Main report

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Cofiring of 500 MW coal-fired power plant with 10% EFB bales or 5% shells and as a 2015 scenario 10% cofiring of POFF

A report prepared under the

Malaysian - Danish Environmental Cooperation Programme Renewable Energy and Energy Efficiency Component

by

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Contents:

1. Introduction

Power plant cofiring means substituting coal (or another fossil fuel) by biomass in the power plant fuels.

The study covers cofiring at an old and at a new cofiring power plant:

- as the old power plant we have selected one of the 500 MWe units at the Kapar power station and
- as the new unit we have chosen one of the three alike 700 MWe units at the Janamanjung power station.

The Kapar and Janamanjung Power Stations are the only power stations at the peninsula of Malaysia that have coal fired units by now. However, plans are made for expanding the coal capacity at two new power stations in Malaysia.

The biomass considered for cofiring are two different residues from the palm oil industry:

1. Shells from the palm oil fruit, and
2. Empty Fruit Bunch (EFB) either in the form of dried and baled EFB or as POFF (Palm Oil Fruit Fibres)

The presence of coal ash and sulphur from the coal helps eliminate the problems from the combustion of the biofuels (known from separately fired biomass boilers).

This study and the recommendations herein ONLY apply for cofiring coal fired units and NOT for cofiring gas- or oil fired units.

An important issue in the change of fuels in the large power plants (either TNB or IPP owned) is whether the cofiring will affect the power plant availability and thereby become a critical issue in the Power Purchase Agreement. The co-firing is an add-on and if it is done correctly it will not affect the availability of the coal fired unit. So in case of biofuel shortage or problems with the biofuel feeding, the power plant will operate on 100 % coal and the power plant will still have the same maximum load and part load capabilities on coal after adding the cofiring possibility.

The following section presents the two power plants on which this study is based. Furthermore the report proposes how the power plants could cofire the shells and the EFB respectively. There is a discussion of different scenarios for cofiring until 2015, and the R&D recommendation for developing of cofiring shells and EFB is listed both for theoretical and experimental investigations at different levels towards market-driven solutions. This section ends by providing the study conclusions.

2. Plant data

The assessment of the technological possibilities for cofiring in Malaysia is based on data and site visits to the power stations. Please refer to Section 5 in the Background Report: Technical Assessment and Data Sheets.

Cofiring a 500 MWe coal fired unit at Kapar Power Station

Kapar Power Station has four coal-fired blocks:

- Two 300 MWe block,
- Two 500 MWe blocks

In the assessment of the technical and economic feasibility in Kapar, we have chosen one of the 500 MWe units for the study. However, the 300 MWe and the 500 MWe units have many similarities and we propose that when demonstrating the technology of cofiring (mainly the EFB) it could be done at the 300 Mwe unit as this is planned for decommissioning in 2013, and if some unforeseen damage should occur, it is easier to accept at an older unit. The 500 MWe units began commercial operation in 2001

Power plant data for the 500 MWe units:

- Boiler manufacturer: Ishikawajima-Harima Heavy Industries (IHI), Japan
- Natural gas and pulverized coal fired
- Electric energy generating efficiency for each of the blocks: Assumed to be 36 %
- Electrostatic precipitators
- The fly ash is sold to the cement industry.

Cofiring a 700 MWe coal fired unit at Janamanjung Power Station

The three 700 MWe blocks at the **Janamanjung Power Station** that were commissioned in 2003 are now in the phase of guarantee testing. All three units are alike.

Power plant data for the 700 MWe units:

- Boiler manufacturer: ALSTOM Power Plants Ltd.
- Electric energy generating efficiency for each of the blocks: 36 % (assumed)
- Electrostatic precipitators
- Sea water scrubbers
- The fly ash is sold to the cement industry.

3. Cofiring methods for EFB and Shells

When discussing cofiring rate in this sector, we always refer to **% energy basis**. Many papers present cofiring rates on mass basis and this may cause some confusion when comparing.

