Indirect gasification: A new technology for a better use of Victorian Brown Coal

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Abstract

Indirect gasification of Brown Coal is an upcoming technology that can be used to not only produce electricity from coal, but also produce chemicals and fuels. It also provides the possibility to capture CO_2 in a highly concentrated gas, reducing the emissions to the environment. Indirect gasification combines the advantages of combustion (full conversion of the fuel) and pyrolysis (valuable products and concentrated CO_2) into one technology. This combination is key in achieving an energy system making the best use of Victorian Brown Coal.

Introduction

Victorian Brown Coal (VBC) is widely used in Australia for energy production. The Victorian government is promoting alternative usage of VBC to lower the emissions of CO_2 and to derive more value from coal, such as fuels and chemicals. At ECN an indirect gasifier is being developed for biomass and waste conversion. From years of experience operating on these fuels, other applications for indirect gasification became possible as well. The indirect gasifier MILENA appeared to be capable of efficiently converting low rank coal (high ash or brown coal) into a medium calorific gas that can be applied for many different applications. In this paper some experimental results from this technology are presented and an outlook is presented for the application of this technology in the Australian market. Key in this technology is the high efficiency, the option of reducing CO_2 emissions and the high-value end products that can be separated or synthesized from the gas. ECN is looking to expand its R&D efforts to the Australian market.

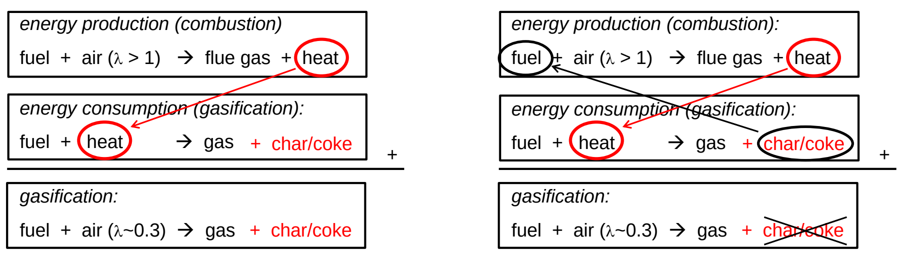
Energy Technology at ECN

ECN is working on clean and renewable energy technology. One of the research groups at ECN is dedicated to solid fuels and the conversion thereof to valuable forms of energy. A key technology is the indirect gasifier technology, called MILENA, which is developed for high efficiency conversion of waste and biomass. Throughout the years many fuels have been tested using MILENA. What started as an installation dedicated to biomass conversion, became an installation capable of converting a broad range of solid fuels, such as agro residues, sewage sludge, refuse derived fuels, high ash coals and brown coal. For fuels containing a low amount of volatiles, the MILENA is operated in reversed mode. This technological twist is explained further on.

For the conversion of brown coal, the idea is that a highly efficient gasifier can be used to produce electricity at small (<100 MW_{th}) and medium (<200 MW_{th}) scale. When the technology matures and grows in capacity the application of the gasification gas will shift to chemicals and fuels. There is a similar development at ECN ongoing for biomass, providing an overlap in the technological developments, such as gas cleaning and upgrading. Furthermore, large scale applications, such as the Great Plains Synfuel plant provide learning's on how to clean and upgrade the product gas from gasification, on a large scale.

Indirect brown coal gasification

Typically, gasification is a process where part of the fuel is combusted to provide heat that converts the remaining fuel into gas (**Figure 1**). This gas can subsequently be used for electricity, heating or high-end purposes. Compared to direct combustion on small scale, the efficiency to power is much better. A gas engine or a gas turbine performs much better on a small scale compared with a steam cycle. The lower temperature in gasification also has a positive effect on the ash behaviour related to the fouling propensity. However, the lower temperature can have a down-side relating to the fuel conversion. For bubbling or circulating fluidized bed gasifiers (BFB or CFB) this conversion stops at 97% (at best according to (Higman and van der Burgt 2007)), but usually it is much worse . To circumvent this issue the gasification temperature needs to be increased, but this will increase agglomeration and corrosion hazard. The high temperature also lowers the efficiency. Indirect gasification offers the unique possibility to reach 100% fuel conversion, without the need to go to high temperatures. In **Figure 1** the principle of a direct gasifier (BFB or CFB) is given on the left and the right figure shows the principle of indirect gasification. The twist is that the processes are separated and a bed material is used to exchange heat between the two processes.



