Clean and Economical Gasification of Combined Coal and Biomass Pelletized Fuels By Industries Worldwide

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Co-utilization of coal, biomass and other fuels

Advances in coal gasification technology

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Abstract

Industrial clean coal utilization is enhanced when gasifying low cost high ash coals combined with locally available biomass and/or biowaste from agricultural and/or industrial operations. The cost of the biowaste is near zero if there is a cost associated with the removal of the biowaste from the industrial site. The clean gas and liquids generated for industrial usage are in the range of 0.12 to 0.15 €/nM³ displacing much costlier petroleum or gaseous fuels.

Sotacarbo S.P.A. and Ansaldo Ricerche S.r.l. with collaboration of Hamilton Maurer International, Inc. (HMI) have designed, installed and commissioned an advanced single-stage fixed-bed gasifier in Sotacarbo's R&D facility in April 2007. Clean coal utilization is enhanced when coal is combined with a biomass or biowaste feedstock. Ansaldo Ricerche and HMI, Inc. designed a single-stage fixed bed biomass gasifier, installed and successfully commissioned in 2001 at ARI's research facility in Genova, Italy. This presentation highlights the simplicity and high efficiency (82 to 87%) of the coal and coal/biomass gasification process.

CPM both in the US and Europe has extensive experience with coal fuels preparation (pelletization). The economics and ability to combine coals with biomass to generate an economical and viable gasification fuel pellets are reviewed.

This paper presents the ability to utilize coal cleanly with biomass (Bio-coal) to lower fuel costs while enhancing the availability and reliability of industrial energy and reducing CO_2 emissions provides a quantum jump forward for both industries and the environment.

Section I

SUMMARY

Energy-intensive industries worldwide face three significant operating costs that impact their economic success: (1) the cost and availability of energy resources; (2) the economic need to move towards CO2 neutral fuels and (3) the cost incurred with the disposal of waste material from operations. During the past 12 months the cost of energy has increased significantly plus the reliable supply of industrial energy (natural gas and/or oil) remains a genuine concern. Added to the industrial energy cost and supply concerns is the cost of industrial waste removal which continues to increase due in part to environmental and legislative drivers (laws) and the availability and cost of landfills. The industrial energy market can benefit from a low cost and more secure, clean coal-based industrial gasification process coupled to economic bioenergy resources. Further more, in specific cases the industrial site can convert their own biowaste into clean energy combined with coal.

This presentation highlights the ability for industries to enhance biomass fuels and to eliminate waste removal costs through the utilization of an economical and historically proven industrial-coal-gasification process available @ Sotacarbo's gasification demonstration site. Industrial gasification of coal can stabilize the supply and cost issues of oil or natural gas, which both fluctuate excessively due to international instability. By combining coal with an industrial biowaste generated daily, the industrial energy user can "take control" of their operating energy requirements and possibly even sell excess power to the grid at a profit.

The basis for this clean and efficient coal-gasification process was generated during a 3 ½ year (1981-1985) demonstration project jointly funded by the United States Department of Energy and industrial members of the Mining and Industrial Fuel-Gas (MIFGA) Group. Since the late 1990's, Hamilton Maurer International, Inc. (HMI) and Ansaldo Ricerche (ARI) have collaborated to establish a similar database for a wide range of biowaste and coal pellets. The Sotacarbo coal gasification project which includes both the pilot and laboratory scale gasifiers will enable fuel flexible bio-coal pellets to be developed and their gasification performance quantified.

This presentation explores the industrial-coal-gasification process being researched and demonstrated by Sotacarbo, S.P.A. applied to coal and/or bio-coal pellets. The presentation also reviews the biomass/biowaste and coal requirements for successful and economical pelletizing. The presentation concludes with a discussion of clean and efficient combustion of industrial fuel-gas and/or the pyrolysis liquids using proven industrial low NOx burners.

Section II

Sotacarbo Coal Gasification Capabilities and MIFGA Reference

Although the United States possesses a long history of operating industrial fixed-bed coal gasifiers, this history does not include operation with low-rank coals or biomass as feedstock. The MIFGA Group was formed to gain fundamental coal gasification performance data using industrial fixed-bed gasifiers for western coals (sub-bituminous, lignites, and MN peat) in the United States. The MIFGA collaborative industrial group needed to quantify the utilization of coal gas in rotary kiln operations for taconite pellet induration, and demonstrate the required gas clean up for industrial utilization (References 1 – 19).