3.1 Cofiring EFB

For cofiring EFB we assume a cofiring rate of 10 %. This cofiring rate is chosen as we have experience in cofiring up to 20 % straw in Denmark. Since straw has a composition that is very similar to EFB, with relatively high confidence we can make use of the Danish experience with cofiring straw. However the EFB may have both a higher ash content and a higher potassium content than straw from grain, so for safety reasons we assume a cofiring rate at 10 %.

It is proposed that EFB is co-fired either as relatively dry biomass with moisture content at 17% in a baled form or as POFF (palm oil fruit fibres) with moisture content at 45%.

If cofiring the baled EFB, this could very likely be co-fired by using the same system as cofiring straw bales used in Denmark. The baled straw is pre-processed at the site of power plant through:

- A bale divider, a shredder, a streightener, a stone trap, a hammer mill and then transported pneumatically to the boiler through slightly modified burners.

The system has turned out to operate satisfactorily and has obtained a high availability. The system is described in details in /1/

In the assessment of cofiring in Malaysia, the burners of the boilers at Kapar and Janamanjung have been investigated, and it appears that the burners at both power plants can be modified for pneumatic feeding of EFB (with moisture content less that 20 %) in a concept similar to the system developed in Denmark.

The EFB has a real low price at the palm oil mills (10 RM/tons) but the different steps of drying (and baling) and transportation results in prices at:

- Baled EFB: 11.8 RM/GJ if transported 30 km and 12.8 RM/GJ if transported 100 km.
- POFF: 7.7 RM/GJ if transported 30 km and 10.8 RM/GJ if transported 100 km.

When compared to a coal price at approx 10 RM/GJ, it is difficult to make cofiring feasible in comparison with cofiring 100% coal.

It is proposed that the **baled EFB** is cofired by using a pre-treatment similar to the pretreatment system used for straw in Denmark, as it is believed to work also for baled EFB and has shown to achieve a high availability for straw. Baled EFB must be pre-processed to be fed into the furnace through the burners.

In the feasibility study for cofiring EFB, we considered options of cofiring EFB in a more wet form to lower the fuel costs. An alternative to cofiring the baled (dry) EFB could be to fire EFB in the form of **POFF**. However, it would not be possible to feed the POFF through the burners. Feeding POFF is proposed to be in a spreader stoker and the furnace would have to be rehabilitated, so the slag in the furnace should be exchanged with a grate. This has been done in other boilers.

3.2 Cofiring shells

For cofiring the shells we assume a cofiring rate at 5 % on energy basis. The rate of 5 % in chosen for two reasons:

1. The lower resources available on shells compared to EFB would require very long transportation distances if cofiring at a higher rate.

2. The shells could be cofired through the coal mills that already exist at the power plants, thus almost avoiding investment costs for cofiring the shells. However the coal mills have a limited additional capacity for the milling of the shells, and as the shells are more voluminous than coal we only believe there will be coal mill capacity for cofiring 5% shells (on energy basis). However, the additional capacity available on the coal mills depends on the quality of the coals being milled.

For cofiring shells through the coal mills at Kapar and Janamanjung stations there is some extra capacity of the coal mills for grinding of the more voluminous shells (compared to coal), thus allowing this method for feeding of 5% shells on energy basis. This was also a result from the visits at the power plants.

3.3 Technical risks in cofiring EFB and Shells

When deciding to cofiring EFB and/or shells it has to be considered if this will have a negative or maybe even harmful effect on the boiler and the boiler performance. However, in most instances, the co-firing of biomass in existing coal-fired boilers provides an attractive approach to nearly every aspect of the development of biomass-to-energy capacity.

Since there is no prior experience in the world for cofiring EFB and we have to assess the technical risks of cofiring EFB by comparing to the Danish experience in cofiring straw that has a relatively similar fuel composition as EFB. However, EFB may have a higher ash content than straw and the ash may have a higher potassium content than straw. The chlorine content of the fuel appears to be at the same level as straw from grain production.

