GAS TURBINE TECHNOLOGY FOR STEEL MILL GAS
AND SYNGAS APPLICATIONS

H. Peter Luessen
General Electric Company

ABSTRACT
Recent market place activity over the past years has shown a
renewed trend in using steel mill waste gas for combustion in gas tur-
bines. To effectively use steel mill gas, as well as other industrial off
gases and syngas from gasification, more than just the combustion
process has to be considered. With steel mill gases some of the more
critical areas involve gas clean up and compression, as well as integra-
tion with the steam system of the host industrial plant.

This paper will summarize some of the special considerations for
applying a gas turbine/combined cycle power plant to a steel mill. Due
to the similarities of the fuels, this paper will also discuss how this is
common to other industrial gases applications. GE has substantial expe-
rience in combustion of low calorific fuels as well as industrial process
gases and more recently steel mill gases.

INTRODUCTION
Efficient use of medium to low calorific waste gases to improve
overall process economics has always been an industry goal. By using
these fuels to augment energy usage for the process, such as steam gen-
eration, overall operation costs can be driven down. Overall efficiency
can be further improved by burning these fuels in a combined cycle.
One such industry that has a high potential for application is the steel
industry. Steel mills have large quantities of low heating value gases
and typically have large requirements for steam and electricity. While
most steel mills use a majority of the waste gas in boilers, the installa-
tion of a combined cycle plant has the added benefit of power genera-
tion to meet internal demand, as well as the potential to sell excess
power to the grid.

GE has had significant experience over the past 40 years with
power generation in industrial sites. In addition to its industrial experi-
ence base, GE has had significant experience in the Integrated Gas
Combined Cycle (IGCC) area, highlighted by the start up of several
large scale plants. As described later in this paper, much of this experi-
ence can be applied to the low heating values fuels, such as steel mill
gases. or even low grade natural gases.

FUELS
The most common steel Mill gases are Blast Furnace Gas (BFG),
Coke Oven Gas (COG), and Basic Oxygen Furnace gas (BOF) also
known as LDG. In addition, there is also gas from the COREX®,
process. There is some variation to the traditional steel mill gases, and
Table 1 gives typical compositions for each of the main gases. It can be
seen that BFG has the lowest heating value and is also the most abun-
dant. COG, while a very high quality gas, is usually only available in
lesser amounts. BOF is a medium quality gas, which is not available in
large quantities, and is very cyclic due to the nature of its process.
COREX® gas is very similar to an Oxygen blown gasified fuel in com-
position and quality. Table 2 lists a range of syngas fuels in which GE
has had experience.

<table>
<thead>
<tr>
<th>Component</th>
<th>BFG</th>
<th>COG</th>
<th>BOF</th>
<th>COREX®</th>
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<tbody>
<tr>
<td>H2</td>
<td>2.5-5</td>
<td>60-62</td>
<td>1-3</td>
<td>15-20</td>
</tr>
<tr>
<td>CO</td>
<td>22.5-26</td>
<td>5-7</td>
<td>69-73</td>
<td>35-45</td>
</tr>
<tr>
<td>N2</td>
<td>50-55</td>
<td>4-5</td>
<td>8-16</td>
<td>0-14</td>
</tr>
<tr>
<td>CH4</td>
<td>0-1</td>
<td>24-26</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>CO2</td>
<td>21-23</td>
<td>1-1.5</td>
<td>-</td>
<td>14-17</td>
</tr>
<tr>
<td>CnHn</td>
<td>-</td>
<td>3-4</td>
<td>0-1</td>
<td>-</td>
</tr>
<tr>
<td>LHV Bu/scf</td>
<td>82-98</td>
<td>450-480</td>
<td>215-235</td>
<td>160-197</td>
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<tr>
<td>LHV MJ/Nm3</td>
<td>3.23-9.6</td>
<td>45.1-47.0</td>
<td>8.46-9.25</td>
<td>15.68-19.31</td>
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</table>

Table 1. Typical compositions of steel mill gases.

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FUEL CLEAN UP

Contaminants in the gases vary substantially. BFG, relative to the other steel mill gases, has a medium concentration of dry dust loading. COG, while low in dust, has a very high tar load and can also have significant amounts of fuel bound nitrogen in the form of ammonia. While not a concern for the gas turbine hardware, NH3 can cause difficulties with a waste heat recovery boiler as well as impact NOX emissions. BOF/LDG has a very high dust load. COREX®, has a relatively low dust load and is probably the easiest to clean.

