NOx Emissions Impacts from Widespread Deployment of CHP in Houston

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Gulf Coast CHP Regional Applications Center	a program of the Houston Advanced Research Center

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ACRONYMS

BACT	Best Available Control Technology
BCHP	Building Combined Heat and Power
CHP	Combined Heat and Power
EGRID	Emissions and Generation Resource Integrated Database
EGU	Electric Generating Unit
EPA	Environmental Protection Agency (U.S.)
ERCOT	Electric Reliability Council of Texas
HARC	Houston Advanced Research Center
HCAD	Harris County Appraisal District
HGAC	Houston-Galveston Area Council
HGB	Houston-Galveston-Brazoria
MW	Megawatt
NAICS	North American Industry Code Standard
NCA	Non-Compliance Area
NOx	Nitrogen Oxide
SIP	State Implementation Plan
TCAA	Texas Clean Air Act
TCEQ	Texas Commission on Environmental Quality
TERP	Texas Emissions Reduction Program

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EXECUTIVE SUMMARY

Combined Heat and Power (CHP) refers to the use of any of a number of commercially available technologies capable of capturing and using the thermal energy that is naturally produced during power generation. To do this, CHP systems are located at industrial and commercial facilities where they provide some or all of the facility's electricity and thermal needs. CHP systems typically achieve overall energy efficiencies in the 70% to 85% range, far superior to the 30-40% efficiency achieved in traditional utility power generation. Thus, the CHP approach is an important energy conservation technique and it could offer an additional technology option to further reduce NOx emissions in the Houston-Galveston-Brazoria (HGB) region. This study provides an initial estimate of potential NOx reductions from deployment of CHP technologies.

Texas has a long and successful history implementing CHP technologies. In 2005, some 16,000 MW of CHP technologies were integrated into infrastructure served by the Texas electrical grid. These systems produced over 20% of the electricity generated in the state. In HGB today, the potential for additional CHP systems in both commercial and industrial sectors is large and growing. In the industrial sector, about 950 new projects with a total electrical capacity of about 1,300 MW have been identified. In the commercial sector, nearly 3000 large buildings could accommodate CHP, thereby creating between 275 MW to 1,300 MW of new electrical generating capacity and reducing demand for fossil fuels.

CHP systems can reduce NOx emissions both at the host site where they are located and at the utility power plants that would otherwise generate electricity for host facilities. The integration of a CHP plant into an electrical power system reduces NOx in the following ways:

1. CHP reduces demand for the use of conventional boilers
2. CHP allows some electrical loads (like heating of water and thermal conditioning of space) to be served directly with the thermal energy that was previously discharged to the environment

3. Replacement of grid power with CHP electricity reduces NOx at the utility power plant, because CHP generated electricity produces far less NOx emissions than do most utility power plants

4. CHP eliminates losses arising from the transmission and distribution of electricity otherwise produced by central station generators and delivered via the grid.

This study estimates the potential NOx savings from widespread adoption of CHP in industrial and commercial facilities across the eight-county HGB region. As shown in Table ES-1, NOx savings are estimated to be in the range of 12.9 - 14.9 tons per day with about two-thirds of the reduction arising from the industrial sector. By 2020, economic and population growth in HGB is anticipated to create opportunities for further deployment of CHP systems, which would likely result in even greater NOx reductions.

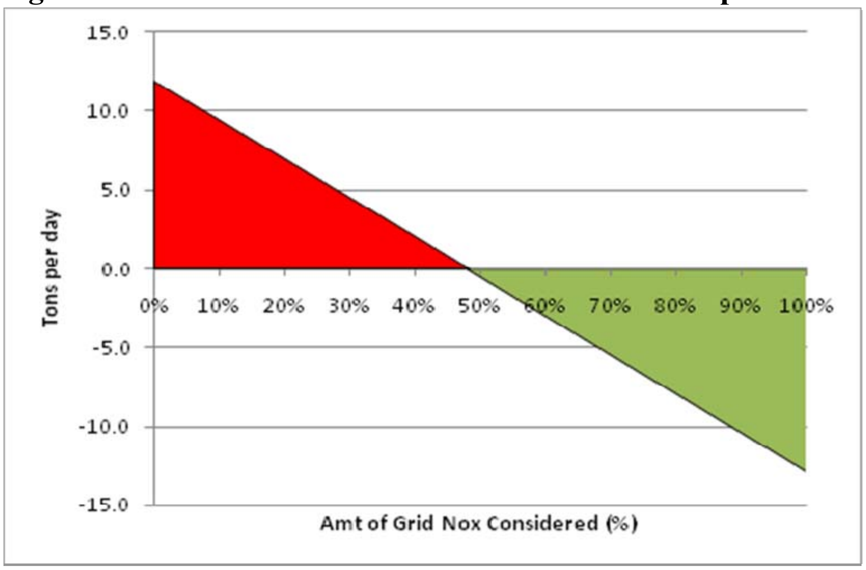
Table ES-1: Potential NOx Reductions in HGB from CHP