The Danish experience for long term full scale tests cofiring 10% and 20% straw (on energy basis) is believed to be close to what will be experienced in Malaysia when co-firing EFB.

There is concern related to EFB because of the composition of the fuel. The ash content and ash composition is a concern in respect to deposit accumulations that may be even more destructive to the boiler if breaking off in big lumps as well as corrosion of the boiler. The boiler performance may be influenced thus affecting the boiler efficiency by higher moisture content in the fuel and a potential lower burn out of the biofuel compared to the coal combustion. Other issues to consider are the impact of SO_2 and NO_x emission from cofiring and the possibility to sell the ash from the combustion for re-use in cement and concrete production.

In the following we try to address the technical risks based on the Danish experiences from cofiring straw. For more details on the experience from firing a fuel very similar to EFB, namely straw, we refer to /1/.

Combustion
The boiler performance has in general been satisfactory. The amount of unburnt in fly ash is generally lower than by firing coal alone, indicating good combustion. The unburnt carbon in the bottom ash is higher by co-combustion of coal and straw than by firing coal alone (around 5% unburnt). From this it can be calculated that the boiler efficiency has not – or only marginally so – been affected by the co-combustion of coal and straw.

Corrosion
Two long-term tests (3000 hours) – co-firing 10% and 20% straw respectively – show that the corrosion by co-combustion of 10% straw is low in general and that it is not, or only moderately so, increased compared to coal-firing only. By co-combustion of 10% straw the corrosion seems to be parabolic and the corrosion rates for 10CrMo910 are at the same low level as normally seen by combustion of coal. The corrosion rate is decreasing at higher alloyed materials as is known to be the case for coal-firing. A slight increase in corrosion is seen at increasing metal temperatures as is also known from combustion of coal with low-corrosive coals. The corrosion increases by increasing flue gas temperature, which emphasises the importance of performing the corrosion tests under the most realistic flue gas conditions possible.

By co-combustion of 20% straw the corrosion rate is increased by a factor 2 to 3 at moderate metal temperatures and here the corrosion rate is at the upper limit for low-corrosive coals. At higher metal temperatures, and especially at simultaneously higher flue gas temperatures, a large increase in the corrosion rate is seen corresponding to medium-corrosive coals or more. The reason for the higher corrosion rate is probably increased sulphate melt corrosion due to higher K_2SO_4 formation.

Both test series presume that no Cl corrosion has occurred and nor Cl been detected in the examined corrosion samples. The corrodant is potassium sulphate from the deposit. The alkali sulphate reacts with the iron oxide from the tubes, forming alkali-iron-trisulphates.

Evaluations of the corrosion mechanisms combined with short-term deposition tests with another type of coal indicate that the corrosion may be dependent on the coal type. However, based on the above results it is evaluated that there are no considerable corrosion risks by co-combustion of 10% straw in plants with steam temperatures up to 580°C. The results indicate that by introduction of co-combustion of 20% straw, the corrosion rates will increase by a factor of 1.5 to 3 in the superheaters of plants with steam temperatures up to 540°C. Still, the corrosion rates are as for low or the low part of medium corrosive coals.

Deposit formation
Based upon the visual analyses of deposits from cofiring with straw shares from 0-20%, it was found that the deposit amount and tenacity on the upstream side of the tube increased with increased exposure time, increased straw share, increased flue gas temperature and increased load. The downstream deposits were in all cases powdery deposits, which could easily be removed by soot blowing.

From burning Columbian coal and straw shares up to 10%, the deposit formation could be handled by increased soot blowing. At higher straw shares (20%) some slag problems were seen.

Emissions
The nitrogen concentration in straw varies depending on the amount of fertiliser used. In general, the NO_x formation process strongly depends on the duration, temperature profile and air-to-fuel stoichiometry profile of the combustion process.

The sulphur concentration in straw is lower than in coal. A reduction in sulphur emission in experiments was therefore expected due to the lower input. However, it was found that the reduction was even higher.

