

# *Combined Heat and Power System For a Carbon Black Manufacturer: System Selection and Specification*

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## ABSTRACT

This research investigates the use of combined heat and power (CHP) system for a carbon black manufacturer to reduce the energy cost. The analysis of the facility energy consumption shows that a steam-turbine-driven CHP system could provide for the electric needs of the company. The recuperation of the heat from the low pressure steam can be injected into the reactor to provide heat, which can substitute for some of the heat from the natural gas. For the electric needs, our study indicates that the facility can benefit from generating a baseline load to ensure that no excess electricity is produced. The suggested solution in this research is to be considered as a preliminary solution. Further studies are necessary to be carried out by professional CHP developers to yield more accurate specifications and costs.

**Keywords:** Combined Heat and Power System, Carbon Black Manufacturing, System Selection, Specification.

## INTRODUCTION

As U.S. population grows steadily every year, the commercial and industrial sectors must increase in size to support population growth. The industrial sector has experienced recent employee layoffs to help lower operational costs and as a measure to remain competitive and in business.

Since 2000, a number of manufacturers in Arkansas, Louisiana, Texas, and southern Mississippi have had energy assessments performed by the Industrial Assessment Center at the University of Louisiana at Lafayette in search of opportunities to help them reduce their energy costs. Many opportunities have been found and implemented by these companies, resulting in more than \$20,000,000 in annual energy cost reduction in slightly over five years [1].

Most of these implemented savings have had paybacks of less than two years. Other projects have been studied with paybacks of two years or more, at the request of company personnel, such as cogeneration, power factor correction, and oxyfuel combustion, among others. From experience, it has been learned that projects with paybacks of two years or more typically are not implemented because of the large capital needed to invest in development, construction, installation, operation and maintenance costs, and ongoing federal and state compliance.

It is also important to add that larger companies require employees to follow a set of procedures for capital requests to be considered by upper management for approval. Usually, management is reluctant to invest in energy projects that involve large investments with long paybacks. Engineers and plant personnel consider these projects as ways of increasing overall productivity, plant reliability, and reducing energy costs. All of these would eventually result in an increase of product throughput at lower costs.

From a recent visit to a carbon manufacturer, an opportunity was discovered where the plant could generate part of its electricity onsite. This company receives and stores large amounts of feedstock (heavy oil residues) to manufacture carbon black. Because of its availability, low cost, and high electric charges, this company makes a good candidate for considering cogeneration as an alternative to provide electricity and recoverable heat that could be injected into the breakdown of the feedstock or any desired process.

Cogeneration requires a fair amount of capital, but now with high prices of energy, the paybacks are starting to reach lower cost levels; levels where companies are now considering installation of these systems. Additionally, the continuous improvements in technologies are making it possible that these systems may be custom tailored to meet specific needs and applications, making them more appealing to manufacturers.

The objective of this research is to propose a cogeneration system that provides a reduction in energy costs to the company, based on

data gathered from a Louisiana carbon black company that utilizes the most common process for making this product, furnace black. This data helps suggest a combined heat and power system to meet part of its electric demand and provide some useful heat to be injected back into the process. The electricity generated will yield reductions in electricity, demand, and other charges associated with providing electricity to the company.

## SYSTEM SELECTION AND SPECIFICATION

Integrating the right technology into the company's existing operation can guarantee the economic and technical success of a CHP system. There are numerous technologies that provide advantages as well as disadvantages. The company must choose a combination of technologies that can deliver the best results at the lowest cost possible. Additionally, it is necessary to consider that company personnel involved in the operation and maintenance of this equipment be trained to ensure that the equipment achieves its highest efficiencies possible. This will ensure 99.9% availability, functionality, and reliability. Choosing the right equipment also requires that the company meets federal, state, and local permitting, environmental, and interconnection requirements for the installation and operation of all components selected for the CHP system.