Direct gasification Indirect gasification

Figure 1: Direct gasification (left) leaves a solid combustible residue called char or coke, whereas indirect gasification (right) uses this as an energy source within the process. Leading to a much higher overall efficiency.

Indirect gasification has more to offer than just the complete conversion of fuel. Below is a short list of the most prominent features of this technology.

- No air separation unit (ASU) needed – the combustion takes place in a separate vessel, hence air can be used and the product gas is essentially N_2 free.
- No carbon loss – the char/coke that remains after gasification is completely burned. The ashes are carbon free.
- High efficiency – because the gasification is decoupled from the combustion the gasification temperature can be much lower than direct gasification.
- Medium calorific gas – the product gas does not contain nitrogen, which increases the heating value substantially. This also offers the possibility to use the gas for more high-end applications.

The technology developed by ECN is an indirect gasifier, MILENA, which can operate in two modes. As it was developed as a biomass gasifier, the gasification normally takes place in a riser reactor where hot bed material and fuel are entrained to produce the gas. The char/coke is internally separated and returned to a BFB combustor producing the heat. In 2008 experiments were done with the MILENA operated on a mixture of wood and brown coal. These experiments showed that with increasing amount of brown coal the carbon conversion in the gasification section reduced (Vreugdenhil et al. 2009). Sufficient conversion of brown coal was not achieved because the lower amount of volatiles combined with a short residence time did not provide enough carbon conversion. In other words: too much coke was left to provide heat for the process.
For low volatile fuels, such as low rank coal (brown coal, but also high ash coal) the gasifier is operated in inversed mode, hence the name i-MILENA. In this mode a large residence time is created for the fuel conversion, using the BFB. The riser reactor is used to combust the coke that is providing the heat for this process. The following simplified scheme clarifies the operation of i-MILENA.

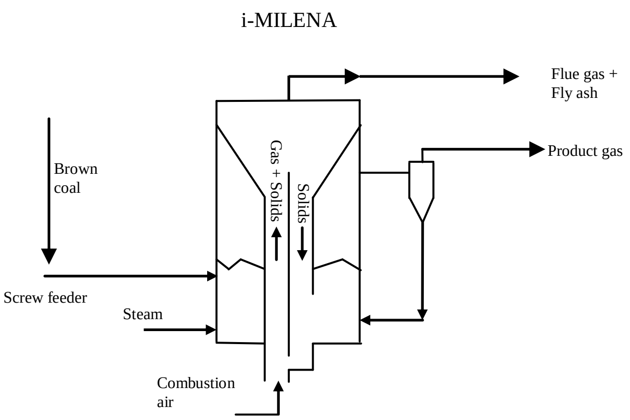


Figure 2: Simplified flow scheme of i-MILENA

The brown coal is gasified in a bubbling fluidized bed using steam. The residence time of the fuel in the bed typically is around 15 minutes. In the centre of the BFB a vertical tube (riser) is placed, with an opening at the bottom, through which the bed material containing coke is transported. The riser is operated with air to transport the solids to the top and to combust the char from the gasification process. The combustion heats up the bed material (solids) and this is returned to the BFB where it provides the heat for the gasification process. Since these two processes take place in separate reactors but integrated in one reactor, the heat loss is minimized. It also allows for complete fuel conversion at much lower temperatures compared to direct gasification. The indirect gasification results in a low N_2 containing product gas, which in turn allows more advanced applications of the product gas, such as CO_2 removal (Campisi and Woskoboenko 2009) that is identified as a key development issue for VBC use.