Residues
One of the success criteria for coal/straw co-combustion in PC-boilers is the utilisation potential for the residues. To evaluate this, the chemical composition of the fly ash has been investigated. The European Code EN 450 prescribes that only fly ash from anthracite or bituminous coal may be used. At the moment intensive work is done to remove this formal barrier and an opening could be expected soon. The possibilities of using the mixed ash in the cement production are restricted due to the increase in potassium in the ash. However, selecting coals with certain ash compositions improves the options for the use of fly ash from co-firing.

The re-use of the ashes from cofiring EFB needs further investigations in the actual cases.

We do not expect any impact on the boiler performance from cofiring 5% shells.

4. Scenarios

The assessment of scenarios covers both use of policy instruments to facilitate the use of biomass in the power sector as well as an assumed technological development to be able to use the resources in the best possible way, thereby lowering the production price for power using biomass.

The instrument for introducing and enforcing the use of biofuel in the power sector could be an obligation saying that all coal-based power production has to be co-fired with 5% biofuels. It is for government agencies, TNB and IPPs to decide which power plants should be cofired, the level of co-firing rate and the biofuel to be used (based on price of biofuel, resource available and the technology to be applied).

An estimate would be that if no obligation is given to the power sector for use of biomass for power production, they could likely decide before 2015 to cofire eg. one of the 500 MWe blocks at Kapar Power Station and one of the 700 MWe blocks at Janamanjung Power Station. The plants will likely be cofired 5% on shells. This would result in a total of 60 MWe on biomass by 2015. The shells would probably be chosen as it is economically feasible even without CO_2 credits.

A commitment to produce 5% of the power on coal fired unit by biofuels would in comparison give 360 MWe on biofuels in Peninsula Malaysia consuming around 15-20% of the biomass resource.

An example of a **technological development** that could help lower the costs of cofiring EFB in power plants should enable a use of EFB with higher moisture content. However the feeding of biomass through the burners is believed to set demands for low moisture content in the biofuel.

The case for a technology could be to burn the biomass on a grate in the bottom of a suspension fired boiler operating on coal. The boiler would thereby have to be modified to exchange the slag removal of the boiler with a grate.

5. Results

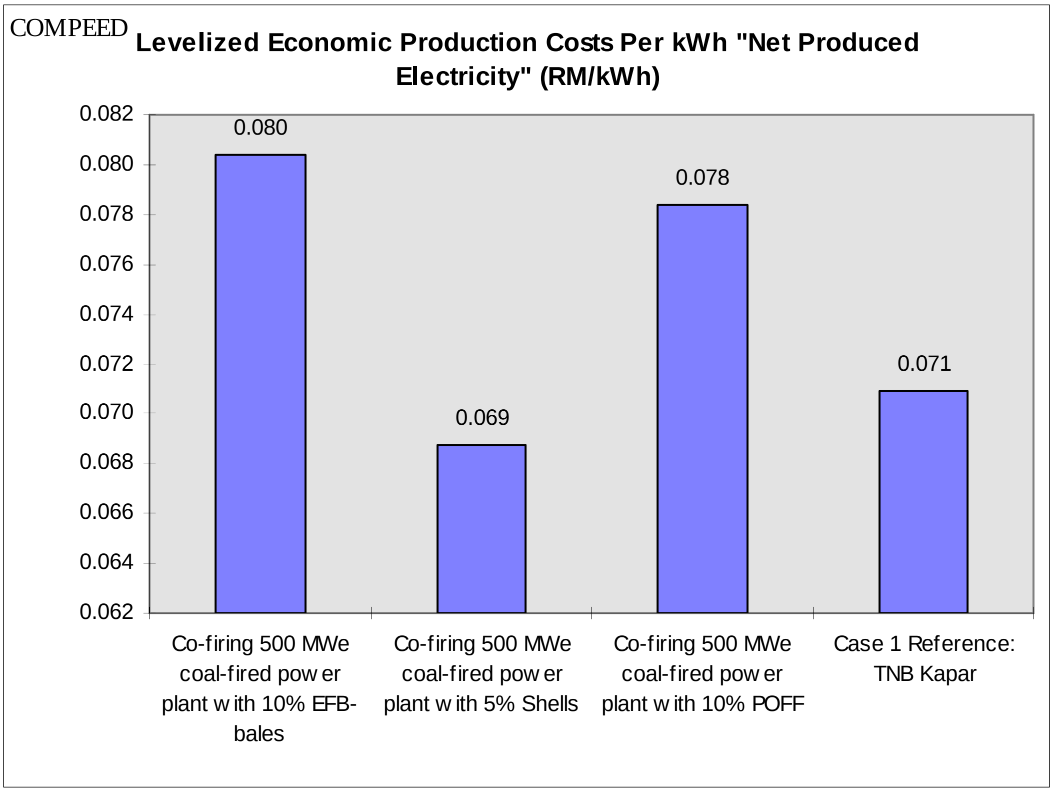
The economic feasibility for cofiring EFB and Shells is presented on the following figures, showing the power production prices and the carbon credits needed to make cofiring become feasible.