One of the major barriers to implementing CHP is the lack of knowledge of how to get started. We present a series of steps that can be used in studying the possibility of installing a CHP system. These steps can aid in determining whether the facility is a good candidate. By performing a walk-through to collect data, a CHP project can be pre-analyzed for technical and economical feasibility. A preliminary study of electrical and thermal needs, and available space, is then carried out.

If the analysis classifies the company as a good candidate for CHP implementation, options are recommended and passed on to a company that implements these types of projects to carry out a more detailed study. With all the costs and detailed work, the company's management and engineers can make a final decision on whether to proceed or not. The decision to proceed with the project is evaluated against a set of company criteria to ensure that the investment returns economic as well as operational benefits.

## Evaluating CHP project

When evaluating CHP project feasibility, first it is necessary to obtain an understanding of the equipment that will be involved in the system, its installation, operating, legal, and space requirements. To create a list of CHP system configurations that could deliver the desired results, it is necessary that the facility's goals and objectives are clearly identified and defined. In doing so, a series of criteria are outlined that can serve as a guide in selecting the most viable options. There are many available technologies for both electric generation and heat recovery that could be combined in an infinite number of arrangements. For example, if the primary goal for a facility is to produce all the electricity on site at a lower cost and the company resides in a market where selling power back to the grid is profitable, then all electricity for use on site should be generated, and the excess can be sold to the local electric company. Another goal would be if it is imperative that the company keeps processes running around the clock, then the CHP system may be considered for reliability purposes. Whatever the objectives or goals might be, it is recommended that these are set from the beginning of the study to help focus all efforts and resources in the right direction [2].

Starting a study for a CHP project could be confusing when many considerations have to be made. After researching CHP development from different sources, we have summarized a set of steps that can be followed to develop a preliminary conceptual design of a CHP system. These steps produce possible systems that meet the facility's electrical and thermal needs.

After results are found, they must be carefully screened to select the most desirable ones based on company's criteria and objectives. These candidates should be taken to professional CHP developers, where they will be given a more thorough study that will produce detailed engineering designs. This is where it turns into a more realistic idea. The most critical step is to implement it, so that the company can benefit financially as well as operationally from it. However, because of the initial investment necessary for its implementation, this step is often not taken, and the project is filed away for consideration in the future, when implementation and paybacks are more favorable for the company.

This research will only concentrate on generating a preliminary solution that will produce the type and size of the system for the application at a carbon black facility. These steps are a guide for working

toward this solution, and each one of them should be carefully studied to ensure the continuation to the next step.

### **Walk-through and Data Collection**

To establish the company's objectives, it is necessary that the plant be surveyed to collect all relevant data about the company's specific operating conditions and energy requirements. The facility walk-through concentrates on obtaining data that can determine whether cogeneration is economically and technically right for the company. As the walk-through is carried out, much attention must be paid to the criteria and objectives established by the company to ensure that the data collected is relevant to the project to be recommended. Focusing on the project's objectives helps employ the necessary time to conduct this step. Because this step is part of a preliminary study, there is no need to spend much time in data collection. If the project is considered for further study, then a more thorough and detailed data collection can take place.

Although there is not one correct way of doing this, certain basic data should be collected to ensure that, during the project preliminary study, decisions can be made as to what system configurations will meet the objectives of the company. Basic data such as electrical needs, thermal demands, fuel prices, electrical rate structure, operating hours, process needs, environmental regulations, space requirements, and expected payback period should provide the project developer with relevant information when selecting a prime mover and heat recovery system. In addition, the Midwest CHP Application Center has made available online on their website, a free example of a data collection sheet to help those interested in performing a walk-through gather all necessary information, or as a template to create customized data collection sheets [3].

### **Preliminary Selection**

After being collected, data should be analyzed to produce a preliminary set of possible CHP configurations, based on the objectives predefined in the first step. In addition to this analysis, there is software available such as Cogeneration, and Ready Reckoner, CogenPro, and SSAT among others that can help identify possible CHP systems that may have potential for technical and economical success.

