Gasification - The Gateway to a Cleaner Future

D J White - Independent Energy Consultant

Abstract

Over the past decade, European environmental legislation has had an increasing influence on the use of energy. Emissions are being controlled to improve air quality while effluents and solid wastes are subject to more stringent regimes to improve water quality. The legislation has already had a considerable impact and emissions from the power generation and transport sectors are steadily falling. Land-fill as a means of disposal for municipal garbage and methods for the disposal of sewage sludge have been reviewed because of the consequential pollution. Sustainability has entered the vocabulary and has led to the recycling of waste packaging materials and studies of the role for biomass.

In parallel with these changes, the EU commitments to the Kyoto agreement and a reduction in global warming introduce constraints on CO_2 emission. The prime response to CO_2 reduction calls for a progressive improvement in the efficiency of energy use. Targets can be met by harnessing the major improvements in gas turbines, CCGT and aero-derivative turbines for power generation and CHP schemes while the many advances in auto engines are set to reduce emissions from the transport sector. Changes in the power sector are also arising from the deregulation and restructuring which is taking place in the industry in many parts of the world.

When all these factors are combined and evaluated in terms of the available technology to achieve the required environmental goals, gasification moves into the spotlight. It is very versatile and is starting to make a significant contribution to the conversion of dirty energy sources into a clean fuel gas and hydrogen. Many energy resources are well suited as feedstocks for gasification but cannot be directly combusted while meeting current emissions standards without costly flue gas cleaning equipment. Gasification is therefore a route to unlock clean energy into a commercial market. Consequently, it can be argued that political decisions which have been taken over the past decade to protect the environment are now contributing to the drive for gasification albeit perhaps by accident rather than by design. The paper will examine EU legislation to illustrate the ways in which specific steps have led to the growing need for gasification.

Introduction

Gasification is one of the key technologies to address the main environmental issues of today. The contribution it can make is only just being recognised but there is now a trend towards the technology as a response to environmental legislation which has been put in place especially in Europe over the past decade. These legislative measures are leading to the application of gasification in a broad spectrum of circumstances and are certainly not limited to the generation of electrical power.

The title of this paper was chosen as the theme for the 3rd European Conference held in Dresden recently organised by the UK's Institution of Chemical Engineers. It appeared to be the most appropriate title for this paper as the intent was to draw attention to the technology and its increasing relevance in solving many environmental problems. Its versatility in being able to convert a range of hydrocarbons into a clean mixture on hydrogen and carbon monoxide creates a series of opportunities for the direct use, or synthesis, of the mixed gases to other clean energy products.

This paper sketches the evolution of European environmental legislation and illustrates how gasification is becoming an increasingly attractive way to respond to the challenges which have been set in each subsector. The driving forces for air quality improvement extend well beyond the power industry and embrace the transport sector, the oil industry and a range of waste streams. There is also a growing interest in biomass gasification as development work proceeds which addresses the question of sustainability - a word of growing importance in the political vocabulary.

The paper will therefore cover the following areas:-

- power generation
- transport sector emissions and the impact on fuels quality
- waste recycling including plastics
- sewage sludge disposal
- carbon dioxide-free power generation
- biomass conversion

1. Power Generation

The emissions limits imposed on the European power industry were set out in 1988 by the EU's Large Combustion Plant Directive. The legislation contained two main components. The first was a series of national emissions reduction targets for SO_2, NOx and particulate for each member state to be implemented over a 15 year period in three 5 year phases, reductions taken from emissions in 1980 as the base year. The second was a set of specific limits on the 3 pollutants mentioned above for all new plant planned to operate on coal, oil or gas. A sliding scale was introduced to allow smaller combustion plant more latitude than the larger installations such as power plants.

Each member state has the obligation to comply with the EU limits but was entitled to opt for local limits which are more stringent than those in the broader legislation.

Tables 1 sets out a few examples of the country limits in the Directive. The original targets recognised the comparative economic strengths of the member states to avoid penalising countries such as Portugal, Ireland or Greece.