The total amount of dust and tar in the above mentioned gases vary significantly from plant to plant depending on process type, vintage, and feed stocks. Some typical values for an older mill would be, COG 18 - 25 mg/Nm³ of tar, BFG 20 - 30 mg/Nm³ of dust, and BOF 110 - 170 mg/Nm³ of dust. Typical contaminants include Sodium, Potassium, Calcium, Vanadium, Lead, Zinc, Chloride, Fluoride, and Cyanide. With ranges of 0.001 to 0.010 ppm in weight for BFG and 0.011 to 0.075 ppm in weight for COG for the trace metals. Chlorides, Fluorides, and Cyanides range from 1.0 to 4.0 ppm for BFG and 4.0 to 100 ppm for COG. When the dust load is reduced to less than 1 mg/Nm³ the total level of contaminants is well within the gas turbine fuel specification requirement.

Table 2. Syngas comparison.

<table>
<thead>
<tr>
<th>Syngas</th>
<th>PSI</th>
<th>Tampa</th>
<th>El Dorado</th>
<th>Pemex</th>
<th>Sierra</th>
<th>Pacific</th>
<th>ILVA</th>
<th>IBIL</th>
<th>Schwarze</th>
<th>Pumpes</th>
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<tbody>
<tr>
<td>COG</td>
<td>24.0</td>
<td>27.0</td>
<td>35.4</td>
<td>34.4</td>
<td>14.5</td>
<td>8.6</td>
<td>12.7</td>
<td>61.9</td>
<td></td>
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<tr>
<td>CO</td>
<td>39.5</td>
<td>35.6</td>
<td>45.0</td>
<td>35.1</td>
<td>23.8</td>
<td>26.2</td>
<td>15.3</td>
<td>26.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CH4</td>
<td>1.5</td>
<td>0.1</td>
<td>0.0</td>
<td>0.3</td>
<td>1.3</td>
<td>8.2</td>
<td>3.4</td>
<td>6.9</td>
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</tr>
<tr>
<td>CO2</td>
<td>9.3</td>
<td>12.6</td>
<td>17.1</td>
<td>20.0</td>
<td>5.6</td>
<td>14.0</td>
<td>11.1</td>
<td>2.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N2 + AR</td>
<td>2.3</td>
<td>6.8</td>
<td>2.1</td>
<td>0.2</td>
<td>49.3</td>
<td>42.5</td>
<td>46.0</td>
<td>1.6</td>
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<tr>
<td>H2O</td>
<td>22.7</td>
<td>16.7</td>
<td>0.4</td>
<td>5.7</td>
<td>11.5</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
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<tr>
<td>LHV, - Btu/h</td>
<td>21.2</td>
<td>202</td>
<td>242</td>
<td>209</td>
<td>127</td>
<td>193</td>
<td>115</td>
<td>318</td>
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<tr>
<td>- LHV</td>
<td>6750</td>
<td>7960</td>
<td>9535</td>
<td>8235</td>
<td>5000</td>
<td>7600</td>
<td>4530</td>
<td>12,520</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp, °F/°C</td>
<td>570/300</td>
<td>700/371</td>
<td>2250/121</td>
<td>200/98</td>
<td>100/538</td>
<td>400/204</td>
<td>1020/249</td>
<td>1000/98</td>
<td></td>
<td></td>
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<tr>
<td>H2/CO Ratio</td>
<td>.63</td>
<td>.75</td>
<td>.79</td>
<td>.98</td>
<td>.62</td>
<td>.33</td>
<td>.63</td>
<td>2.36</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diluent Steam</td>
<td>N2/H2O</td>
<td>N2/Steam</td>
<td>N2/Steam</td>
<td>Steam</td>
<td>Steam</td>
<td>Steam</td>
<td>Steam</td>
<td>Steam</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Equivalent LHV</td>
<td>150</td>
<td>118</td>
<td>113</td>
<td>198</td>
<td>110</td>
<td>-</td>
<td>-</td>
<td>200</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Btu/h</td>
<td>5910</td>
<td>4550</td>
<td>4460</td>
<td>7800</td>
<td>4334</td>
<td>-</td>
<td>-</td>
<td>7600</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Always co-fired with 50% natural gas
** Minimum range
Gas clean up for steel mill gases has to be very specifically designed. Wet scrubbers, precipitators, bag houses for dry gases may all be required. In addition, the method of cleaning will vary depending on the redundancy needed to meet the required plant availability. Figure 1 shows a very simplified schematic of the gas clean up used for the ILVA Taranto project, a 3x9E Nuovo Pignone/Turbo Tecnica project in southern Italy.