The feasibility is calculated for three cases:

- Cofiring a 500 MWe coal-fired power plant with 10% EFB in bales
- Cofiring a 500 MWe coal-fired power plant with 5 % shells
- Cofiring a 500 MWe coal-fired power plant with 10% EFB as POFF

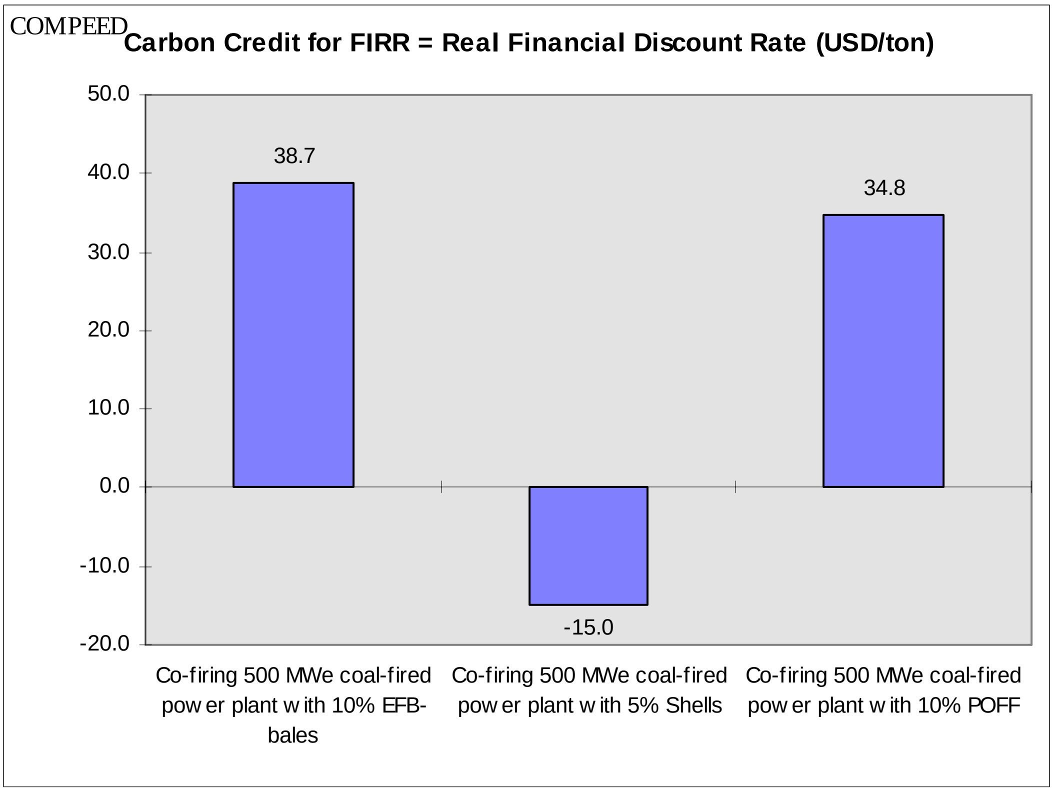
The first cases are what is included in a scenario for 2005 and the scenario for cofiring POFF is considered for at 2015 scenario.