A ~2 meter (6.5-foot) diameter single-stage fixed bed industrial gasifier was installed at the US Bureau of Mines, Twins Cities Research Center in 1977-78. The objectives of the industrial coal gasification demonstration/research program were:

1. Quantify the coal gasification performance limitations for industrial fixed-bed gasification and the overall conversion efficiencies.

2. Quantify the impact of coal properties on gasifier operation.

3. Characterize the total gasifier product(s) under various operating conditions.

4. Identify gasifier operational and control design improvements, which can reduce both downtime and operational requirements → **The Sotacarbo pilot gasifier has automation features designed into its' operation based on the MIFGA coal gasification performance database**.

5. Generate and quantify a source of coal gas and coal derived liquids for characterization, processing and utilization studies.

6. Provide an opportunity for "hand-on" gasifier operational experience for MIFGA industrial cooperators.

7. Quantify environmental impacts for industrial fixed-bed gasifiers.

Facility and Process Description

The Wellman-Galusha industrial gasifier installed at the US Bureau of Mines facility is shown schematically in Figure 1 (Reference 2).

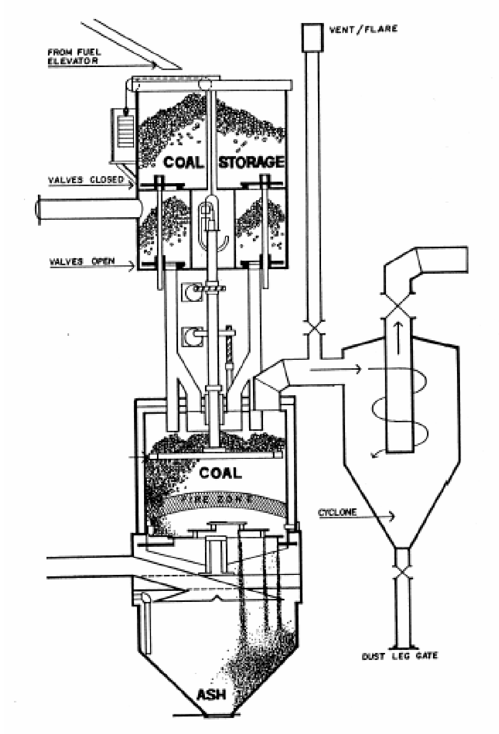


Figure 1, Wellman-Galusha Industrial Fixed-bed Gasifier

The Wellman-Galusha gasifier historically operated a few inches wg above atmospheric pressure. Coal was choke fed from an overhead lock-hopper through feed pipes into the gasifier vessel. Within the reactor vessel, the coal slowly descends to the grate, it is dried, devolatized, gasified, and finally the char residue is burned in a thin layer just above the ash bed. The coal-ash thermally insulates the rotating, eccentric, step-type "Galusha" grate. Ash is removed continuously from the process as a dry granular solid.

Moving counter to the coal flow is the gas flow. Blast air, saturated with steam at a controlled temperature moves up through the ash layer where the ash is cooled and the air/steam mix is heated. The blast saturation temperature (air/steam ratio) controls the incandescent zone temperature, maintaining it just below the ash fusion temperature. Within the incandescent zone oxygen in the saturated air blast reacts with the carbon to form carbon monoxide and carbon dioxide. As CO and CO2 move through and above the incandescent zone the high temperature steam and CO2 in the blast react with the hot char above the oxidation zone to produce CO and H2. The endothermic reactions cool the gas but there is sufficient sensible heat in the reactor bed to preheat, devolatize, and dry the fresh coal feed as it moves down through the packed bed. The counter flow design yields product gas temperatures in the range of 200 – 500° C. The efficiency of the gasification process is in the range of 92+% (hot-raw gas) to over 85+% with gas cleaning (gas and pyrolysis liquids).

Coals Gasified during the MIFGA Project:

During the 3½ year MIFGA project, a total of 18 different coal gasification tests were conducted and documented. The fuels gasified spanned the range from "green" delayed petroleum coke on the high rank end to four different physical forms of Minnesota peat on the low rank (or biomass) end see Table 1, below (References 3 – 18).