The results produced from these tools, along with the engineers' analysis derived from the data gathered during the walk-through, can be

compared against each other to generate a more refined list of possible solutions. Here, external issues such as fuel market behavior and viability of selling electricity to the wholesale market need to be considered so that a proper selection of systems is made.

### **Preliminary Design Development**

Once the list of possible CHP systems is generated, these should be developed into preliminary designs, taking into consideration as many equipment configurations as possible. In this step, the solutions take a more specific form; the technical aspects are used to determine the components of the systems. First, the primary need (electrical or thermal) is met through the selection of the right thermodynamic cycle (topping, bottoming, or combined). The arrangement can be a topping-cycle, where electricity is the primary product and thermal energy is a secondary product; a bottoming-cycle, where thermal energy is the primary delivered product and electricity is a secondary product; or a combination of these two cycles. Secondly, the prime mover is selected. If feasible, the use of two or more prime movers should be considered for better fuel utilization and to protect against scheduled and unscheduled shutdowns.

The type and size of the prime mover is based on the amount of electricity and thermal output, space available, fuel availability, noise, emissions, and operation and maintenance costs of the system. As previously mentioned, prime movers could be microturbines, reciprocating engines, fuel cells, gas turbines, and steam turbines, each having their own unique characteristics. For example, a small commercial building located close to a residential zone considering cutting down on electricity costs should choose a microturbine and not a steam turbine, because space and noise may be an issue.

Lastly, the heat recovery equipment is selected based on the thermal needs of the company's processes and thermal energy available from the prime mover. The heat recovery equipment is selected based on how much and where heat is needed. A balance between electric generation and heat recovery needs to be decided, because having more electricity means less heat available for recuperation and more heat means less electricity available.

As the systems are put together, it is necessary to build redundancy in them to handle both scheduled and unscheduled outages. The components of the CHP system need to be able to provide all the required electrical and thermal needs at any time under any given conditions

without causing major impacts on the company's daily operations.

As the options become more refined, there will be a need for seeking help from a team of knowledgeable professionals that has understanding in related engineering sciences to organize the CHP configurations into more realistic concepts. When the engineered solutions are generated, these should be studied to determine their economic success.

### **Economic Screening Analysis**

Once the preliminary designs are selected, it is necessary to study the economic success of the project. A set of guidelines should be generated that can serve in evaluating the economic feasibility of all CHP options. The main objectives for doing this analysis are to identify all those systems with potential for success and eliminate those that present some type of disadvantage that may hinder it from delivering positive results. In this analysis, the results should provide the company with information that can justify its implementation, including costs for developing a detailed study.

At this stage, with the understanding of what the major components involved in the project are, an estimate of the capital and operating costs can be made. It is necessary to understand how sensitive the payback period is to variations in operating hours and escalating fuel, electricity, operating, and maintenance costs.

### **System Sizing**

Sizing a CHP system requires considering many different factors, such as space available, budget, fuel costs, fuel availability, and waste heat applications available. However, one of the main factors used in basing the size of the system is the demand pattern.

There can be different ways of sizing a system that can indeed yield different results. The most conservative method is by calculating a baseline kW; this consists of taking the total energy usage and dividing it by the number of hours of operation. This method creates a mid-point of the needed generation capacity to satisfy the electrical needs of the facility. This ensures that the facility can produce at least the minimum amount of energy needed for its normal processes. This also ensures that the facility does not produce excess power that is not profitable to sell back to the utility company (because only the avoided cost of fuel usage to the electric utility providers would be credited to the company). Other costs, such as depreciation, operation, and maintenance of the

equipment are not returned to the facility for supplying energy back to the grid. It is necessary that the facility stay connected to the grid to consume energy when peaks above the baseline kW occur.