CHP Systems	Annual Average (tons/day)	Peak Ozone Season (tons/day)
Commercial Sector	2.9 – 4.9	5 - 9
Industrial Sector	10.0	11.7
Total HGB	12.9 – 14.9	17 - 21

While implementation of CHP reduces total NOx emissions, it also shifts the location of NOx emissions. Whereas the conventional approach would primarily result in NOx emissions at the utility power plants, which are located mostly outside of the eight county region, use of CHP would relocate some of those emissions to those facilities adopting its use. Thus, the geographical distribution of NOx emissions is changed through CHP implementation. For HGB, this could mean that NOx emissions within the eight-county region could increase, even though overall NOx emissions are reduced.

The actual impacts on the HGB region from NOx produced by utility power plants are the key to assessing the overall NOx impact of CHP. The extent to which NOx emission reductions resulting at utility power plants have a direct impact on lowering NOx and ozone concentrations in HGB determines the overall benefit of CHP. As shown in the figure below, this study suggests that CHP provides a net NOx benefit to HGB if more than half of the NOx savings from decreased use of grid electricity is realized in lowered NOx concentrations in the eight-county region.

Figure ES-1: Effect of Grid NOx on Overall CHP Impact



In recent years, commercial real estate owners and developers are increasingly looking at CHP for economic and environmental reasons, and a few CHP projects are under construction in HGB. However, the adoption rate for CHP, especially among industrial facilities, has slowed due to volatile natural gas prices and uncertain economic conditions. If substantial additional NOx savings are to be realized from CHP, a number of regulatory and market barriers will need to be addressed and incentives provided to adopters to value the NOx benefits produced by such systems.

This report provides an initial, preliminary examination of the potential NOx impacts from greater adoption of CHP technologies in HGB. The potential NOx impact was found to be highly dependent on the regional benefits resulting from NOx reductions taking place at central station power plants serving the Texas electrical grid. Additional study is needed to address this issue and to further quantify the potential for NOx gradients to develop at a micro-scale due to the distributed nature of CHP implementation, especially with regard to the effect of stack height on NOx plume diffusion, mixing layer dynamics, and the photochemistry of ozone formation.

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1.0 Introduction

Central station power generation preferred by most electric utilities today is based upon inefficient steam generation, where economy of scale is used to compensate for poor energy performance. The typical power plants built by electric utilities in Texas are steam plants that are 25 to 35% efficient; meaning only about 30% of the energy content of fuel is converted to power. The balance of the energy is released to atmosphere as unused thermal energy.

Combined Heat and Power (CHP) refers to the use of any of a number of technologies to capture and productively use the thermal energy that is naturally produced during power generation. In contrast to large scale central station power plants, a central feature of CHP systems is their high efficiency, which typically falls into the 70% to 85% range. Thus, CHP facilities are a major energy conservation technique, even compared to modern natural gas combined cycle power plants that operate at about 50% efficiency.

Texas has a long and successful history implementing CHP technologies. In 2005, some 16,000 MW of CHP technologies were connected to the Texas electrical grid, which produced over 20% of the electricity generated in the state. This capacity is located primarily at major industrial facilities, many of them in the greater Houston area.[1] Over 95% of these existing CHP facilities use natural gas to power the system.

Adoption of combined heat and power technologies at industrial facilities, and at commercial and institutional buildings in the region could offer an additional technology option to reduce NOx emissions in HGB. This study evaluates the potential NOx impacts that might occur in the Houston region should combined heat and power technologies achieve even more widespread implementation.