Table 1: MIFGA Coals Gasified

Coal		Rank (*)
Jetson		hvBb
Rosebud		subB
Leucite Hills		subA
Stahlman Stocker		hvAb
Petroleum Coke		NA
Piney Tipple		hvAb
River King IL # 6		hvCb
Elkhorn		hvAb
Benton Lignite		lig
Peat Pellets		NA
Peat Sods		NA
Blind Canyon		hvBb
Kemmerer		subB
Absoluka		subC
SUFCO		hvBb
Indianhead		lig
Hiawatha		hvBb
(*)		
hvAb high volatile A bituminous		
hvBb high volatile B bituminous		
hvCb high volatile C bituminous		
sub B subbituminous B		
sub C subbituminous C		
lig lignite		

All coals were from resources of the United States. Eight different bituminous coals and five different sub bituminous coals were gasified. Two lignites were gasified, one from the Wilcox seam in Arkansas, the other from the Indianhead seam in North Dakota.

Industrial Gasification Design Performance of MIFGA Coals:

Fifteen of the eighteen coals gasified were successful. Three coals were judged not suitable feedstock for industrial fixed-bed gasifiers. The three unsuitable fuels are listed below:

BOM/FGT-004	Stahlman Stoker Bituminous (Reference 6)
BOM/FGT-006	Piney tipple Bituminous (Reference 8)
BOM/FGT-002/016	Rosebud Sub-bituminous (References 4 & 16)

Stahlman Stoker and Piney Tipple bituminous coals are both high swelling bituminous coals from Pennsylvania. Both Pennsylvania bituminous coals have swelling indices

(FSI) above 6.5. The swelling and agglomerating characteristics of these coals could not be effectively managed using the agitator of the gasifier. The agglomeration in the upper bed resulted in extremely non-uniform gas flow through the bed, which in turn resulted in low carbon conversion and a low quality product gas with very low coal throughput achieved.

The high swelling bituminous coals not suitable for gasification feedstock in their natural state would produce excellent bio-coal pellets combined with biomass or biowaste.

The Rosebud lignite (on the low rank end) demonstrated excessive friability and decrepitation, which impacted the coal throughput and resulted in very low gas quality.

The design performance data for selected bituminous, sub-bituminous, and lignites are presented in Tables 2 through 4 to provide an overview of the gasification performance of various coals in the single-stage fixed-bed gasifier.

Design Point Characteristics for Gasification
of Blind Canyon Bituminous Coal

Coal Throughput - 1.8 tons/hour (108 lb/hr/sq ft grate)

Air/Coal	2.09	lb/lb
Steam/Coal	0.384	lb/lb
Blast Saturation Temperature	145	deg. F
Gas Offtake Temperature	800	deg. F
Wet Gas/Coal	52.8	scf/lb
Gas Dewpoint	117	deg. F
Tar Yield	14.2	lb/100 lb coal
Tar Analysis		
HHV (dry)	17157	Btu/lb
Pourpoint	92	deg. F
Viscosity (210 F)	62.2	SUS
Specific gravity (60/60 F)	1.0394	
Dry Gas Composition (mol %)		
Hydrogen	18.30	
Carbon monoxide	27.00	
Methane	1.84	
Ethane	0.181	
Ethylene	0.151	
Propane	0.054	
Propylene	0.057	
Carbon Dioxide	6.30	
Nitrogen + Argon	45.90	
Water	5.4	lb/1000 dscf
Dry Gas HHV	174	Btu/dscf
Dry Gas LHV	162	Btu/dscf
Thermal Efficiencies		
Hot, raw	93	percent
Cold, with tar	84	percent
Cold, without tar	66	percent

Table 2, Gasification Design Performance of Blind Canyon Bituminous
(Reference 14)

Design Point Characteristics for Gasification of Absaloka/Robinson Subbituminous Coal

Coal Throughput - 2.0 tons/hour (121 lb/hr/sq ft grate)

