developed (Vattenfall Chlorout process, [23]). The ash chemistry during co-combustion has been extensively studied at the Chalmers fluidized bed research boiler (see for example [24]). In addition, a number of applied research projects has been reported by the Swedish Thermal Engineering Institute [25].

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