

## **Innovative Slagging Gasification Using The British Gas Lurgi (Bgl) Gasifier - A Co-Gasification Case Study For Western Macedonia**

Karlopoulos E., Koukouzas N., Katsiadakis A.

Centre for Research and Technology Hellas (CERTH)/

Institute for Solid Fuels Technology and Applications (ISFTA),

4<sup>th</sup> km N.R. Ptolemais-Kozani, P.O. BOX 95, 502 00, Ptolemais, Greece.

Co-gasification of coal and solid wastes is a relatively new technique, while experience is concentrated exclusively in Northern Europe and Northern America. Taking into account not only the fact that the international energy policy trend is to promote the development of decentralized energy production units, but also the favorable attitude towards biomass and various solid waste types, BGL-gasification constitutes a promising option for industrial and district heating boilers. Compared to grate gasifiers, the BGL offers the benefits of much higher specific throughput, significantly lower gasification steam requirement, the production of molten slag and the possibility of partial or total recycle of tars and oils to the gasifier.

The aim of this study is to investigate the techno-economic feasibility, concerning the installation and operation of a 30 MW<sub>e</sub> co-gasification power plant based on Integrated Gasification Combined Cycle (IGCC) technology, using lignite and Refuse Derived Fuel (RDF), in the region of Western Macedonia Prefecture (WMP)/Greece. The gasification block was based on the British Gas-Lurgi (BGL) gasifier, while the gas clean up block was based on cold gas purification.

The competitive advantages of co-gasification systems can be defined both by the fuel feedstock and production flexibility but also by their environmentally sound operation. It also offers the benefit of commercial application of the process by-products, gasification slag and elemental sulphur.

The preliminary cost estimation indicated that the establishment of an IGCC RDF/lignite plant in the region of WMP is not profitable, due to high specific capital investment and in spite of the lower fuel supply cost. The technology of co-gasification is not mature enough and therefore high capital requirements are needed in order to set up a direct co-gasification plant. The cost of electricity estimated was not competitive, compared to the prices dominating the Greek electricity market and thus further economic evaluation is required.

The project would be acceptable if modular construction of the unit was first adopted near operating power plants, based on parallel co-gasification, and gradually incorporating the rest process steps (gas purification, power generation) with the aim of eventually establishing a true direct co-gasification plant.

## 1. Case study for Western Macedonia

Taking into account the available technologies, a case study for WMP was carried out with regard to the potential of establishing and operating a direct co-gasification (IGCC) unit utilizing lignite and solid wastes in the form of RDF. The selection of this specific geographical region relies mainly on the presence of significant lignite deposits, but also on the operation of integrated solid waste treatment system within this region.

The annual production of lignite in Greece is around 60 millions tons, out of which 48 million tons derive from the coalfields of WMP. This advantage has been exploited to a great extent, since 67% of the total power requirements of Greece are generated within this region (Koukouzas et al., 2004).

The annual amount of municipal solid waste in WMP comes up to 117.000 tones. Around 20% of this quantity responds to non-combustible components, which will be removed during Refuse Derived Fuel (RDF) production (Solid Waste Management of Western Macedonia S.A., 2004). RDF was selected instead of MSW because of better quality characteristics, although the RDF production unit increases considerably the sum of Process Plant Cost (PPC).

The main process stages in the case of direct gasification include fuel pre-treatment, gasification, syngas clean up and finally power generation. The gasifier feed consists of RDF and lignite mixture in the form of pellets with 75:25% mass proportions. This high RDF/lignite mass fraction is feasible to be utilized for direct BGL co-gasification, according to tests performed at the facilities of SVZ Schwarze Pumpe during the THERMIE project (CERTH/ISFTA, 2002). Taking into account the total annual production of MSW, the installed power capacity of the unit was calculated to around 30 MW<sub>e</sub>. The power capacity estimation was also based upon the fuels' heating values and process efficiency.