Table 1 - Reduction Targets vs 1980 Emissions

Units - % 1980	SO_2 Phase 1 1993	SO_2 Phase 2 1998	SO_2 Phase 3 2003	NOx Phase 1 1993	NOx Phase 2 1998
Denmark	-34	-56	-67	-3	-35
France	-40	-56	-70	-20	-40
Germany	-40	-60	-70	-20	-40
Italy	-27	-39	-63	-2	-40
Netherlands	-40	-60	-70	-20	-40
U.K.	-20	-40	-60	-15	-30

Source: EU Directive

Countries have responded in different ways. Germany, for example, implemented their programme in full and by 1988 had retro-fitted 38 GW of coal fired capacity with FGD and most with SCN. Their 1995 figure already exceeded the reduction required by 1998 while the forecast is that the reduction for the whole of Germany will meet the target set for West Germany in the Directive. The Netherlands and Denmark also installed FGD on their coal stations. The UK only installed 8 GW of FGD on 2 major coal stations while the remaining 13 GW of coal fired capacity are without emission control. However, the UK emissions were reduced substantially by the introduction of natural gas and combined cycle gas turbines which have kept the total emissions well inside the commitments required by the Directive.

The process has now been made more complex because the present Government wishes to preserve jobs in the coal industry whilst avoiding over-dependence on gas. A moratorium was proposed on new CCGT capacity which would limit installation of the cleanest, most efficient and lowest cost capacity for the older, least efficient and most polluting. However, this remains subject to free market forces and new gas capacity has not been banned. Any reversion to coal needs to be set against a backdrop of UK Government commitment to reduce CO_2 emissions as part of the Kyoto Agreement - by a unilateral 20% by 2010. The protection of jobs in deep mines is incompatible with the CO_2 commitment. In fact, there is concern that the West European commitment to reduce CO_2 emissions may have strategic implications - particularly a growing dependence on the need for substantial gas imports from eastern Europe.

Three countries have recognised the merits of gasification. The Dutch wished to retain coal in the energy portfolio and SEP, the Dutch Electricity Generating Board, were very far-sighted in their decision to demonstrate IGCC on a large scale. The Buggenum project can now be considered a success and is acknowledged as the cleanest coal based plant in Europe. Spain has followed with the Puertollano project converting a mixture of local coal and petroleum coke to power.

In Italy, the challenge was rather different. For many years, the power industry had tried to introduce coal fired capacity at proposed new coastal stations but planning permissions were not forthcoming. In consequence, over 20m tonnes per year of heavy fuel oil continues to be used as a fuel to the power sector supplemented by a growing quantity of imported natural gas. The power industry needed to reduce emissions and the oil industry did not wish to lose a market outlet for substantial quantities of fuel oil. Joint venture arrangements to install IGCC operating on heavy oil residues was an attractive option and this was supported by the Italian Government who were willing to agree an electricity price for the first 8 years of the projects. In consequence, 3 projects are at the late stages of construction due for commissions in the summer of 1999. A fourth project is being evaluated.

These projects differ from the refining projects in that power production is the prime product of the gasification process. As will be seen in the next section, another driver for gasification at refineries is the generation of hydrogen.

The 1988 Large Combustion Plant Directive contained a mandatory review of progress in 1996 - to be undertaken in the light of technical progress, with the authority to modify the original target as appropriate. The review has been completed and the conclusions have been drafted into new legislation. The result is a tightening of the emissions standards for new plant but some of the more extreme proposals which were being sought have been dropped. One interpretation of the new limits is that the major generators and the boilermakers have pressed for limits which allow post combustion clean-up on steam-based systems. The limits have not been set to Best Available Technology based on gas turbine technology.

Table 2

Units mg/m^3	SO_2 Original	SO_2 New	NOx Original	NOx New	Particulate Original	Particulate New
Coal	400	200	650	200	50	30
Oil	400	200	450	200	50	30
Gas	n.a.	35	350	150	5	5
Size MW th	>500	>300	>500	>300	>500	>300
% Desulph	unspecified	>95%				

Source: Directive Amendments

During the debate on the changes, there was a strong possibility that the SO_2 and NOx levels would be set by the criteria of Best Available Technology - namely, the levels which could be achieved by using CCGT operating on natural gas (or synthesis gas). The European Parliament appears to have backed away from that position because of the risk of over-dependence on gas imports, while leaving the door open for a portfolio of energy sources. The levels adopted are also achievable using ultra-super critical boilers and state of the art flue gas cleaning equipment but capital cost will play an important part in such investment decisions.