Brown coal gasification

Based on the resemblance in fuel analysis done on German brown coal (Heizprofi) and what can be found in literature for different VBC (Bhattacharya 2006), the German coal was chosen to simulate the VBC from Australia. The fuel was bought from a briquette supplier. It should be noted that it does not contain the same amount of moisture as VBC from the mines. For the gasification characteristics this is not important, because normally the fuel is dried before gasification. The fuel gasified in this experiment contained 10% moisture. The main composition is given in Table 1.

Table 1: Comparison between German brown coal (Heizprofi) and analysis done on VBC from different locations.

	C [% db]	*H [% db]*	*N [% db]*	*S [% db]*	*Ash [% db]*	*VM [% db]*	*M [%]*
Heizprofi	60	5.2	0.59	0.32	4.4	53	10
Loy Yang	68.4	4.8	0.68	0.31	1.1	49.4	13
Morwell	66.1	4.6	0.62	0.27	2.5	49.3	18.5
Yallourn	65	4.5	0.5	0.23	1.7	51	14.5
Lochiel	58.2	4.4	0.52	3.5	15.2	47	15

All is on a dry basis (db) except moisture (M). VM stands for volatile matter.

Figure 2 shows the lay-out of the gasifier used for the experiment. In this particular experiment the bed was fluidized with steam and a small amount of argon (tracer gas) was used to be able to calculate the gas flow. The total amount of steam was 2 kg/h, and 3.5 kg/h of brown coal (Heizprofi) was gasified. The remaining coke was combusted in the riser using 126 nl/min of air. The test had some starting issues relating to gas analysis, but was operated stable for 4 continuous hours. In Figure 3 the product gas composition for the main components is depicted over time.

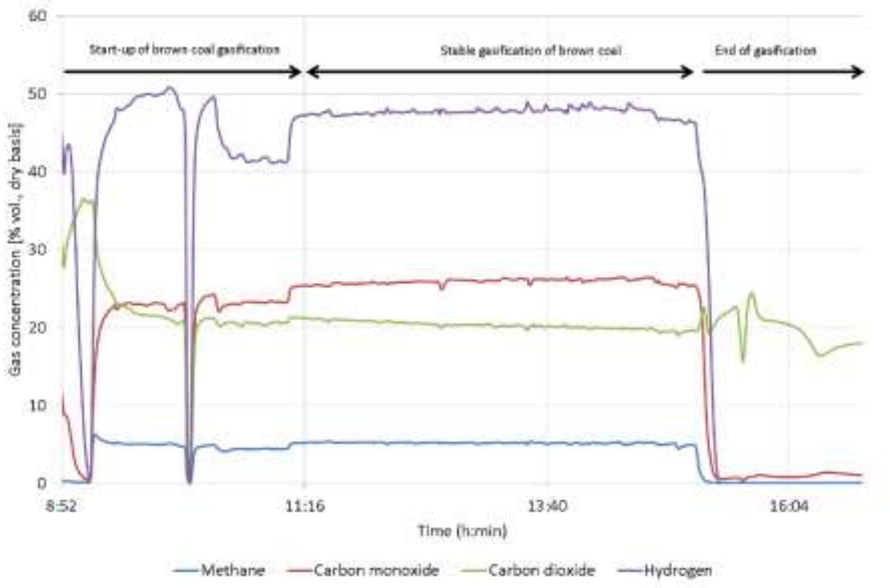


Figure 3: Composition of the product gas from brown coal gasification in the indirect gasifier i-MILENA

The complete gas composition of the product gas is given in Table 2. Behind the values obtained from the experiment also possible end-use applications are given. In principle the gas is of such quality that it can easily be converted into electricity. This is the most simple and straight forward application. For this application gas engines, turbines or boiler applications are foreseen. When the technology is scaled-up other possible applications become interesting as well. The amount of CO_2, ethylene and BTX in the product gas start to become financially attractive and for the largest scale also synthesis routes or cryogenic product separation steps become interesting.

Table 2: Gas composition for brown coal gasification in i-MILENA (on a dry basis).