Air/Coal	1.80	lb/lb
Steam/Coal	0.415	lb/lb
Blast Saturation Temperature	152	deg. F
Gas Offtake Temperature	635	deg. F
Wet Gas/Coal	48.0	scf/lb
Gas Dewpoint	132	deg. F
Tar Yield	4.2	lb/100 lb coal
Tar Analysis		
HHV (dry)	16995	Btu/lb
Pourpoint	85	deg. F
Viscosity (210 F)	9.7	SUS
Specific gravity (60/60 F)	1.0454	
Dry Gas Composition (mol %)		
Hydrogen	18.6	
Carbon monoxide	28.8	
Methane	1.41	
Ethane	0.100	
Ethylene	0.059	
Propane	0.028	
Propylene	0.034	
Carbon Dioxide	5.15	
Nitrogen + Argon	45.7	
Water	8.84	lb/1000 dscf
Dry Gas HHV	171	Btu/dscf
Dry Gas LHV	160	Btu/dscf
Thermal Efficiencies		
Hot, raw	90	percent
Cold, with tar	81	percent
Cold, without tar	73	percent

Table 3: Gasification Design Performance of Absaloka/Robinson Sub-bituminous (Reference 13)

Design Point Characteristics for Gasification of Peat Pellets

Peat Throughput - 1.8 tons/hour (108 lb/hr/sq ft grate)

Air/Peat	1.29	lb/lb
Steam/Peat	0.19	lb/lb
Blast Saturation Temperature	139	deg. F
Gas Offtake Temperature	251	deg. F
Wet Gas/Peat	41.5	scf/lb
Gas Dewpoint	153	deg. F
Tar Yield	7.9	lb/100 lb peat
Tar Analysis		
HHV (dry)	15552	Btu/lb
Pourpoint	+110	deg. F
Viscosity (210 F)	56.9	SUS
Specific gravity (60/60 F)	1.0491	
Dry Gas Composition (mol %)		
Hydrogen	17.20	
Carbon monoxide	28.40	
Methane	1.46	
Ethane	0.100	
Ethylene	0.087	
Propane	0.024	
Propylene	0.040	
Carbon Dioxide	7.97	
Nitrogen + Argon	44.30	
Water	17.1	lb/1000 dscf
Dry Gas HHV	168	Btu/dscf
Dry Gas LHV	158	Btu/dscf
Thermal Efficiencies		
Hot, raw	92	percent
Cold, with tar	82	percent
Cold, without tar	66	percent

Table 4, Gasification Design Performance of Minnesota Peat Pellets
(Reference 12)

Sotacarbo - extends the MIFGA Coal Gasification Database to Bio-coals:

The Sotacarbo coal gasification facility (References 20 & 21) comprised of the 1.3 meter diameter pilot gasifier (Figure 2a) and the 300 mm diameter laboratory scale gasifier with complete gas clean-up and laboratory R&D capability for syngas shifting to hydrogen (Figure 2b) will offer to industries throughout Europe and the US the ability to assess bio-coal pellets relevant to their industrial operation. The Sotacarbo coal and bio-coal pellet gasification facility is shown in Figure 2 below.