Application of the above fuels vary by site and typically depend on what steel making process are there and how the steel mill is currently using the waste gas. Physical location of the various process is also a consideration, as in many instances, the coke ovens are a significant distance away from the blast furnaces. Due to all these variations, fuel available to the gas turbine can vary widely in both heating value and quantity. Typically, BFG is the primary fuel, then COG and finally BOP. The optimal application has all three fuels available with the gas turbine running on a blended mixture. In the absence of COG and BOP, often a back up fuel for blending is required. Typically this fuel is natural gas and is used for start up as well as a trim for the waste gas stream, especially if there is significant variation of the heating value.

**FUEL COMPRESSION**

Another important consideration when using steel mill gas is fuel compression. Unlike gasified fuels and many industrial process gases, steel mill gas is at nearly atmospheric conditions. Therefore, it is necessary to compress the gas. In most applications, the most economical method is to drive the fuel gas compressor (or compressors) from the same shaft as the gas turbine. Depending on the total flow rate and volume of the gas, axial and/or centrifugal compressors can be used. At the ILVA site two centrifugal compressors were used in tandem as the optimal arrangement (Figure 2). For larger flows, such as a 7FA gas turbine, an axial as well as a centrifugal compressor can be applied. Figure 3 shows the fuel system schematic of a STAG™ 107FA single shaft gas turbine arrangement in tandem with an axial flow and centrifugal fuel compressor arrangement.

For steel mill applications, or process gas applications requiring fuel compression, GE is able to offer a complete single (or multiple) train package. The ability to supply and integrate this package so well comes through Nuovo Pignone’s extensive experience in the design and development of industrial compressors. In 1994 Nuovo Pignone joined GE Power Systems and extended GE’s heavy duty gas turbine and steam turbine product line with centrifugal and axial compressors, centrifugal pumps, and reciprocating compressors. The broad and integrated NP/GE product line provides an equipment capability that is unique in the industry. In the LNG field, NP has supplied equipment for three of the largest LNG plants built in the world in the last eight years. The LNG plant for Malaysia uses the 7EA gas turbine in a single train with the AN200 and a 2MCL 1007 double flow centrifugal compressor, along with a helper steam turbine. Figure 4 shows the axial compressor.
Table 3. Typical outputs on steel mill gas mixture.

PLANT CONFIGURATION

In addition to the fuel compressors, GE is able to provide the steam turbine for the power plant and cogeneration. The optimum configuration is to have the steam turbine on the same shaft as the gas turbine and fuel compressor. In this configuration it is possible to use the steam turbine as the starting means to overcome the large torque speed characteristics of fuel compression in larger applications. This configuration also reduces overall plant costs by requiring only a single generator, as well as reduced civil costs. This single shaft arrangement can be applied to a majority of the product line. Table 3 gives an indication of some typical outputs achievable while burning a relatively low quality steel mill gas mix with various frame sizes. The numbers given in this table are not the maximum output numbers that can be achieved, either by the gas turbine or in combined cycle, and do not include any additional firing in the HRSG. The average LHV of the steel mill gas mix used in Table 3 was 4.92 MJ/Nm³ (125 Btu/scf). Depending on constituents, especially H2, fuel heating value can go as low as 4.17 MJ/Nm³ (1000 kcal/Nm³, 106 Btu/scf).

When natural gas is used in conjunction with the steel mill gases, it is blended with the waste gas after compression, or run through a separate fuel system for co-firing. This is done to avoid the compression power loss. To also minimize power losses due to fuel compression, GE uses its patented, integrated low pressure control fuel system. Here, the gas turbine control system uses the fuel compressor to regulate the gas turbine output. In effect, running the gas turbine with its normal control valves wide open, minimizing the fuel compressor output. The natural gas trimming is there to provide a minimum heating value as well as smooth out variations in heating value due to the steel making process.

![Figure 5. GE 10-year IGCC technology and product development program.](image-url)
When steel gas production is at its maximum output this trim is expected to be minimal or completely shut off. Another added benefit of the trim is that it enables the gas turbine to have a large turn down capability with excellent combustion stability.