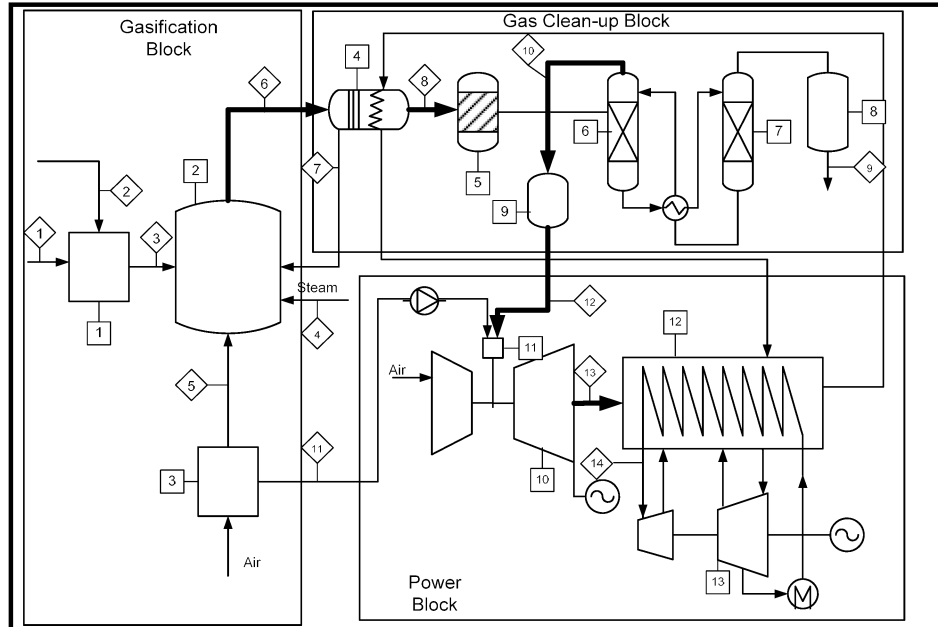
The feedstock requirements concerning lignite, RDF and oxygen and the by-products throughput, ash and elemental sulphur, were calculated based upon the results obtained from a US DOE/NETL report (NETL/Process Engineering Division, 2000), after appropriate escalation. The report is dealing with BGL gasifier IGCC base cases of the same type that was selected for the case study performed. The heat and mass balances in this report were performed using ASPEN PLUS (Version 10.1) simulation models.

### 1.1 Fuel pre-treatment and gasification (Gasification Block)

A simplified process flow sheet of the whole process is depicted in Figure 1. The RDF production unit (1) consists of standard equipment such as shredder, magnetic separators for metallic materials removal, classifier and screens for inert materials removal, dryer, mixer, cooler and pelletising press. MSW (stream 1) enters the fuel preparation unit and at the pelletising process step, lignite is added (stream 2) acting as a binder medium and hence producing uniform RDF/lignite pellets with great mechanical stability.

The feed mixture (stream 3), lignite/RDF pellets, is fed into the top of the BGL gasifier (2) via a lock hopper system where it is pressurized to the operating pressure of about 27 to 30 bars and reacts while moving downward through the gasifier. The BGL

gasifier is a counter-current, moving-bed, slagging gasifier. The reactor vessel is water and refractory lined. The drying and reduction zone temperature is between 40-700 °C. The gasification zone temperature is approximately 700-1500 °C, whereas the combustion zone temperature is around 1500-2000 °C. The gasification medium, steam (stream 4) and oxygen (stream 5), is injected through the bottom of the gasifier via tuyere nozzles, whilst the raw syngas (stream 6) exits from the top at 500 °C approximately. Ash is removed from the bottom of the gasifier as molten slag through a slag tap, then quenched in water and removed.



1. Fuel preparation 2. BGL gasifier 3. Air separation unit 4. Gas quenching – cooling and Gas – liquid separation 5. Gas cooling and COS hydrolysis 6. MDEA unit 7. SCOT unit 8. Claus unit 9. Gas preheating and saturation 10. Gas turbine 11. Combustion Chamber 12. HRSG unit 13. Steam turbine

*Figure 1. IGCC process flow chart.*

### 1.2 Syngas treatment and power generation (Gas-clean up block and power block)

Cooling of the produced synthesis gas via direct water quench (4), results in condensation of the heavy hydrocarbons components, such as tars, oils and naphtha. These compounds are then recovered in a separation unit (4) and recirculated back to the gasifier (stream 7). After additional cooling and Carbonyl Sulphide (COS) hydrolysis (5), the syngas is then driven to the cold gas clean up unit, where the Methyl Diethanol Amine (MDEA) (6) and Shell Claus Off-gas (SCOT) (7) methods are used in sequence to separate sulphur compounds, chlorides and ammonia, while elemental sulphur to be marketed is reclaimed simultaneously (stream 9) from the Claus unit (8). Afterwards, the clean syngas (stream 10) is preheated and resaturated (9) and after the addition of nitrogen (stream 11), derived from the cryogenic air separation unit (3), is

fed to the gas turbine (10). Nitrogen is added in order to increase the volumetric flow through the gas turbine and thus increasing power output.