In summary, it can be argued that in the power sector, gasification is now being pushed by environmental constraints and pulled by the major advances in gas turbine technology. Developments over the past 15 years put CCGT systems well in the lead in power generating technology unrivalled on capital cost, minimal emissions and very high efficiency. The following table summarises the position and illustrates the increase in size and efficiency over the period. It also shows the efficiency when operated on natural gas and if operated in IGCC mode. These figures suggest that the economics for new plant will be more closely focused on the natural gas price and the cost of producing syngas from other energy sources. Although syngas from coal may not be competitive at current European bulk gas prices, heavy oil residues now appear to be an economic source which may benefit from a hydrogen credit in some locations, as covered in the next section.

Table 3

	Unit	KWU V94.2	KWU V94.3	GE 9FA	KWU V94.3A	KWU * V94.3A	MW 701G1	GE 9G	MW 701G2	GE 9H
1st Yr Available		1981	1992	1991	1995	1995	1997	1997	1998	1999
Power Outpt GT	MWe	159	229	275	242	301	330	345	370	390
CCGT Efficiency	%LHV	54.4	57.3	58.6	58.9	60.4	61.1	60.1	60.6	62.7
Nett Power Outp	MWe	254	365	404	384	420	470	476	525	555
IGCC Efficiency	%LHV	44.2	47.1	47.2	48.5	48.4	49.1	48.3	48.9	51.0

Source:- Demkolec article - Modern Power Systems Nov 1997

Note* The Siemens Model V 94.3A has a modified air compressor to allow air side integration at a level of 40%. The remaining 60% of the air to the ASU would be supplied by a free standing air compressor.

2. Transport Emissions and Fuels

The European, US and Japanese debate on urban air quality has been focused on the transport sector for many years. Unleaded gasoline was introduced many years ago to allow tail pipe clean-up using catalytic converters while various schemes have been devised to encourage passenger pooling and reductions in the use of passenger cars. A great deal of progress has been made by the auto industry in reducing vehicle emissions and the environmental performance of new vehicles is very impressive. However, the growth in the vehicle population has offset some of the improvement while the criteria being set for clean air have tightened. Higher air quality standards continue to be sought but the proposed criteria appear to be influenced more by environmental lobbyists than by medical evidence about the impact of selected pollutants on human health.

The introduction of lead-free gasoline was only the beginning. European legislation mandated catalytic converters on all new gasoline-driven vehicles from 1 January 1993. The latest designs of 3-way catalytic converters remove some 90% of the CO, NOx and hydrocarbon in the exhaust gases. Concern then switched to diesel and in October 1996, an EU Directive required that all diesel fuel had to meet a sulphur level of 0.05% - a reduction from 0.2% previously. This step alone put refiners under considerable pressure both for desulphurisation capacity and hydrogen to operate it.

Over this period, Europe was breaking new ground in the area of consultation on environmental issues. The EU Environmental Directorate opted to consult and jointly prepare a tripartite study - the Auto Oil Study - working with representatives of the oil industry and the motor manufacturers. The study was designed to identify the most cost effective routes to further reduce total emissions by examining the levels of pollution from both the vehicles themselves and the refining sector. The additional processing required to improve quality increases the amount of refinery fuel consumed and the corresponding increase in potential pollution from the refineries. Hence the need for an integrated system analysis.

The tripartite study successfully defined the paths which should be followed and the adjustments to diesel quality which would be most effective. However, when the tripartite recommendations were debated by the politicians, a vociferous minority raised questions about the proposed European fuels quality citing Californian quality as being superior. It opened up the question of Best Available Technology (regardless of cost) and Best Available Technology Not Entailing Excessive Cost (BATNEEC). Attention was also drawn to the very high city diesel quality specified by the Swedish Government for Stockholm which added weight to the political argument for better quality. (Sweden requires an Arctic quality of diesel in winter, a grade more akin to kerosene than conventional European diesel).

Political pressure has prevailed and very low sulphur limits have now been set along with improvements in other specification points such as a reduction in aromatic components. Reductions in the sulphur content of diesel and gasoline have to be achieved by hydro-desulphurisation. Consequently, most refineries are becoming short of hydrogen and must find ways of generating it either by reforming natural gas or by gasification of streams such as heavy oil residues. Table 4 overleaf sets out a few of the changes required in diesel quality by the year 2000 and 2005. These changes have crystallised the decision-making process for most refiners and new capital projects are emerging rapidly with most European contractors busy in preparing tenders.