GAS TURBINE TECHNOLOGY ENHANCEMENTS

As part of GE's IGCC technology and product development plan, a significant amount of system optimization has been done to date. The 10 year plan is shown in Figure 5. This development program for IGCC has provided a solid foundation for the application of low heating value gas fuels. Some of the areas are specifically described below.

Combustion

A key component of the GE IGCC technology development program is the ability to run syngas combustion tests at full flow, pressure, and temperature conditions in the GE combustion laboratory. This facility was used for tests on the 7E combustion system used in the Cool Water prototype demonstration unit, and has since been used to map performance of combustion systems used across virtually the entire product line on a wide range of syngas fuels, including those produced by steel mill gases. Although only certain design features developed are needed for a given application, the overall program has provided the database necessary to support a wide range of plant design applications with defined modifications to standard production model gas turbines.

Turbine Design

In addition to combustor design modifications, some ten turbine design modifications have been developed and are available to allow the gas turbine unit output to be enhanced by as much as 30% for IGCC applications. As shown in Figure 6, if no air extraction is required, the increased mass flow of low heating value fuel gas adds to flow through the expander portion of the gas turbine power plant. In this example of an IGCC application, a 14% increase in fuel mass translates into a 28% increase in gas turbine output. This capability is a unique characteristic of the GE gas turbine product line, and provides significant benefits in terms of power plant economies of scale that are also applicable to steel mill and other low heating value gases.

Certain applications can be better suited to the extraction of some...
compressor discharge air from the gas turbine, such as for use in an air separation unit (ASU). The applications may also have nitrogen return to the gas turbine. The GE gas turbine design modifications include the capability for full integration with the ASU for IGCC applications as well as partial integration for steel mills.

With natural gas fuel, the base load output of a gas turbine is a function of ambient temperature, which determines the compressor air flow with the inlet guide vanes at maximum opening. This characteristic is shown as the lower curve in Figure 7. With gases of low heating value, if not otherwise limited, the same firing temperature would yield the parallel, higher output curve shown. GE gas turbines and much of their associated equipment are typically designed to operate on natural gas fuel at the lowest achievable ambient temperature. The units also have sufficient compressor surge margin capability and/or turbine design modifications which make it possible to operate in a flat rated mode. A flat rating, with an ISO (59 F/15 C) output substantially greater than that with natural gas fuel, but with minimal impact on hardware or efficiency, can therefore be achieved by varying inlet guide vane position.

STEAM TURBINE APPLICATION

By adding a steam turbine to the low heating value fuel application, significant improvements in efficiency and power output can be achieved. The steam turbine configuration will depend highly on the process plant’s steam demands. Single auto extraction units, back pressure, or straight condensing can be applied. The steam turbine can be used in a single shaft configuration with the gas turbine and fuel gas compressor. It can also be used in a multi-shaft arrangement, driving either a separate generator, fuel gas compressor, or both. Also, any additional

- 192 MW 7FA
- Repowering - 262 MW
- Dow Gasifier 2 x 100%
- 1995 Operation
- Coal Fuel
- 1400 $/kW-1995$

Figure 8. Current IGCC Projects.

![Figure 8. Current IGCC Projects.](image)

Figure 9. Wabash River repowering project—PSI energy.

![Figure 9. Wabash River repowering project—PSI energy.](image)
- 260 MW IGCC
- 192 MW 7FA Flat Rating
- Texaco Gasifier
- Nitrogen Injection
- HGCU Demonstration
- First GT Power From Syngas - 9/12/96

Figure 10. Tampa Electric—Polk IGCC project.

waste gas not consumed by the gas turbine can be fired in the HRSG for added plant output, process steam production, or peaking demands.

EXPERIENCE
IGCC plants

While ILVA is the first direct application for GE/NP in the steel mill market, GE has had significant low heating value fuel gas experience in the IGCC market, as well as over 40 years of industrial gas turbine application experience in refineries and chemical plants. This experience includes use of multiple fuels, both gas and liquid, as well as a wide range of heating values in single and multiple nozzle combustors. GE currently has 15 commercial IGCC projects (Figure 8) in progress, not including its experience in Cool Water or several pilot plants. These projects have given GE significant experience with non-standard fuels, fuel handling, controls, and integration of the total power plant with the surrounding industrial process. Following is a brief description of the seven plants and ILVA:

PSI Energy—Wabash Repowering Project

This project (Figure 9) uses a GE 7FA gas turbine and a Destec gasification system with steam side integration only, no air extraction or nitrogen return. It has confirmed enhanced ratings and combustion characteristics required of F technology gas turbines in IGCC applications. Operability has been excellent. Full load rejection has been accommodated without shutdown, operation on syngas, as well as switching to/from syngas, is very smooth and NOx levels are very low. Power availability has been similar to that of a conventional combined cycle.