### **Specification**

For this application, because of the type of fuel available to be used for the CHP system, a water-tube boiler and steam turbine are the only choices for a prime mover. Electricity is the principal need in a carbon black facility, and waste heat is a secondary useful by-product. For this application, a steam turbine topping-cycle is selected. A steam-to-air heat exchanger is selected to deliver hot air to the reactors. Additionally, long operating hours (4,000 or greater) make the facility a good candidate for the implementation of a CHP. The following section presents the description of the system to be recommended.

### **SYSTEM DESCRIPTION**

The carbon black process uses heavy oil residues as the raw product for manufacturing carbon black. One of the main ingredients that make this project feasible is the fuel availability and lower cost with respect to other fossil fuels. In addition, this fuel is already being shipped, stored, and handled on site exclusively for the manufacturing of the product, further reducing costs of the implementation of this CHP project. The fuel to be used has a higher heating value (HHV) (heat content in a fuel) of 15,000 Btu/lb.

The system to be recommended will be a steam turbine topping-cycle driven CHP system, which means that electricity will be produced first and then low-pressure steam is produced as a secondary product. The system will consist of a backpressure steam turbine, high-pressure water-tube steam boiler with superheating coils to produce dry steam, steam-to-air heat exchanger, and other components such as emissions control equipment, pumps, and generators. A brief description of the specifications of the main components of the CHP system follows.

### **Steam Turbine**

Because electricity is the primary resource in demand, a backpressure turbine for this application is suitable because there is a need for extracting as much energy as possible to generate electricity; no intermediate pressure steam needs to be produced. Low-pressure steam

is sufficient to provide the waste heat for the heat exchanger. Further detailed studies will determine the number and exact configuration of the turbine(s). It may be possible that it is more feasible to utilize several smaller turbines rather than using one large turbine to generate all the power required. The main consideration is that the total generating capacity should approximate the baseline kW.

### **Boiler**

For this application, a water-tube boiler is recommended because of the high pressure and the quality of the steam needed to run the turbine(s). The boiler should be sized according to turbine specifications (inlet and outlet steam conditions) for generating maximum power. It is necessary that the boiler be retrofitted with superheating coils to produce superheated steam or dry steam, which is the recommended type of steam for optimal operation of steam turbines. The steam production must be supported by additional equipment, such as a piping, valves, condensate recovery system (to ensure recycling of the water condensed from the process and turbine), steam traps (to remove condensate), de-aerator tank (to strip the excess oxygen from the feed water), and pumps to maintain circulation of the water.