Table 4

Diesel Fuel Quality - European Proposed Standard

	Current	2000	2005
Cetane Number	49	51	51
Density Max kg/m^3	860	845	845
Distillation 95% ^oC	n.a.	360	360
Polycyclic Aromatics % Max	n.a.	11.0	6.0
Sulphur ppm	500	200	50

Source: UKPIA n.a. not applicable

One unresolved question centres on the cetane number (the diesel equivalent of octane). The oil industry and the auto makers have been working well together on the auto-oil study but there has always been a difference of view over cetane. The refiners have claimed it would be too costly to increase cetane while the auto-makers know they could design more efficient engines if cetane could approach say 56. The growing demand for higher quality diesel is now leading many oil and gas companies towards gas-to-liquids technologies based on the Fischer Tropsch process. These processes will yield a sulphur free diesel of uniform density and high cetane i.e. in the 70 - 76 range which appears to be a new way to supplement demand for diesel while improving quality.

In Europe, gasification had been used for many years at the German Leuna refinery and at the Schwarze Pumpe complex. Following re-unification, the French company - Elf - purchased the Leuna refinery and has substantially expanded the gasification capacity with a new gasifier. The largest oil gasifier has now been built by Shell at their Pernis refinery in Rotterdam. A new refinery complex has been completed and successfully commissioned consisting of a gasifier with a capacity equivalent to about 500 MW. Some 300 MW equivalent is taken as hydrogen for a new hydrocracker and for desulphurisation. A portion of the clean gas is used as refinery fuel which virtually eliminates SO_2 emissions while the balance is used for power generation with some 100-120 MW being exported to the grid.

As a result of recent confirmation of the EU quality specifications for diesel and gasoline required by 2000 and 2005, several other projects are being studied across Europe with a major plant out for tender in Spain, a new joint venture between Electricité de France (EDF), Total and Texaco in France announced at their Gonfraville refinery in Normandy and many strong rumours in other countries for similar refinery investment.

The outcome of these investments results in the Netherlands now having both Europe’s cleanest refinery and the cleanest coal based power generating capacity as a result of gasification.

3. Waste Streams

The handling of bulk waste streams has posed problems for many years. Municipal solid waste (MSW) is a case in point. Many countries have used landfill as the least cost method of disposal but space is becoming an increasing problem so alternative methods are being examined. In countries such as Germany, environmental activists have influenced government policy and formed an influential political party themselves. Sustainability has also become a much discussed topic with growing interest in the recovery and recycling of materials in everyday use.

One European target was packaging and the vast amount of material consumed in simply transporting goods from manufacturers to the consumer in pristine condition. Packaging waste became a perceived problem - almost a ‘cause célèbre’ and EU legislation was passed in the form of the Packaging Waste Directive 94/62/EC. It came into force on 21.12.94 with formal compliance by 30.6.96. The two key dates motivating action were 1 January 1998 when ‘compliance with essential requirements’ came into force and 30 June 2001 by which time compliance with the 5 year targets will be required.

Purpose of the Directive is best summarised with a brief extract from the introductory text.

“The Directive has three main objectives:- to reduce the impact of packaging on the environment; to harmonise national measures in order to prevent distortions to competition; and to ensure free movement of packaged goods. The environmental objective is to limit the amount of packaging waste going to final disposal through reuse and recovery. The Directive sets out to achieve its objectives (a) by requiring Member States to establish return, collection and recovery systems (b) by setting a number of targets for recovery and recycling, and (c) by guaranteeing free circulation within the EC of packaging which meets certain essential requirements”.

Two other fundamental parts of the Directive merit a mention. It assigns responsibility for recovery to specific types of company in the use cycle - the Activity Obligation. Table 5 sets out the obligation as:-

Table 5

Activity	*Percentage Obligation*
Raw Materials Manufacturing	**6**
Converting	**11**
Packaging/Filling	**36**
Selling	**47**

The activity obligations require companies in the four categories to contribute to the level of their obligations. The basic idea is to spread the responsibility for recovery and recycling between packers, fillers, retailers and packaging manufacturers. Nevertheless, it is clearly easier for some to comply than others - e.g. retailers. Table 6 sets out the recovery and recycling targets which each European country is expected to achieve.