1.1 Background

Houston is the fourth most populous city in the United States, the largest city in Texas, and the 6th largest metropolitan area in the U.S. The city is a major port and the center of the country's petroleum refining and chemical industries, much of which is located along the Houston Ship Channel between Houston and Galveston. The greater Houston area is heavily industrialized and rapidly growing. The population of the region is projected to increase by more than 50% by 2030.

Since the passage of the 1990 Clean Air Act Amendments, the Houston-Galveston-Brazoria (HGB) region[2] has been classified by the U.S. Environmental Protection Agency (EPA) as being in non-attainment for ground level ozone. Under the 1-hour ozone standard, Houston was classified in the category of "Severe" non-attainment, second only to the Los Angeles area. Under the 8-hour standard, Houston was classified

[1] Elliott, R. Neal, Maggie Eldridge, Anna M. Shipley, John "Skip" Laitner, Seven Nadel, Alison Silverstein, Bruce Hedman, Mike Sloan, "Potential for Energy Efficiency, Demand Response, and On-site Renewable Energy to Meet Texas's Growing Electricity Needs, American Council for an Energy-Efficient Economy, Report # E073, March 2007 (Elliott 2007)

[2] The Houston-Galveston-Brazoria (HGB) non-attainment area, as defined by federal legislation, includes the eight counties of Brazoria, Chambers, Fort Bend, Galveston, Harris, Liberty, Montgomery, and Waller.

as “moderate” in the same category as 21 other urban areas. Recently, the Texas Commission on Environmental Quality (TCEQ) requested and EPA approved a reclassification of the HGB area from “moderate” to “severe” nonattainment, pushing back the area’s attainment deadline from 2010 to 2019.

Due to Houston’s industrial mix and climatological characteristics, ozone reduction is particularly challenging and will require extensive mitigation measures both inside and beyond the region to achieve current standards. In addition, the potential for further tightening of the ozone standards in the future exists. The EPA is expected to finalize the new ambient ozone standards sometime in March of 2008. Reduction of NOx emissions is a primary strategy promoted in the region to reduce ozone formation.

1.2 HGB NOx Overview

The Houston SIP is the primary device used to manage air quality in the region. The SIP includes information regarding sources of NOx emissions, quantifies NOx emissions, and addresses strategies for mitigating NOx emissions. In the most recent SIP filing,[3] total regional NOx emissions for 2008 are estimated to be approximately 548 tons per day, down from 831 tons per day in 2002.

Table 1-1: NOx Emission Inventory, HGB (2008 RFP SIP)

Source	2002 Base Year (tons per day)	2008 Uncontrolled (tons per day)	2008 Controlled (tons per day)
Point	339.48	381.59	174.89
Area	40.15	55.18	55.18
Non-Road	167.74	243.03	146.66
On-Road	283.2	364.83	171.65
Total	830.57	1044.63	548.38