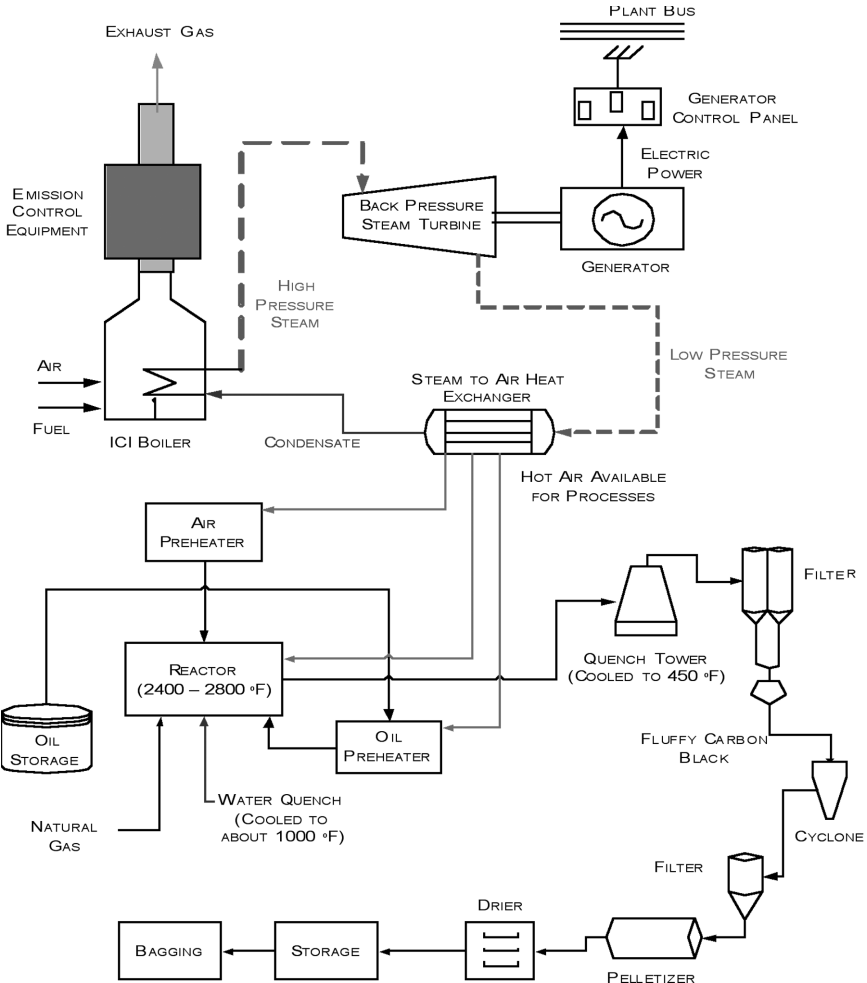
### **Heat Exchanger**

This component will be a steam-to-air heat exchanger type that handles low-pressure steam. The main purpose is to recover heat from the steam, transfer it to the air, and mix it in the reactor. Another possible use is to warm the pipes that handle the heavy fuel, where currently electric element heaters are used. The exact size of this heat exchanger will be based on the exit conditions of the steam available after electricity has been generated.

A balance between desired power and heat outputs must be found to be able to specify the size of this equipment. Figure 1 illustrates the conceptual CHP system to be proposed and how it integrates with the current carbon black process flow.

## **OTHER CONSIDERATIONS**

After the selection and specification of the system, some issues must be considered and analyzed by the decision makers (engineers and management) to ensure that the project will follow through and will



**Figure 1. Conceptual Scheme of Proposed CHP System**

meet federal, state, and local requirements and regulations. One major issue arises when the company needs to decide whether it should stay connected to the grid or not. There are certain rules and equipment necessary to establish a connection between the system and the grid. These must be implemented to ensure compatibility and to avoid mismatches in frequency and voltage that could have adverse effects in either the grid or the CHP system.

Other issues such as fuel, permits, taxes, site planning, and insurance also need to be addressed, along with the project feasibility study process mentioned previously. It is known that these issues could hinder the implementation of a CHP system, but with appropriate project organization and resource utilization, these issues can be overcome with relative ease.

### **Utility Challenges**

CHP systems present an array of benefits on the customer side such as reliability, electricity at lower costs, and control over the outputs from the system (thermal, electrical, emissions, and noise). Depending on the power generation scheme that a company decides to run on, either producing part or all of its electrical power, there is still a need for staying connected to the public grid.

There are times when the CHP system has to be taken offline for regular scheduled maintenance or because of unexpected circumstances. During these times, the electric grid can be used to compensate for the loss of energy.

For over 50 years, the utilities market has been monopolized and controlled by the same players. Federal legislation has promoted this monopolization through incentives for old coal-fired power plants, and few incentives or excessive fees on newer, more efficient, and cleaner technologies. For many years, legislation has not favored the improvement of overall efficiencies of power plants. This, in fact, has resulted in the poor utilization or waste of the energy available in fossil fuels.

Electrical utilities do not entirely favor the installation of CHP systems because these systems present themselves as competition in their service territories, and in time, the utility companies could have fewer customers. Some critics suggest that the increase in implementation of on site cogeneration systems will indeed offset the costs of expansion of the power generation industry and provide a relief for the electric grid.