In the figure with the power production prices the reference situation with coal combustion is included for comparison.



The results show that cofiring palm kernel shells are economically beneficial and will result in a lower power production price. The cofiring of baled EFB (in suspension) or as POFF (on a grate) are not feasible compared to coal combustion.

It is however a question if the increase in price is relatively small that some may decide to do the cofiring of EFB because of other political reasons, like positive contribution to environment.



From the figure showing the carbon credits needed to make cofiring become feasible, it can be seen that cofiring of EFB would require carbon credits at 35-40 US$/tons which would be a lot more than would likely be the carbon price. So carbon credits are not enough to make cofiring EFB beneficial in the concepts assessed in this study.

However, there could likely be other ways to optimize the use of EFB in the power industry that could make it more attractive. In the following section, there are some R&D recommendations both to lower technical risks and to increase the economical feasibility.

6. R&D recommendations

In the following there is a list of R&D recommendations related to the use of EFB primarily for cofiring. The recommendations are discussed at different R&D levels and referred to as technology classifications.

Technology level classification:
1. Theoretical basis, no practical experiences
2. Experimental testing, technical pilot projects
3. R&D driven full scale demonstration projects
4. Market-oriented subsidized demonstration projects
5. Market-driven solutions available from multiple manufacturers

Level 1. Theoretical basis, no practical experiences

There is no experience in cofiring of EFB. From consulting a large data-base from IEA on the references for cofiring (the data-base is not public available yet) covering approx. 150 references for cofiring none of them cofire EFB. However, EFB appears to have a relatively similar fuel composition as straw and therefore a lot of the knowledge obtained in straw cofiring can be used in the assessment of the performance, challenges and risks of cofiring EFB.

Level 2. Experimental testing, technical pilot projects

The EFB needs to be characterised to obtain fuel analysis that we have confidence in. Standardisation of methods to describe and analyse biofuels is one important task in developing of the task of cofiring and biofuel combustion in general.

There are no experiences in cofiring of EFB in the world. Therefore it makes sense to investigate the fuel experimentally at lab-scale and pilot scale to characterize the combustion behaviour of the residues from the palm oil production (shells and EFB).

If cofiring the shells from the palm oil fruits, it needs investigation of the particle size to which the shells need to be grinded to be small enough for burning in the 1-2 seconds available in the furnace.

Level 3. R&D driven full scale demonstration projects

A full scale demonstration of cofiring of EFB is not done anywhere in the world and therefore it is important that has to be done within a R&D approach.

In collaboration with the cement and concrete industry it needs investigation of the limits of cofiring rate where the fly ash from cofiring can still be reused. Demands for reuse of the mingled ashes in the cement and concrete industry needs to be investigated within the cement and concrete industry.

For a more broad assessment of pre-treatment possibilities for biofuels (mainly EFB) it could also be relevant to consider transforming to a different form of energy carrier at the site of the palm oil mills, eg. pyrolysis oils (for cofiring at power plants) or ethanol (to use as transport fuel as addition to gasoline) just to mention some. Another pre-treatment of the EFB could be gasification on site of the power plant and cofiring the producer gas. All these suggested pre-treatment will avoid the inorganics of the biofuels to be introduced into the furnace of the power plant and therefore not be added to the fly ash of the coal.

Level 4. Market-oriented subsidized demonstration projects
Most likely the cofiring of EFB will be relatively unproblematic in respect to the combustion, and the potential slagging/fouling and corrosion will be manageable.