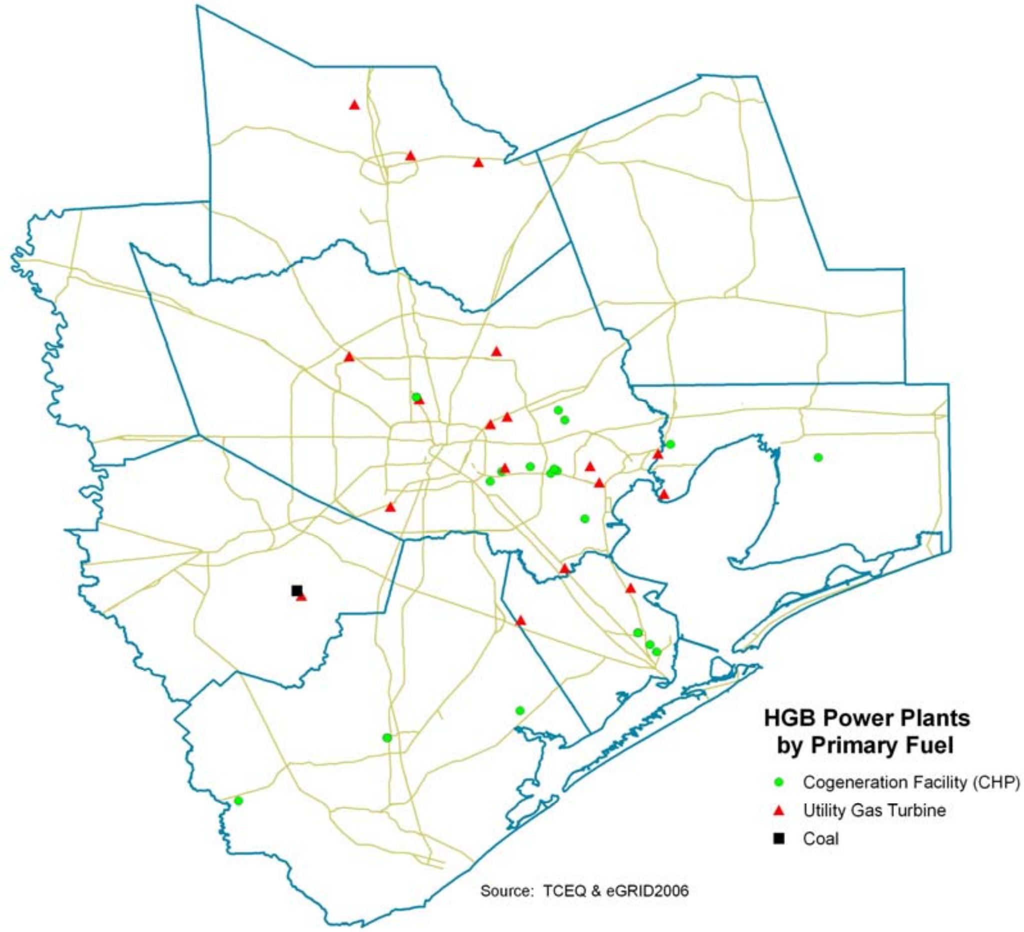
Source: Houston-Galveston Brazoria Eight-Hour Ozone Nonattainment Area Reasonable Further Progress SIP, TCEQ, (2006-030-SIP-NR), Adopted HGB RFP SIP Revision Narrative, Adopted by Commission May 23, 2007

As shown in Table 1-1, about 58% of NOx emissions come from mobile sources, including cars, trucks, locomotives, airplanes, ships, and construction equipment. Because on and off-road vehicles now generate a majority of the region’s NOx emissions, state and federal programs are focused primarily on reducing emissions from non-road equipment and on-road vehicles. State government is pre-empted by federal law from

[3] See http://www.tceq.state.tx.us/implementation/air/sip/hgb.html#rfp. This site was last accessed on February 14, 2008.

regulating most on and off-road emission sources, As a result, state regulators rely heavily on federal controls, such as vehicle emission standards, although voluntary programs, such as the Texas Emission Reduction Plan (TERP), are also used to reduce NOx emissions from some of these sources.

Figure 1-1: Location of HGB Region Electric Generating Units



Stationary[4] or "point" sources produce about 32% of total NOx emissions in HGB, while area sources, which include small commercial facilities like dry cleaners and gas stations that are too small to be considered point sources, account for about 10%. The State of Texas has the authority to regulate most point and area sources. In recent years, regulations required point source emitters to reduce NOx emissions by 80% by 2007. However, even with these aggressive reductions, point sources are projected to contribute

[4] Major stationary or point sources of NOx emissions include only those sources that exceed permitted levels of pollutants as specified by state regulations. Regulatory limits vary by pollutant and by location. Point sources account for stationary NOx emitting devices including industrial and commercial boilers, electric-utility boilers, turbine engines, wood and pulp processers, paper mills, industrial surface coating facilities, refinery and chemical processing operations.

about 175 tons per day in 2008 or about 32% of the region's total NOx emissions. Electricity generating units in the HGB area, which are mapped in Figure 1-1, produced an estimated 37 tons per day of NOx in 2005.[5] By 2008, utility power plants will account for an estimated 29.4 tons per day.

In the most recent SIP submittal (TCEQ, May 23, 2007), TCEQ reports that NOx emission reductions from energy efficiency and renewable energy were estimated by the Energy Systems Laboratory at Texas A&M to be 5.05 tons/day in 2009. These estimates did not include the deployment of CHP in the Houston area, although the methodology for calculating NOx reductions from reductions in grid supplied electricity appear to be similar to analyzing NOx impacts from CHP.