Many have little experience on how to manage all technical and non-technical issues related to the interconnection between the CHP systems and the grid. These issues certainly make utility companies react negatively to this type of project with the use of technical, procedural, and legal tools. It is necessary that federal, state, and local governments develop new legislation that promotes the implementation of more efficient technologies by educating key players, organizing partnerships

among private and public sectors, and creating agreements where both the facility and the utility companies can benefit from the implementation of the CHP system.

It is necessary that measures be taken because the power generating infrastructure is deteriorating and is reaching its useful service life. Implementation of an on site CHP system must be seen as a solution to the emission-reducing efforts that are being increasingly implemented domestically as well as worldwide.

### **Grid Interconnection Issues**

Installing a CHP system will provide the facility with a certain independence from the local electric grid. The system either can be connected to the grid or can operate isolated from it. In the United States, it is required that the CHP system must be connected to the grid along with a smaller system to serve as a backup in case the main system has to be taken offline for scheduled or unscheduled maintenance.

These systems have faced some opposition from the utility companies and because of this these companies may refuse to establish a connection between the system and the grid. If the interconnection is allowed, then the utility company might want to impose heavy tariffs for any operational costs they may incur in providing part or no electrical energy to the company. When the facility decides to operate with little or no help from the grid, the utility company will charge the customer standby and backup charges. According to electric providers, these charges are to reserve capacity in their generation equipment to provide for those times when the facility requires power, because it has exceeded the CHP capacity or because the CHP system is not available.

If the facility decides to operate completely independently, then the CHP system should be sized adequately to meet all power demands and have extra capacity for those unexpected times when needs may temporarily peek above the baseline. When interconnecting the system and the grid, the facility and the electric provider must sign an Interconnection Agreement to set all rules and regulations under which the CHP system must operate. The Federal Energy Regulatory Commission (FERC) and state authorities are the governmental entities that will oversee this agreement, with rules that vary according to the state where the agreement is made.

For the interconnection to take place, it may be necessary to install special meters, isolation transformers, redundant breakers, and

other components to establish a compatible connection between the CHP system and the grid. The system must provide protection against “islanding,” which is a condition where a generating facility continues to supply power to a portion of the grid whenever the grid has been de-energized by the public utilities company. Islanding is a particular safety concern voiced by the utilities because during maintenance, the grid may stay energized when thought otherwise, presenting the risk of electric exposure to personnel performing work on the grid. Because it is well understood by those working with electricity, safety must be made a priority while connecting CHP systems to the grid. Costs associated with safety must not be spared, but this concern can be employed by the utility as a tool to delay the interconnection procedure [4].

Any interconnection issues must be discussed and solved with the utility company during the development phase of the project. If unsuccessful, the facility may want to “operate independently of the electrical grid or abandon the project” at this point.

### **Addressing Site Issues**

When installing the CHP equipment, things like noise and emissions must be considered to ensure that the equipment meets local and state regulations and does not have a negative impact on its surroundings. If the equipment generates large amounts of noise and/or emissions, then the system must be installed in a remote location. For example, large rotating equipment such as a gas or steam turbine produces large amounts of noise originating from the turning of the shaft.

Gas or steam should be either installed away from urban locations or if under special circumstances it must be installed near residential zones, the equipment must be properly enclosed in a building to contain the noise. Another example is when a hydroelectric dam is considered for electric generation. A thorough study should be performed to study all the effects the dam has over its surrounding. The construction of the dam must have little or no impact on its surroundings [5].

### **Permits**

CHP systems are subjected to permits from local, state, and federal authorities to ensure compliance with environmental regulations, utility regulations, fire, zoning, and building codes. When developing the project, these need to be considered along with the selection of the technologies. It is necessary that the equipment selected meets the requirements

of the jurisdiction where the CHP system will be installed. Permits have a cost that must be included in the total cost required to develop the project. If unfamiliar to the world of permitting, the company may consider outsourcing the task to an "integrated service provider" [6], which will oversee the entire process of obtaining the permit. Its tasks will include a site analysis for CHP consideration and the entire process and paperwork to obtain environmental and construction permits.