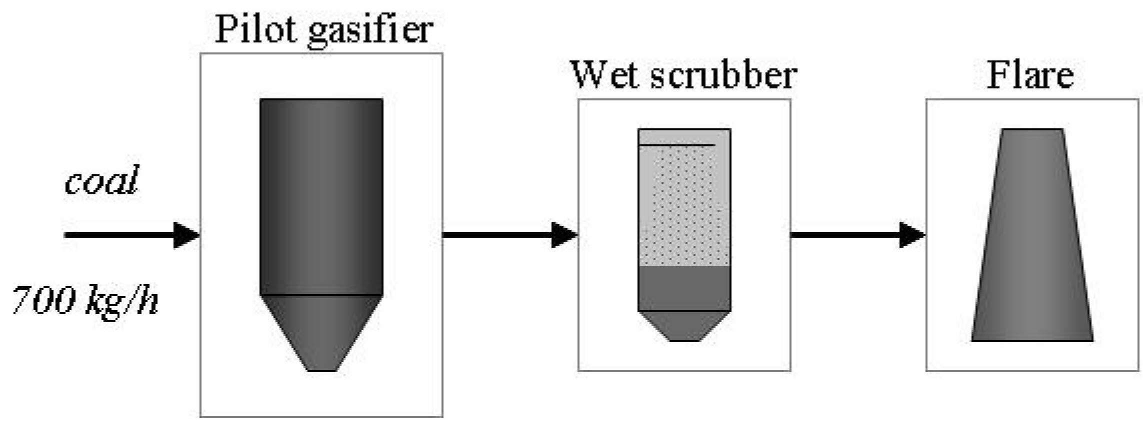


Figure 2a Sotacarbo Pilot Gasifier Schematic

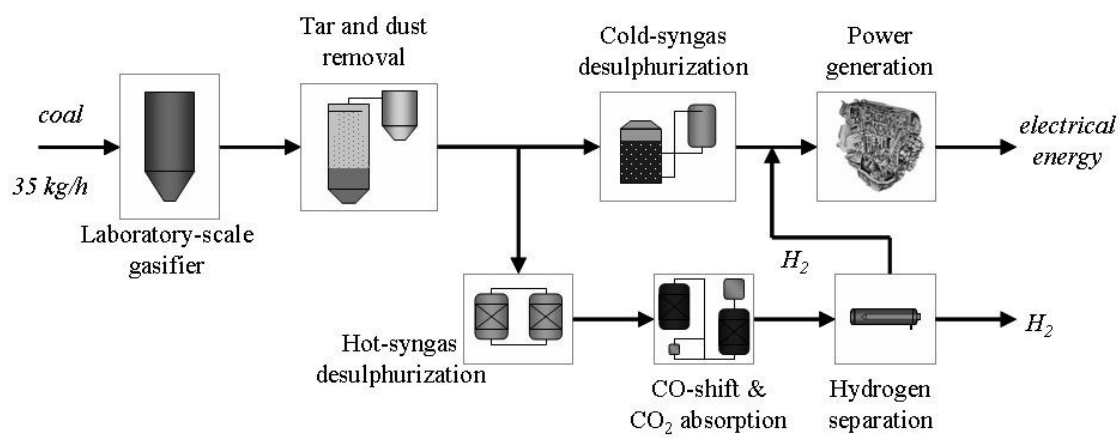


Figure 2b Sotacarbo Laboratory Scale Gasifier Schematic

Figure 2, Sotacarbo Gasification Operations

Sotacarbo will be able to demonstrate a small scale ~ 1 MWe industrial scale coal and bio-coal fueled distributed power generation system integrated with both the local electrical grid and Sotacarbo's laboratory power requirements demonstrating different commercial gas and diesel engines.

Sotacarbo with assistance from ARI and HMI's industrial marketing focus will provide a state-of-the-art coal and bio-coal gasification facility with the following capabilities to develop industrial clean coal and bio-coal fueled projects worldwide.

- A nominal 1 MWe pilot gasifier with complete gas clean-up., including pyrolysis liquids recovery and utilization in dual fueled diesel engines along with gas in high efficiency gas engines for distributed power generation (0.5 to 1 MWe).

- Laboratory scale gasifier with complete gas clean-up and pyrolysis liquids recovery and complete analysis for dual fuel industrial utilization and gas shifting capability for hydrogen generation (Reference 20).

- Laboratory scale gasifier for oxygen/steam gasification with or without CO2 displacing nitrogen in the air for high temperature industrial applications where nitrogen in the syngas would result in excessive NOx emissions. This holds great potential for bio-coal fuels being applied to the glass industries manufacturing processes.

- Laboratory scale gasifier for bio-coal pellet development and gasification performance demonstration for industrial clients (co-funded by industrial clients).

Sotacarbo can establish the laboratory scale and pilot scale gasifiers as definitive tools for industries worldwide to fund and support the development of bio-coal pellets and gasification process specific for their process requirements and the most reliable sourcing and economic fuels available.

Section III

Pelletizing Coal & Biomass/Biowaste

Fresh mined coal (sized feedstock) does not present a fuel preparation challenge for industrial gasification systems, other than the minus ¼ inch material must be screened from the feedstock prior to entering the gasifier as demonstrated during the MIFGA industrial gasification project (Section II). Waste coal and biomass fuels, which present both an environmental and economic advantage for industrial gasification systems must first be made uniform and sized/densified for fixed bed gasification.