Table 6

Year	**Recovery Rate %**	**Recycling Rate %**
1997	**-**	**-**
1998	**38**	**7**
1999	**38**	**7**
2000	**43**	**11**
2001 onwards	**52**	**16**

The materials specified as packaging are paper/cardboard, aluminium, iron, glass and plastics but wood will be added from the year 2000. Targets have been set for each (wood is to be introduced by 2001) for recovery and recycling (method unspecified). Data for the first four categories suggests that the targets are achievable with little difficulty. In fact, over-recovery is possible in some categories such as secondary and tertiary packaging and glass. However, the target for plastics is likely to be very difficult to achieve because the bulk of the mixed waste plastic is to be found in the municipal solid waste streams. Separation of plastic from this stream is complex and costly while the plastic itself, where used for food wrapping, is likely to be contaminated. Table 7 indicates the degree to which each of the targets is likely to be met in the UK.

Table 7

Recovery Target 2001 %	**52**	**52**	**52**	**52**	**52**	**52**
Recycle Target 2001 %	**16**	**16**	**16**	**16**	**16**	**16**
1998 Estimate	**40**	**10**	**15**	**10**	**5**	**n.a.**
Annual Quantity million tonnes	**4.5**	**0.2**	**0.4**	**1.0**	**2.0**	**1-1.5**
	Paper/board	**Aluminium**	**Iron**	**Glass**	**Plastic**	**Wood**

Plastic is the second highest volume and will be the biggest challenge - a position which prevails in most member states.

All the legislation is in place to pursue the environmentally attractive path of recovery and recycling. The threat of harsh penalties for non-compliance is embodied in the legislation. In the past 25 years of the European Common Market, no precedents have been set whereby Directives have been rescinded. Many have been superseded or amended to introduce more stringent targets so it seems unlikely that this would happen on such an environmentally driven topic as waste packaging. In fact, in the April issue of the UK environmental report ENDS (1), an article uncovered a recent EU cost benefit study which could lead to an increase in the requirement to recycle from 16% to 36%.

One of the key questions which still has to be resolved is the definition of recovery and recycling. Physical recovery is only the first stage and this must be followed by reprocessing either into reusable packaging material or for energy recovery. Energy recovery by incineration is one possible option for defining recovery. However, recycling means processing for reuse which may not difficult for aluminium, steel or glass and perhaps cardboard. Plastics is an entirely different problem and it will difficult agree on a definition which suits all European nations. The UK definition tabled for agreement is that recycling should return the plastic to the hydrocarbon family either by physical recycling as another form of the product e.g. garden furniture or by reprocessing. Depolymerisation or processes such as gasification appear to be two of few which will meet the definition of recycling. One major advantage of gasification is that it has the ability to safely remove fillers pigments and halogens which most other processes fail to do.

In Germany, Schwarze Pumpe are gasifying plastics on a large scale. Over 500 kt has been processed in the past 4 years. Texaco has plans for a 40 kt/yr mixed plastics gasifier in Rotterdam where the CO would be routed to Exxon Chemicals to synthesise alcohols and thus back to plasticisers. BP propose the use of depolymerisation and the reprocessing of the resultant liquid thereby returning it to the hydrocarbon family. Fife Energy has plans to refurbish the British Gas Slagging Lurgi gasifier in Scotland to process a mixture of wastes and coal. The main hold-up on these types of project at present is that the local authorities who have the prime responsibility to collect the waste streams and ensure their safe processing are reluctant to commit themselves to contracts exceeding 1 year and this is totally inadequate for companies wishing to invest in processing capacity. A political resolution of this problem is urgently needed.

4. Sewage Sludge

The disposal of sewage sludge is becoming a major challenge on a global scale. In Europe, many countries with access to the North Sea had dumped at sea or had sewage outfalls directly into relatively shallow coastal waters. The quantity of sludge for disposal has already been increased some 50% as a result of a 1991 EU Directive on urban waste water treatment. For many years, EU legislation has also existed to set sea water quality standards for the popular bathing beaches and this in turn had forced many municipalities to install sewage treatment plants. However, dumping in the North Sea has still been legal but from the end of this year it will be banned by the Urban Waste Water Directive. This has crystallised all plans for treatment and processing among all the water/sewage authorities who now face a tight deadline for compliance. The 1996/7 estimate of annual dumping from the UK alone was 260 kt equivalent of dry solid so the problem is not small. The position was exacerbated by another piece of legislation which limited the amount of sewage sludge which could be put to land-fill as no more than 25% of the total land-fill mix.