- Texaco Refinery - El Dorado, Kansas
- 1 x MS6001B
- Texaco Quench Gasifier
  - Pet Coke/Waste Oil
- Multi Fuel With N2
  - Return and Air Extraction
- First GT Power From Syngas - 9/12/96

Figure 11. Texaco—El Dorado cogeneration project.
Tampa Electric—Polk Project
F technology with steam side integration and nitrogen return only—no air extraction—will be verified in this project (Figure 10). A small scale (25 MW) hot gas clean up slip stream is included to carry forward technology developed under a U.S. Department of Energy sponsored program.

Texaco—El Dorado Cogeneration Project
Full air side integration has been verified in this project, where air extraction and nitrogen return are integrated into the cycle (Figure 11).

Sierra Pacific—Piñon Pine Project
F technology with full air extraction will be demonstrated with this project. In this case, the gasification system is air blown and uses a fluidized bed gasifier which can provide wider fuel flexibility for high ash fuels.

Shell—Pernis Cogeneration Project
This project will verify co-production of hydrogen, and also requires the gas turbine fuel system to handle a variety of gas fuels, including Liquefied Petroleum Gas (LPG) and natural gas. The gas turbine combustion system is designed to meet the following requirements:
- unlimited operation on natural gas over the complete load range
- unlimited capability to burn various syngas compositions, ranging from 6.5 to 11.1 MJ/m³ in lower heating value
- up to 35% (weight) mixing of LPG into the syngas
- supplementing of syngas with natural gas when insufficient syngas is available
- NOx levels at all operation points not exceeding 65 g/GJ.

SVG Schwarze Pumpe GmbH—Schwarze Pumpe, Germany
This project uses an oil/lignite slurry to feed the gasification system, producing syngas for power and co-production of methanol. The 6B gas turbine is designed to use syngas, purge gas from the methanol plant, natural gas, and distillate oil for startup or co-firing.

IBIL—Sanghi Project
An important new project in India will install a 6B combined cycle pre-designed for conversion from direct firing on naphtha to IGCC with lignite as a feedstock (Figure 12).

Sarlux—Sardinia, Italy
The largest commercial IGCC project to date at 550 MW has been contracted as a complete turnkey plant. The technology includes three low-pressure Texaco quench gasifiers with three STAG® 109E single shaft combined cycle power trains to produce hydrogen, steam, and power. The project is aimed at the commercial community acceptance rather than technology demonstration, for project financing is itself a significant step in the commercialization process. Project costs are less than $1100/kW.

ILVA
ILVA is comprised of three cogeneration combined cycle power plants for ILVA steel mill in Taranto, southern Italy. The three power plants burn a mixture of BFG, COG, and LDG to generate approximately 500 Mw of electric power and 150 T/h (136,000 kg/h) of process steam. Each power plant is made up of a 9E heavy duty gas turbine generator, and two fuel compressors driven through a gear to increase the driven speed from 3000 to 5040 rpm. The 9E's at ILVA have multiple passage, single nozzle combustors. ILVA also incorporates a natural gas trim system, shown in the schematic, to minimize variations as mentioned above. As of October of 1996 the plant is in commissioning having already operated initially on natural gas and then on steel mill gas. The fuel transfer and purge sequences have been demonstrated as well as the fuel gas clean up.

CONCLUSIONS
Applying combined cycle power generation plants for steel mills...
or other industrial plants does not involve high technical risk. A good understanding of the fuel gas composition and contaminants, as well as a good understanding of the planned operation modes, makes it possible to install a highly reliable, flexible power plant that will meet the owners needs. Gas clean up and compression technology have been well proven in other fields, as well as the ability of the gas turbine to reliably combust these fuels. Putting the entire plant together requires a good overall systems approach, similar to the one that GE has been applying to its successes in the commercialization of IGCC plants.

REFERENCES