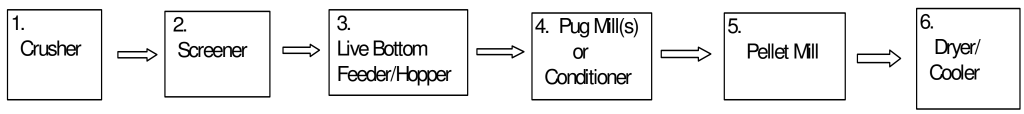
California Pellet Mill (CPM), founded in 1883, is today the world's largest producer of pelleting equipment with a worldwide presence of sales, service, and manufacturing for industrial applications. CPM has two pelleting test facilities: one in Waterloo, IA (USA) and the other in Amsterdam (Netherlands). CPM's pelletizing experience encompasses most industrial wastes including the following: paper sludge, coffee chafe, potato pulp, PVC, polypropylene, wood waste, cellulose, car-fluff, coal and coal sludge (fines from coal wash plants).

Combining coal with the wide range of biowaste materials has been done to some extent in the CPM laboratories, both in the United States and Europe. In general, adding coal to Biowaste can yield a higher energy dense pellet for gasification depending on the coal/biowaste used. Varying percentages of coal fines to biowaste can be achieved by either changing the die specifications and/or moisture content to match the desired addition rate. Particle size will influence pellet quality with smaller particles (1/8 x 0) having more surface area for bonding together and therefore more consistency in both pellet production and pellet quality than larger particle sizes.

For industrial clean energy, pelletizing waste coal and biomass requires a sized pellet suitable for easy handling and feeding into the gasifier with the correct size/properties for continuous gasification in a fixed-bed gasification process. The diameter of the pellets should be between 12-19 mm (1/2 to ¾ inch) with the length of the pellets being less than 25 mm. Combining waste coal with biowaste for industrial gasification yields an energy density enhancement in the fuel pellet and a more consistent product gas.

CPM's Experience in Pelletizing Coal:

Below is a typical flow for a site using crushed coal. If a plant were using coal fines directly from a prep plant, then the first 2 steps would not be necessary. The dryer may or may not be necessary depending on the moisture level required for the end use of the pellets. If two or more products were blended together, they would be combined in steps # 3 and # 4.



1. Crusher designed to reduce coal to minus 1/4 inch or desired product size.

2. Hoppers can be loaded either with front end loader or belt conveyer. Varible speed discharge needed in order to feed Pellet mill correctly. If feedstock moisture is variable and if precise water/binder additions are needed, then a belt scale/moisture meter is recommended between the feeder/hopper and pug mill or conditioner. If feedstock moisture is always constant, scale may not absolutely be needed

3. Screener/Shaker removes +1/2 inch or size desired.

4. Pug mill (Mixer) designed to add water and liquid binder. Amount added dependent on feeder/hopper speed. Dry binder addition is also added at front end of pug mill. A small electric feeder with a porportioning screw is typically used. This is usually manually adjusted to match feed rate. A conditioner can be added in place of a pug mill for water addition. In this case, the dry feeder would be placed between the feeder/hopper and the pug mill.

5. Pellet Mill: Recommended to install an emergency water additon to minimize die from plugging in event water in conditioner/pug mill is shut down.
6. Dryer/Cooler.

Other: A control system is necessary to connect all motors and drives to a localized control room. Pellet mill amps must be monitored in order to be able to add/subract water additon or to speed up/slow down feeder to match desired pellet mill performance. Belt scale at discharge of Pellet Mill or dryer is optional.

The pellet mill components required for pelletization consist of a rotating ring die and generally two rolls inside the die that mechanically force or push the product through holes in the die. Each die is drilled with a specific hole diameter and specific length holes. The die specification will vary with each product. In very general terms, the die thickness with any given hole diameter will cause resistance in the die. The thicker the die, the more resistance and therefore more force is required to push the product through the die. The opposite is also true. A thinner die results in less force needed to push the product through the die. Other factors affect resistance such as moisture and particle size. It is therefore, very important that all factors remain constant in order to produce constant results.

CPM has had extensive involvement in the United States with coal pelletization beginning in 1997. Hundreds of tests were done with many different coals. The section below briefly explains the knowledge and experienced CPM has gained through the commercial pelletization of coal. In general, whether pelleting coal, plastics, wood waste, or Biowaste, the same basic process is used. Some parameters are more critical with some products than with others.