The problem of sludge disposal required a more scientific approach and this led to a more detailed evaluation of the characteristics of the material. The least cost disposal options were land-fill or spreading on land with incineration as a safer option. However, each of those routes has associated problems and increasing associated costs. Land-fill is becoming limited in many places while spreading on the land even with reprocessing has proved to allow live bacteria to survive with the associated risk of re-entering the food chain. Processing by incineration or some other energy recovery process such gasification has therefore gained acceptance. Lurgi undertook much development work and assessed the quality of the dried sludge by comparing it with other low energy fuels. There are similarities between dried brown coal, wood waste/biomass and dried sewage sludge which led them to develop a thermal gasification process for the sludge. Table 8 indicates the quality similarities.

Table 8

Typical Data	Dried Sewage Sludge	Dried Brown Coal (Rheinisch)	Wood Waste or Biomass	
C	57.0	67.3	54.7	wt % daf
H	8.0	5.0	6.0	wt % daf
O	30.2	26.3	38.9	wt % daf
N	4.2	0.5	0.3	wt % daf
S	0.6	0.9	0.1	wt % daf
Total	100.0	100.0	100.0	wt % daf
Volatile Matter	87.0	55.0	>85	wt % daf
Ash	18.6	5.6	1.5	wt % wet
Moisture	7.0	17.1	19.1	wt % daf
Net CV	17.6	19.3	15.4	MJ/kg

Source: Lurgi

The Lurgi Residue (LR) process was developed for this purpose and several plants have now been installed in Europe. One of the most recent is in the UK for a large water company, Northumbrian Water. The plant has been built on Teesside to treat all the sludge within their catchment area - primarily the city of Middlesbrough and the many industrial complexes on the Tees estuary.

The simplified process takes granular dried sewage sludge and raises the temperature very rapidly (>150^{o}C/sec) to 850^{o}C. The organic matter is thermally cracked to produce a mixture of vaporised liquid and gaseous hydrocarbons as well as residual carbon and ash which remain behind on the heated carrier bed of sand. In the second stage, the gases and liquid vapour come into contact with hot sand where further cracking takes place to hydrocarbons in the C_1 - C_4 range. This boosts the calorific value of the product gas to around 23 MJ/m^3 making it a very useful clean fuel gas for heating or fuelling say a gas turbine. The conversion efficiency or 'cold gas' efficiency is 75-85% which is an excellent heat recovery from material which has hitherto gone to waste. The skill of the process is to utilise all the low grade heat to dry the sludge and this is where the Lurgi technology has been a success. The Middlesbrough installation has been conceived as a combined heat and power plant so the fuel gas is routed to two natural gas fired turbines each capable of producing 5 MW of power. In the next phase, another turbine is to be installed to run on an increased quantity of sewage derived gas.

In Germany, sewage sludge is being gasified with brown coal at Schwarze Pumpe and a new methonla plant has been started up to cover the syngas from these streams.

Two major advantages of thermal gasification are that a) the high temperature destroys any bacteria and b) any residual metals remain in the minimal quantity of ash which can then be disposed of safely. The economic drive for this type of gasification process and of other waste disposal processing is the increasing alternative cost of disposal. This approach to economic evaluation is becoming increasingly important as environmental legislation continues to close low cost routes which have been acceptable in the past

5. Zero CO_2 Emission Power Generation

The Norwegian Government along with other European countries has been debating the introduction of a carbon tax. Power generation in Norway has almost entirely been centred on hydro-electric power with a remarkable system of control which enables water to be conserved at high elevations to provide the maximum reserve of renewable energy. Any move toward significant quantities of fossil fuel would increase CO_2 emissions in a country visibly dedicated to sustainability.

Norsk Hydro has therefore developed a project which will utilise the combined cycle gas turbine system with technology to convert the natural gas feed to hydrogen. The gas turbine will operate on hydrogen diluted with nitrogen to produce a CO_2 free exhaust gas. The hydrogen will be gasified/reformed. The CO produced in the first stage of gasification is converted to more hydrogen using the shift reaction. Norsk Hydro is enhancing the environmental benefit by publicising that additional hydrogen is being made from water. The CO_2 is then sequestered using the usual gasifier gas clean-up system. The CO_2 is then returned to the offshore gas wells where it will displace an equivalent quantity of natural gas thereby increasing the yield of the gas field.