### **Fuel Supply Issues**

Part of the long-term success of a cogeneration project is the availability and price of fuels considered for the selected system. It is necessary that the facility negotiate an interruptible supply of fuel with the local fuel provider at a reasonable cost to ensure the CHP system stays online. Continuous increases in fossil fuels prices may at one time surpass the electric rates. At this moment, the CHP system operability is no longer feasible, and in fact may produce losses for the company. One way to handle this if it ever occurs is to consider maintaining an inventory of an alternative fuel such as biomass, wood waste, or agricultural by-products on site.

### **Insurance and Indemnification**

Electricity is a very useful resource, but, if mishandled, it can have terrible consequences. Safety equipment and procedures need to be in place when establishing the interconnection of CHP systems to the utility's electric grid. Also, because accidents may happen by unexpected causes, it may be necessary that the facility obtain liability insurance to protect their equipment and personnel while the interconnection is performed. This also protects the facility in case the electric utility wishes to file any claims against any damages, losses, or injuries during the CHP system and grid interconnection.

## **CONCLUSIONS**

Current energy prices have forced changes in consumption habits as well as in methods of energy generation. It is necessary to secure a reliable and affordable source of energy to promote further economic development and to protect ourselves from natural disasters and other events that may endanger our energy supplies in the United States. Com-

panies have already been working on solutions to develop technologies that can better utilize fuels and resources available in the United States as part of the nation's goal of becoming more energy independent.

This research presents a solution to the problem of high-energy prices for large consumers. Cogeneration, or combined heat and power (CHP), is not a new concept. It has been used for many years in the power generation industry. Now, it is gaining a place in the commercial, residential, institutional, and industry sectors. The major reason is that these systems can be custom built to meet specific site needs, allowing flexibility in the selection.

The carbon black industry as a whole makes a good candidate for the implementation of this concept. This industry's electric and thermal energy needs can be met with the use of a CHP system, but this research is not limited only to the carbon black industry. It is expected that this research can help the advancement of this concept in other sectors where there are energy and thermal needs and where inexpensive fuels are available.

The analysis of the energy consumption of the carbon black facility studied in this research shows that a steam-turbine-driven CHP system could provide for the electric needs of the company and the recaptured heat from the low-pressure steam can be processed and injected into the reactor to substitute for some of the heat currently supplied by the natural gas. For the electric needs, it has been concluded that the facility can benefit from generating a baseline load of approximately 5,659 kW; this will ensure that no excess electricity is produced. It is recommended that the remaining electricity be purchased from the local utility company.

The CHP described in this research can yield savings of approximately \$2,274,115 per year. These savings are based on 2004 electric and natural gas rates. With today's energy prices, savings are expected to be greater. The payback of this project is approximately 3½ years. It must be considered that the equipment life span is about 30 years. This means that after the payback time has passed, the company will profit from implementing the project.

Installing a combined heat and power system in a carbon black facility can provide many benefits. These systems can help reduce the amount of fuel consumed, which each day is becoming less abundant and more expensive. The industrial sector, being the largest energy consumer, is a good candidate for implementing this concept. Aside from money savings, reductions in greenhouse gases are achieved, which

could aid in compliance with environmental requirements.

The suggested solution in this research is to be considered as a preliminary solution. It is necessary that further detailed studies be carried out by professional CHP developers; these would yield a more accurate set of specifications and costs.

There is a vast choice of efficient technologies commercially available for both electric generation and heat recovery, but more research must be carried out to improve existing technologies and create others that are even more efficient. With the introduction and advancement of distributed generating equipment, prices will come down, and this will indeed make developing a CHP project more technically and financially attractive. CHP is definitely a way of helping industries in this nation reduce operating costs, which in the long run can contribute to their growth and to the ultimate goal of remaining competitive in the business world.

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