Product gas			*Possible routes for the components*
CH_4	5,2	[vol.%]	LNG production
CO	26,3	[vol.%]	FT or methanol production
CO_2	20,4	[vol.%]	CCS or EOR
H_2	47,8	[vol.%]	FT or methanol production
N_2	0,5	[vol.%]	
C_2H_4	1,6	[vol.%]	Ethylene production
H_2S	1098	[ppmV]	
COS	64	[ppmV]	
Benzene	3532	[ppmV]	BTX production
Toluene	161	[ppmV]	BTX production
Tar	<15	[g/Nm^3]	
Flue gas			
CO_2	12,9	[vol.%]	-
O_2	5,0	[vol.%]	-

Before going into the three different options for VBC gasification and the foreseen track to go from small scale to large scale application, an overview is given in Table 3 that shows the value that is available in the product gas for different scales. The economic margin is defined as (profits – coal costs) divided by the amount of wet coal used.

Table 3: Estimate of the economic margin at different scale, with 8000 operating hours annually.

	50 MWth	*100 MWth*	*500 MWth*
Brown coal in tpa (wet)	105.000	210.000	1.049.000
Brown coal costs @ 3,5 $/ton wet	**0,37 M$**	**0,73 M$**	**3,67 M$**
E-production in a CC [0,05 $/kWh]	**8,6 M$**	**14,1 M$**	
Syngas [400 $/ton]			**107,3 M$**
C_1 [720 $/ton]			**19,6 M$**
C_2 [1200 $/ton]		**3,8 M$**	**17,2 M$**
C_6/C_7 [1200 $/ton]		**2,5 M$**	**11,1 M$**
CO_2 [20 $/ton]		**1,3 M$**	**5,9 M$**
Economic Margin [$/ton VBC]	78	100	150

VBC for electricity

The route foreseen for the development of i-MILENA operated on Victorian Brown Coal is similar to the route taken for the development of MILENA for biomass gasification. The idea is to mitigate risks and maximize the product development by keeping the first applications simple and add other developments (beside E-production) in on larger scale. Electricity production from VBC can be done using a gas engine or turbine, or couple the gasifier to an existing power plant, where it is possible to combust the gas. The scale at which this can be done is from 5 to 100 MWth input. In this scaling process a fluidized bed steam dryer is the best choice to dry the VBC and produce the necessary steam to fluidize the i-MILENA, thus increasing the efficiency. The gas quality is such that with minimal gas cleaning it can be send to a gas engine or turbine. Removing tar and water can be skipped when the gas is co-fired in an existing power plant.

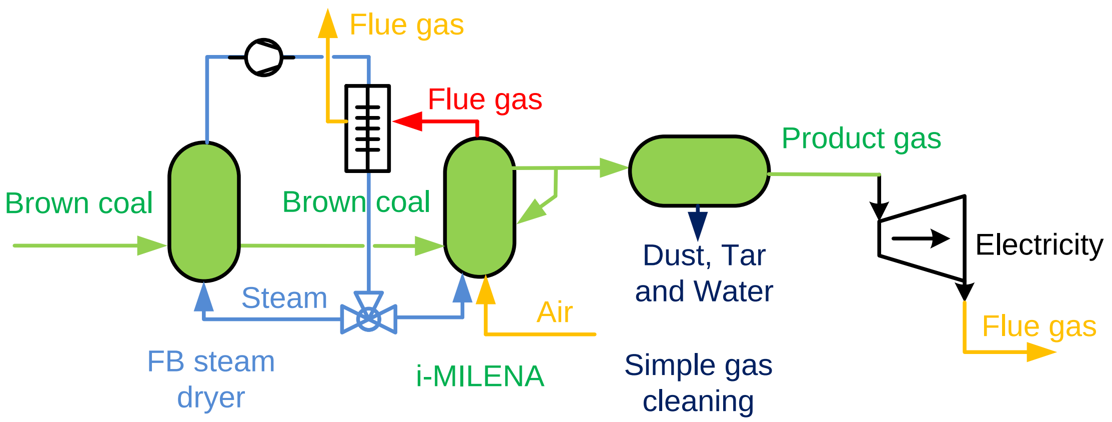


Figure 4: Simple flow scheme where VBC is gasified and the gas is used in an engine or turbine, typical scale 5 – 100 MWth.