Efficiencies and economics have not been disclosed but the cost of sequestering the CO_2 is said to be more than offset by the additional natural gas yield from the wells.

6. Gasification of Biomass

The whole question of sustainability has led to much research and development of renewable energy particularly featuring wood and other biomass. In many ways, this is a case of turning the clock back because of the role wood has played throughout history. Today, wood wastes are used as a source of energy in the paper and board industries. However, to make best use of the characteristics of wood as a renewable resource, further conversion steps such as making gaseous and liquid fuels need to be considered. The energy density may need to be increased and the raw material converted into other hydrocarbons such as methanol or alcohols.

Gasification using air and fluidised bed systems or thermal gasification as illustrated in the Lurgi Residue process provides the means of generating either CO/H_2 mixtures or C_1 - C_4 fractions. These 'intermediate' gases can either be used as fuel or as building blocks for other liquid fuels or chemicals. The chemistry is basically simple - the main challenge is economics, both in terms of assembling sufficient of a flow of the material to support a process plant and in finding a way to reduce the water content of the raw material by utilising all the low grade heat available.

Continuity of supply of the raw material is important and in the case of wood, for example, coppicing of hazel and willow, has been examined. In warmer climates, eucalyptus offers potential as a fast growing source. However, studies indicate that one plant can only be served economically within a radius of up to 70 km and the costs, fuel usage and emissions from the plant and transport to cut and deliver the feedstock to the plant need to be taken into account. Other crops such as oil seed rape and sugar have been studied (the latter to produce gasohol as in Brazil) but these types of crops are very dependent on agricultural policy and often subsidy.

Demonstration projects have started in Europe and the USA using wood. The ARBRE project in Yorkshire is an 8 MW gasification combined cycle plant operating on willow. It is using Swedish technology and is supported both by the UK's Non Fossil Fuel initiative (NFFO) and the EU Thermie programme. In Italy, there is a 12 MW project using a Lurgi Circulating Fluidised Bed gasifier to generate power from wood. Another large project is the 15 MW unit in Burlington, Vermont using fluidised bed technology and high temperature pyrolysis. An intermediate char is produced which is then gasified to a better quality gas than is normally produced by air-blown systems.

The key to the use of biomass is economics. There is little doubt that it can be used and the technology will continue to evolve primarily based on optimising the low grade heat for drying and enriching the product gas by increasing the ratio of hydrocarbon to CO/H_2 . There are some other factors that need to be assessed. There has to be a question over whether it can be considered to be totally CO_2 neutral when there is such a relative high energy input into the harvesting and transport of a low energy density material. Furthermore, in some parts of the world, fast growing trees can absorb a vast quantity of water and in parts of S Africa, for example, eucalyptus can no longer be planted because of the threat to potable water resources.

The other aspect of cost is that of the actual cost of power from biomass versus that of the more conventional alternatives. Recent UK studies of renewable power generation suggest that little can be produced without a doubling or tripling of the electricity price.

Summary

Gasification has been widely used for the past 40 years in the chemicals industry. To date, it has been considered too costly a process for other applications such as power generation. However, environmental legislation is beginning to make the process attractive as a method of converting the dirtier hydrocarbons and hydrocarbon bearing waste streams into a clean gaseous fuel and a building block to other useful products.

Gasification is a versatile technology. However, the scale of the operation will be dependent on circumstances. In refining or power generation applications, they will be related to the power output required or the economic size of the gas turbine which matches that demand of up to 550 MW. In the case of wastes, it will relate to the quantity which can economically be assembled at one location to continuously feed a plant and that may vary from 25-50 kt/yr. Gasifiers have been used for the past 35 years on a smaller scale in the chemicals industry so the broadening of their application brings relatively little risk albeit that it is a new concept to the power industry.

One of the features of gasification which is starting to emerge is that the process may need to be scaled to match the prime purpose for its choice. For example, its application for plastics recycling, sewage sludge or biomass will mean it has to be sized to the economics of the collection system. For oil refineries, it will be the economic balance between residue disposal and the demand for hydrogen and/or electrical power while for power generation, the size of the gas turbine might be the prime determinant of size given an outlet into a large power market.

D J White
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Reference 1. Environmental Data Services (ENDS) Monthly Report - April 1998