Coal fines were tested and pelletized as a response to a US government incentive that was instituted in the late 1970's and early 1980's to encourage the use of alternative fuels to reduce US dependence on imported foreign oil. The subsequent testing and pelleting of waste coal that had been recovered from coal ponds or coal impoundments were a result of this program.

Most coals tested produced a pellet having 11,000 to 12,500 BTU's/pound except the western coals, which have about 8400 BTU's/lb. The western coals were tested due to their lower sulfur content. The ease or ability to pelletize the various coals was greatly influenced by several factors:

1. **Coal type (rank).** Both hard and soft coals were pelleted successfully. Some coals were more abrasive than others. Utilizing coals with higher BTU value with lower abrasive characteristics should be considered for greater economic benefit.

2. **Moisture.** Moisture levels required for pelleting varies considerably with the various coals. Many coals pelleted best at 16-18% total moisture. However the range was 8% to 36%. The western coals having high inherent moisture (14-30%) still require additional surface or added moisture for pelleting. The eastern coals usually have 3-5% inherent moisture and best pellet between 14 to 18% moisture. Most coals from prep plants have moisture levels of 17-22%. Optimum pelleting moisture is also dependent on particle size as coarser coals have less surface area (and less frictional resistance on the die surface) and therefore require less moisture. Fine particle coal from wash plants generally requires more surface moisture to optimize the pelleting process.

3. **Ash content.** The higher the ash content, the greater the ease of pelleting. Coals tested had ash content between 3-5% on some coals to as high as 20% ash on other coals.

4. **Economics.** Pelletizing operations need to be above 5 T/hr for the economics to be reasonable. The 5 T/hr bio-coal fuel pellet throughput fits a single 3 meter diameter HMI/ARI fixed-bed gasifier with a nominal out-put of ~ 5 MWe. Above the 5 T/hr pelletization production capacities, the investment for the pelletization process/operation ranges between € 75 K and € 120 K per Ton pellets generated. For pelletization systems with greater than 10 T/hr pellet production capacity, the investment drops below € 100 K per Ton pellet.

   The pelletization process investment and operational costs will yield a pellet production cost in the range of € 9 to € 12/T.

Summary

In addition to coal, CPM has tested and has placed pelleting equipment at sites for pelletizing wood and wood/paper byproducts, RDF (Refuse Derived Fuels), and plastics to be used for energy or for other uses. Photos of sample coal and coal/Biowaste pellets are shown in Figure 3.

Figure 3: CPM Coal/Biomass Pellets

CPM has also demonstrated the pelletization of car-fluff and coal. Pellets with 50/50 car-fluff/coal fines are shown in Figure 4 below.

Figure 4: CPM Development of car-fluff/coal pellets

CPM/HMI/ARI and Sotacarbo have the people, expertise, and experience to effect success for the industrial generator of Biowaste who is now paying to remove the Biowaste from the industrial site and can recover and utilize the energy within the Biowaste (enhanced with coal) through clean and efficient gasification.

Economic/Environmental Drivers for Worldwide Bio-coal gasification

The primary technical, economic and environmental drivers for industries to embrace the generation of industrial fuel-gas on-site using the on-site generated biowaste and high ash coals are:

- The economic benefit derived from the utilization of bio-waste materials generated on-site. The savings from removing the biowaste material and transporting it to a landfill can be very large (in the range of 40 to 60 €/Ton).
- Moving from CO_2 emitting fuels to bio-fuels will have significant economic benefits for industries.
- The industrial scale (1 to 15 MWe, equivalent) gasification process is automated and economical to operate.
- The fuel pellet generation process is both economical and reliable with a low cost of pellet generation (fuel pellet production costs range from € 9 to € 12/Ton → 0.03 €/nM^3, equivalent).
- Site specific (industry specific) fuel pellet development and gasification performance can be achieved within a six (6) month period.
- A complete site specific fuel pelletization facility and gasification facility can be completed and commissioned within 18-24 months.
- Clean and secure industrial fuel-gas (including all required gas treatment and cleaning) will be generated in the range of 0.12 to 0.15 €/nM^3 (~ 50 to 60% the cost of natural gas).