Despite the actual impact on NOx concentrations in HGB, TCEQ concluded that emission reductions occurring at electric generating plants (EGUs) due to implementation of energy efficiency or renewable energy projects would not produce excess emission credits under the NOx trading program (MECT Program) for the HGB area.[6] TCEQ states that:

> "[T]his methodology (used by ESL), though, does not address the complication created from the NOX cap and trade program in the HGB area. The MECT Program caps the NOX emissions at point sources, including EGUs, in the HGB nonattainment area. If an EGU is located within the HGB nonattainment area and demand on that EGU is reduced due to effective EE/RE programs, then the EGU may emit less NOX than its cap allows. The EGU could then have excess NOX allowances that could be sold or traded in the HGB area, resulting in no net reduction in NOX emissions. Therefore, in the HGB area, SIP-quality reductions from EE/RE cannot be directly credited in the SIP.[7]"

1.3 Combined Heat and Power Systems

Combined Heat and Power (CHP) refers to the use of any of a number of technologies to capture and productively use the thermal energy that is naturally produced during power generation. In contrast to large scale central station power plants in common use, a central feature of CHP is its location at a facility with a thermal load. By locating the CHP power plant nearby a thermal host, heat produced in the process can be used efficiently. The advantage of CHP systems is shown schematically in Figure 1-2.

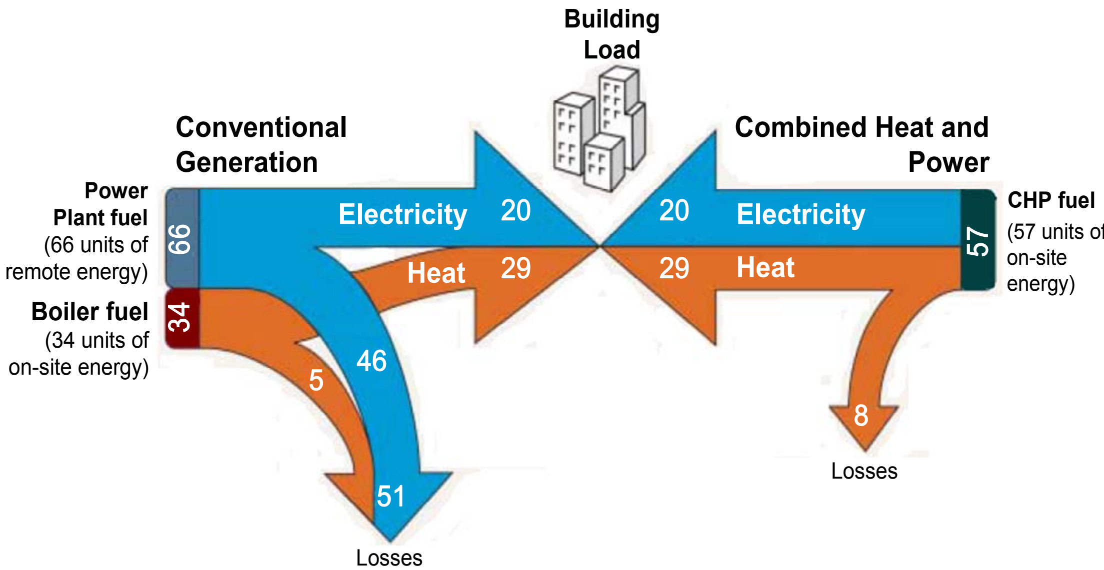
The typical central station power plant serving much of Texas today is only 25 to 35% efficient, meaning only about 30% of the energy content of fuel is converted to power. The balance of the energy is released to atmosphere by evaporating water or through the exhaust gases. CHP systems, which are typically 70% to 80% efficient, are a major energy conservation technique compared to central station power plants.

[5] Texas Commission on Environmental Quality, 2005 Point Source Inventory.

[6] Note that such credits can be accrued in the DFW nonattainment region because that region does not operate under a NOx trading program.