VBC for co-production

When the system reaches sufficiently large scale (~100 MWth) other applications become interesting as well. For instance separating CO_2 will improve the sustainability of the overall process. Removing benzene and/or ethylene increases the product range of the installation. What remains is gas containing mostly CO, H_2 and CH_4. This gas can efficiently be burned in for instance a turbine. In Figure 5 a simplified lay-out of a co-production scheme is presented. After the gas clean-up the gas can be separated using conventional or to be developed technologies for harvesting benzene, ethylene and CO_2.

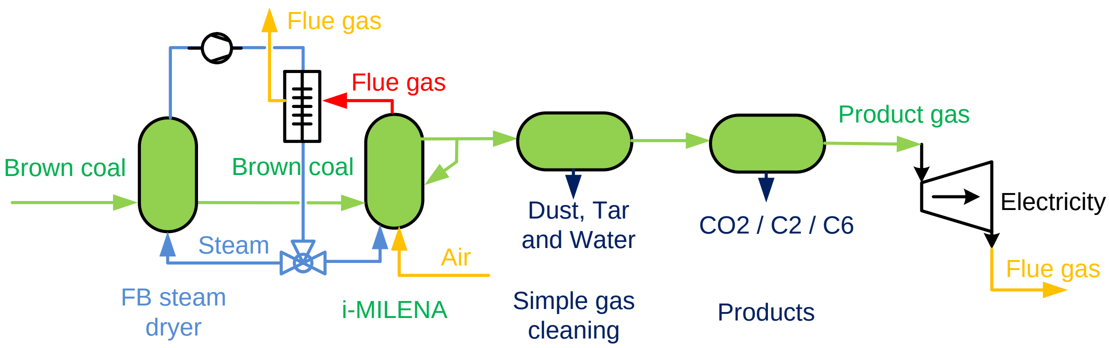


Figure 5: Victorian Brown Coal gasification to produce electricity but including products separation, typical scale is 100 – 200 MWth.

When the installation reaches a scale of 200 MWth the product gas at the end can also be used for synthesis routes.

VBC for fuel production

With the technology maturing, the size of the installations will increase as well. It is foreseen that i-MILENA can be scaled up to 500 MWth. At this scale, and larger, the amount of chemicals, methane and syngas are such that it is advantageous to develop a strategy to go from electricity to fuel production with this remaining syngas. Removing some of the remaining impurities such as sulphur and chlorine components makes it possible to go for catalytic process, some of which are shown in the Figure 6.

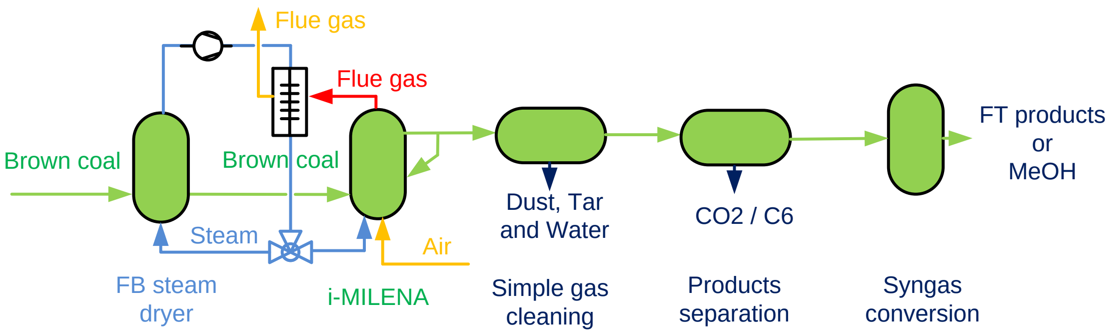


Figure 6: Victorian Brown Coal gasification to produce products and fuels, typical scale is 200 – 1000 MWth.