The hot saturated mixture is burnt in the combustion chamber (11) of the gas turbine and the flue gases (stream 13) are then driven to the Heat Recovery Steam Generator (HRSG) unit (12), where superheated steam is produced. The produced steam (stream 14) is utilized for electricity generation in a two-stage steam turbine system (13), but also for internal steam demand purposes within the overall process. Power generation is accomplished by 67% in the gas turbine and by 33% in the steam turbine. The gross system efficiency of the unit is 47%, while internal power consumption is up to 7,5% (CERTH/ISFTA, 2002). The produced ash of vitreous structure, which contains non-combustible feed compounds, is either driven to landfills or stored for potential utilization.

### 1.3 Economic analysis – Assumptions

The aim of the economic analysis is to estimate the cost of purchasing and installing the process machinery equipment, the total capital requirements and the electricity production cost (€/KWh) for the IGCC plant.

By calculating the economics of the process being studied and comparing the resultant cost of electricity to the prices within the Greek electricity generating market, the potential profitability can be assessed.

### 1.4 Specific capital investment

Capital costs for the RDF/lignite IGCC plant were estimated using a combination of capacity factored and equipment-based methods. Capacity factored estimations utilize the ratio of the capacity (flow rate, heat duty etc) of an existing piece of equipment to the new equipment multiplied by the cost of the existing equipment, to estimate the cost of the new equipment. A scale-up factor particular to the equipment type was applied to the capacity ratio (Peters and Timmerhaus, 1991; NREL, 1996). This technique is used quite frequently to an accuracy of  $\pm 20\text{-}30\%$ .

All costs were calculated to instantaneous 2006 Euros. Where necessary, costs were corrected to 2006 basis using the Marshall and Swift equipment cost indices, published in Chemical Engineering Magazine. The major Delivered Equipment Costs (DEC) were multiplied by a factor to arrive at the Process Plant Cost (PPC).

PPC is converted to Total Plant Cost (TPC) initially and then to Total Plant Investment (TPI), after adjustment for interest and inflation during the construction period. Lastly, Total Capital Requirement (TCR) is estimated. TCR is used so that realistic estimates of constructing an RDF/lignite IGCC plant can be calculated.

For the case of Western Macedonia, the specific capital investment for the 30 MW<sub>e</sub> IGCC plant came up to 3.867 €/KW<sub>e</sub>. The gasifier and the HRSG-steam turbine unit exceed 50% of the total DEC. The air separation unit has also a great contribution to DEC. Therefore, it is recommended to erect small-scale gasification plants within large industrial areas, so as to share utilities without bearing extra capital costs. The specific capital investment was then calculated in order to examine the effects of scale.

It was found that the specific capital investment for units smaller than 350 MW<sub>e</sub> is not competitive enough compared to the cost of conventional power stations utilizing solid fuels, which comes up to 1.000-1.200 €/KW<sub>e</sub>.

## 1.5 Cost of electricity

The cost of electricity was estimated using the levelized bus-bar cost method by dividing the total annual production cost by the annual electricity output (Ntelkis, 2000). No profit element is taken into account during the implementation of this analysis. This method is expressed by the equation:

$$C = \left\{ \left[ i \times (1+i)^d / (1+i)^d - 1 \right] \times IU + foc \right\} \times 1/h + (voc + fc) \quad (1)$$

Where: C= Electricity production cost (€/kWh), IU= Specific capital investment cost (€/kW), foc=Fixed annual operating cost (€/kW), voc=Variable annual operating cost (€/kWh), fc=Fuel cost (€/kWh), h=Annual operating hours (hr), d=Project life (yr), i=Nominal interest rate

Based upon this method, a 0,0926 €/KWh unit electricity production cost was calculated for the 30 MW<sub>e</sub> RDF/lignite IGCC plant.

The electricity selling price in Greece, from power generated from RES and CHP installations and supplied to the main grid comes up to 0,0684 €/KWh for low, medium and high voltage (Regulatory Authority of Energy, 2006). The cost of electricity for the case examined was 0,0926 €/KWh and therefore further economic evaluation is required. The corresponding selling price for decentralised power generation from RES, not connected to the grid (mainly the Greek Islands) is 0,0846 which makes the investment more attractive and competitive, but the establishment of such a plant in isolated regions will be confined by logistics. The main factor that renders the 30 MW<sub>e</sub> project non-profitable is the high value of specific capital investment cost. A considerable diversification in the economic analysis is observed by increasing the installed capacity.