However, the pre-treatment of the EFB including drying and milling/cutting to a particle size that can be fed pneumatically will probably result in a price for EFB (RM/GJ) that will not be competitive to coal, and will therefore need subsidization. The fuel preparation system as a whole could benefit from optimization of the process steps.

A way to be able to cofire EFB at much higher moisture content would be to modify the bottom of the furnace of the power plant by exchanging this by a grate, thus fire the biofuel on the grate under the suspension firing of the coal. This will allow the cofiring of palm oil fruit fibre (POFF) at 45 % moisture content.

Level 5. Market-driven solutions available from multiple manufacturers
Improving the equipment for the fuel processing may likely lower processing costs and increase the availability of the cofiring facility. It could even be relevant to develop new equipment for the fuel preparation of the EFB to a size fraction, structure and at a moisture level that will easier allow pneumatic transportation of the fuel to the burner.

The power plants could consider the cofiring of the shells from the palm oil fruits. This appears to be feasible today with a fuel price at 40% of the cost of coal. The shells could most likely be fired through the coal mills and would have very low investment costs. Alternatively, the shells could be milled separately and fired similar to the firing of EFB, ie. separately in mixed fuel - coal and biomass – burners in the opposed wall fired units in Kapar, or maybe 100 % in the tangential firing at Janamanjung.

7. Conclusion

This study covers the technical and economical investigation of cofiring Empty Fruit Bunch (EFB) and Shells from palm oil fruits in a new and an older type of coal fired power plant, both in suspension.

The study shows that most likely there will be no technical problems in cofiring the power plants by 10% EFB and/or 5% shells.

It appears that legal issues may be resolved as the cofiring will not influence the availability of the plants for power production and thereby affect the Power Purchase Agreement.

There is no experience in cofiring EFB in the world. However, EFB has many similarities to cofiring of straw at Danish power plants, from where there are results from 2 years demonstration of the technology for cofiring up to 20% straw (% energy basis). The technical problems showed to be negligible or manageable. We believe that if it should decided to cofire EFB, this will be manageable without technical risks up to a cofire rate of 10% by energy, depending on the coal type to be cofired with. The biggest challenges for cofiring of EFB may be optimization of the fuel pre-processing steps that are very costly.

The shells from palm oil fruits are relatively dry (12% moisture content) at the site of the palm oil mills and do not need a number of drying and prepossessing steps before cofiring. If additional capacity is available in the coal mills (at the power plants) then the shells may be fired into the furnace through the coal mills, where it will be milled. Because of capacity limitations at the coal mills we assume a cofire rate at only 5% of shells. There seems to be very little or no effect on the boiler performance from the cofiring of the shells.

The feasibility is shown to be very promising for cofiring of the shells resulting in a reduced power production price without assuming any subsidies. However, EFB cannot become economically feasible with the high fuel prices of the pre-processed EFB (drying, baling, transportation, debaling). The many steps for this voluminous fuel have to be investigated and optimized significantly to make cofiring of EFB become feasible also including a reasonable/likely additional income/subsidy from CO2 credits.

Some recommendations for further R&D primarily for the use of EFB in power production are also presented in the report. The recommendations include a better characterization of the biofuel and more investigations both at pilot scale rigs and demonstration of the technology.

It should be noticed that the biggest challenge in the use of EFB for power production is to resolve the pre-processing and logistic problems, to lower the fuel price. As part future investigations it is utmost relevant to consider if EFB could be transformed to a different form of energy carrier at the site of the palm oil mills, eg. pyrolysis oils (for cofiring at power plants) or ethanol (to use as transport fuel as addition to gasoline) just to mention some.

References:

/1/ Peter Overgaard, Bo Sander, Helle Junker, Klaus Friborg and Ole Hede Larsen: “Two years operational experience and further development of full-scale co-firing of straw”. Paper at the Conference and Technology Exhibition on Biomass for Energy, Industry and Climate Protection. Rome, May 2002.

/2/ Statement by IEA Bioenergy on biomass co-firing (FINAL)