Section IV

Sotacarbo Pilot Gasifier for Bio-coal pellet development

Extend the MIFGA Coal Gasification Database to Bio-coals:

The Sotacarbo coal gasification facility is comprised of the 1.3 meter diameter pilot gasifier and the 300 mm diameter laboratory scale gasifier with complete gas clean-up and laboratory R&D capability for syngas shifting to hydrogen will offer to industries throughout Europe and the US the ability to assess Bio-coal pellets relevant to their industrial operation. The Sotacarbo coal and bio-coal pellet gasification facility was reviewed in Section II above.

Sotacarbo will be able to demonstrate a small scale ~ 1 MWe industrial scale coal and bio-coal fueled distributed power generation system integrated with both the local electrical grid and Sotacarbo's laboratory power requirements.

Sotacarbo with assistance from ARI and HMI's industrial marketing focus will provide a state-of-the-art coal and bio-coal gasification facility with the following capabilities to develop industrial clean coal and bio-coal fueled projects worldwide.

- A nominal 1 MWe pilot gasifier with complete gas clean-up., including pyrolysis liquids recovery and utilization in dual fueled diesel engines along with gas in high efficiency gas engines for distributed power generation (0.5 to 1 MWe).

- Laboratory scale gasifier with complete gas clean-up and pyrolysis liquids recovery and complete analysis for dual fuel industrial utilization and gas shifting capability for hydrogen generation (Reference 2).

- Laboratory scale gasifier for oxygen/steam gasification with or without CO2 displacing nitrogen in the air for high temperature industrial applications where nitrogen in the syngas would result in excessive NOx emissions. This holds great potential for bio-coal fuels being applied to the glass industries manufacturing processes.

- Laboratory scale gasifier for bio-coal pellet development and demonstration for industrial clients (funded by industrial clients).

Sotacarbo can establish the laboratory scale and pilot scale gasifiers as definitive tools for industries worldwide to fund and support the development of bio-coal pellets and gasification process specific for their process requirements and the most reliable sourcing and economic fuels available.

Section V

Clean and Efficient Industrial Utilization of Bio-coal Derived Fuel-gas and Pyrolysis liquids

Prior to the availability of natural gas in the United States (early 1950's) many industries fired their process with LBG (Low-BTU gas) generated from coal. Just as industries were reluctant to switch from the "known-fuel" (coal derived LBG) to natural gas in the early 1950's almost 60 years later the reverse is true. Industries have used and relied on natural gas delivered through a valve at the plant boundary will begin to consider alternatives to utilize their on-site generated bio-waste or biowaste available in the local energy market.

The economic drivers today for industries in Europe to seriously consider clean bio-coal gasification using fixed-bed air blown gasifiers are very strong. Industrial coal gasification provides a stable and environmentally clean energy resource that is available (sourced) from many parts of the world at very competitive pricing. When industries factor in the current costs of removing and disposing of their Biowaste, the fact that the Biowaste can be combined with internationally available coal to supply clean energy for heat and power provides an economically attractive option.

The MIFGA industrial coal gasification database provides industries worldwide the proof that industrial coal gasification is an environmentally clean and commercially viable option. Sotacarbo will be able to extend the MIFGA database to bio-coal pellets for industrial energy users worldwide. The MIFGA gasifier operation and gasification database verified the following for coal:

- Clean coal gasification using low pressure fixed-bed gasifiers yields a conversion efficiency of 82 to 87% efficiency with the gas and pyrolysis liquids used as usable products.
- Industrial coal gasification systems can be installed for € 400 to € 450 /KW
- Clean fuel-gas from coal and coal/Biomass pellets can be used for industrial steam raising and heat treating requirements or for power generation using clean and efficient fuel cells.
- Industrial Biowaste which may cost from € 40 to € 55/Ton (> 0.09 €/nM^3 fuel value) to dispose can be pelletized with coal on-site resulting in a bio-coal pellet with a near zero cost (considering the landfill cost savings).
- The resultant fuel-gas cost generated from bio-coal pellets will range from 0.11 to 0.15 €/nM^3. This is very competitive with the cost of natural gas in Europe today (~ 0.25 €/nM^3), while reducing the CO2 emissions and stabilizing the future industrial energy costs from supply driven excursions.
- HMI/ARI/CPM and Sotacarbo are prepared to perform funded feasibility studies for industries with biowaste disposal costs which warrant serious consideration and demonstration/quantification of a coal based industrial clean energy gasification system thereby stabilizing their fuel costs for the future.

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