Depending on several factors (market prices, location, incentives) different routes towards valorisation of the syngas can be followed. One route could be to introduce a cryogenic separation step after the products separation. This results in an LNG and ethylene product. The remaining syngas can be converted into methanol. A different route is to go for a FT synthesis step, where waxes are produced from the syngas (still containing C1 and C2 components). At this point the VBC gasification process has grown from a side stream electricity producing option to a full stream chemical plant, where chemicals and fuels are produced.

Technology status

ECN has been working on the development of the MILENA technology for over a decade. Throughout the years the gasifier operated on biomass, sewage sludge, grass, straw, brown coal, RDF and high ash coal. The lab scale installation is 30 kWth and was scaled up to an 800 kWth pilot installation in 2008. This pilot gasifier also operated on several fuels. The technology currently is entering the market with a 4 MW_{th} Substitute Natural Gas (SNG) demonstration planned on wood in the Netherlands, a 22 MW_{th} power application on RDF is tendering in the UK and a 4 MW_{th} power application on soya stalks is currently being constructed in India.

With some minor adaptation to the technology, the MILENA can be converted into what is called i-MILENA. It has been proven that this installation is the better choice for fuels such as lignite and high ash coal. The work over the past years has already shown that co-gasification of brown coal in our “standard” MILENA works well and also high ash coal (>50% ash) can be gasified in the i-MILENA. Tests done this year show that an even better cold gas efficiency is obtained for brown coal in the i-MILENA. For dry coal on HHV basis this was 77%. Based on these results some preliminary calculations were done to explore what the possibilities are for applying this gas and these show that with a gradual build-up of the technology (adding separation processes and synthesis processes) the technology can become a versatile vehicle for producing anything from electricity to fuels.

Although the outlook for i-MILENA gasifying VBC and producing fuels and chemicals is very promising, some topics are still open for further investigations. First of all the drying step and integration with i-MILENA, which is going to be crucial in the overall process, is not tested at ECN. Looking into the known technologies, steam drying seems like the best option, because the i-MILENA uses a substantial amount of steam. Also steam drying is far safer compared to drying with flue gasses. Other issues remain with the separation of the different products and synthesis processes that are mentioned briefly in this paper. At ECN a lot of effort is devoted to the production of SNG, in this process the gas cleaning and product removal (such as benzene and ethylene) is being developed. Finally, the proposed route to fuels production from VBC with additional product separation is more complex coming from a power application, but one must not forget that a similar process has already been operated for many years. The Great Plains Synfuel plant is producing chemicals and fuels from coal already since the 1970’s. A lot of synergy for the large scale can be found here as well.

Conclusions

ECN is developing technology for a sustainable energy system. Gasification is part of the portfolio of ECN and the indirect gasifier MILENA is capable of gasifying numerous different fuels (biomass, waste and coal) to produce a medium calorific gas at high efficiency. The i-MILENA concept developed especially for low rank coal (high ash or brown coal) shows great potential in converting these fuels. This development builds on the years of experience gained in operating the MILENA, which is not so different from the i-MILENA. First tests in the i-MILENA show a carbon conversion of 100% with a cold gas efficiency of 77% on HHV basis, which is much better than earlier tests showed for gasification in the MILENA. Key features for i-MILENA are.

- No ASU needed;
- High efficiency even when gasifying at lower temperature;
- Full conversion and carbon free ashes;
- Medium calorific value gas, applicable for high-end applications.

The processes which are depicted in this paper provide an outlook to what the i-MILENA might achieve with VBC in Australia. This development is supported by ECN's development of the regular MILENA operated on biomass and waste. Some examples were given where the next steps in the technology development already are taken. Reasoning back from a plant, such as the Great Plains in North Dakota, the whole concept can also learn from the experiences gained there.

The first analysis of the potential for i-MILENA in Australia is good. ECN is looking to cooperate with Australian partners to further explore and develop this vast potential.

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