For a unit with installed capacity greater than 200 MW<sub>e</sub> the resultant unit electricity production cost is 0,0366 €/KWh, whereas for a 400 MW<sub>e</sub> plant the production cost becomes almost equal to the cost of the lignite-fired power stations of Public Power Corporation S.A (PPC S.A.).

## 2. Discussion - Conclusions

For the case of Western Macedonia, the high capital investment cost of IGCC systems can be overcome by utilizing the modular construction ability for this kind of installations, based on parallel gasification technology. Firstly, only the gasifier can be constructed and fed with wastes and lignite. The produced syngas, with minor treatment, can be fed to the thermal power stations of PPC S.A., located at WMP, as an auxiliary fuel during low capacity demand or as a fuel for start-up purposes. It can also be utilized by the PPC S.A. power stations in cases where the lignite quality is very poor and outside the required limits. By these means, significant amounts of petroleum oil can be saved or substituted and thus resulting in great capital savings.

This is the most reasonable option to adopt as an initial stage, since there are still uncertainties and technical barriers in the IGCC technology that have been observed in their operation. Another driver towards this direction is the seasonal variation in waste fuel quantity and quality. An installation with the calculated RDF/lignite fuel fraction (75/25 w/w) will be at high risk and therefore the limited capacity factor constitutes another constraint.

Then, by optimizing and gaining know-how on the gasifier operation, the syngas clean up unit can be developed and added. Thus, the ability of utilizing syngas as a fuel in combined cycle/gas engines/fuel cell systems or as raw material for the chemical industry is provided. This will gradually turn the parallel co-gasification project into direct, independent co-gasification project.

The lowest investment cost per unit of electricity generated can be achieved by the use of the gas in an existing large power station (parallel gasification). This has been done in several large boilers, often with the gas fired alongside the main fuel and it seems to be the best way of applying co-gasification, especially for small scale gasification units and preferably as an initial stage. The above technical considerations and the high cost of electricity that was estimated during the case study for WMP, indicate some of the incentives for large size of power plant. Labour requirements per unit of installed capacity provide yet another driver towards large unit size. High efficiency IGCC power plants are therefore almost always in the several hundreds of MW<sub>e</sub> size ranges. At smaller capacities, reciprocating engines can become relatively more attractive compared to rotating turbines.

In the medium term, coal, biomass, solid wastes and mainly the combination of them will constitute the main feedstock fuels for gasification systems. The need for extensive recycling, the stricter environmental regulations, the relatively high availability of coal deposits in conjunction with the crude oil resources shortage, do not allow any other option. Especially in Greece, relied on the domestic lignite deposits, the innovative power technologies of the 21<sup>st</sup> century can be adjusted directly and effectively to the energy and waste management system.

### 3. References

- CERTH/ISFTA, 2002. Co-gasification of Coal and Wastes for Power Generation, THERMIE-SF/08/98/DE, Final Report.
- Koukouzas, N., Kakaras, E. and Grammelis, P., 2004. The Lignite Electricity-generating Sector in Greece: Current Status and Future Prospects, *International Journal of Energy Research* 28, 785-798.
- Ntelkis, K., 2000. Electric Power Production Cost, National Technical University, Electric Power Department, Athens (in Greek).
- Peters, M.S. and Timmerhaus, K.D., 1991. *Plant Design and Economics for Chemical Engineers*, 4<sup>th</sup> Edition, McGraw-Hill Inc., New York.
- Regulatory Authority of Energy, 2006. Schedule of Rates for Electricity from Co-generation and Renewable Energy Sources, Athens (in Greek).
- Solid Waste Management of Western Macedonia S.A., 2004. General data on Integrated Solid Waste Treatment System of Western Macedonia, Kozani (in Greek).
- U.S. Department of Energy/N.E.T.L./Process Engineering Division, 2000. BGL Gasifier IGCC Base Cases, PED-IGCC-98-004, Washington DC.
- U.S. Department of Energy/.N.R.E.L., 1996. Cost and Performance Analysis of Biomass-based Integrated Gasification Combined-cycle Power Systems, NREL/TP-430-21657, Colorado.