[7] Revisions to the State Implementation Plan (SIP) for the Control of Ozone Air Pollution, PROJECT NO. 2006-027-SIP-NR, DOCKET NO. 2006-1874-SIP, TCEQ, Adopted May 23, 2007, p. 4-7 to 4-8

Figure 1-2: Efficiency Comparison – Central Station vs. CHP



The vast majority of CHP systems in Texas are located at industrial sites, primarily at chemical industry plants and petroleum refineries, as shown in Table 1-2. Natural gas is used to fuel over 95% of these CHP systems, although a wide range of fuels can be used for CHP. About 92% of this capacity uses conventional gas turbine generators, steam turbine generators, and natural gas engines. Over 98% of the existing capacity is comprised of large systems over 20 MW in size. [8]

While Texas industry has already implemented significant CHP systems, significant opportunities remain at chemical plants, refineries, and especially among other industrial facilities where historical CHP adoption rates have been lower. In addition to industrial locations, however, recent development of microturbines and "packaged systems" combining reciprocating engines and absorption chillers into a single unit are extending the market for CHP systems to the commercial building sector, which is virtually untouched.

Packaged systems developed by several companies provide greater plug-and-play capability and deal more effectively with the need to generate chilled water instead of steam for commercial building adopters. These product enhancements will lower the design and installation costs for systems, and make them more attractive. Today, CHP can be effective in a wide range of commercial buildings including hospitals, hotels, malls, airports, prisons, office buildings, universities, and high schools. In the commercial sector, economics often drives CHP facilities to be designed and operated to

[8] CHP Market Status, April 25, 2005, page 15-28, Bruce Hedman. Presentation located at http://files.harc.edu/Sites/GulfCoastCHP/News/RoadmapWorkshop2005/GulfCoastCHPOverview.pdf This report was last accessed at this site on October 30, 2007.

meet a facility's thermal needs first. In these cases, CHP systems can be thought of as a "boiler that also produces electricity."

Table 1-2: Existing CHP Capacity in Texas by Industry

Industry	Share of Existing Capacity
Chemicals	66%
Refining	22%
Paper	4%
Manufacturing	4%
Commercial	2%
Food	1%
Other Industrial	1%

Source: Hedman, 2005

1.4 NOx Impacts of CHP

The dramatic efficiency gains achievable with CHP systems result in an overall decrease in NOx emissions. A comparison of NOx emissions from four different power generating options is shown in Figure 1-3, where NOx emissions from a natural gas turbine CHP plant are shown to be more than an order of magnitude lower than that produced by a utility coal boiler. CHP systems produce the same level of NOx emissions as a combined cycle gas turbine (CCGT), the utility industry's most efficient power plant option.[9]

The high overall efficiency achieved by CHP systems translates into NOx emission reductions in two ways:

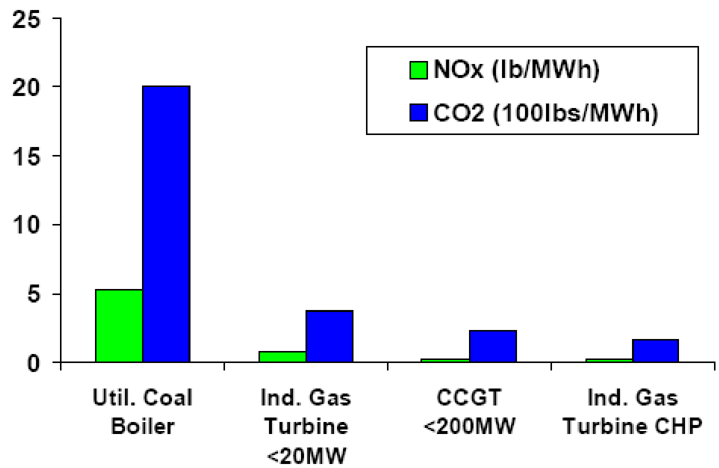
1. On-site NOx Impacts – CHP systems provide some or all of a facility's thermal energy needs, thereby reducing the need to operate conventional boiler systems. As a result, on-site boilers are used much less frequently and NOx boiler emissions are thereby reduced or eliminated. In addition, the combustion of natural gas to operate the CHP system increases NOx emissions. With CHP adoption, NOx emissions at the facility site will increase.
2. Off-site NOx Impacts – CHP systems provide some or all of a facility's electrical energy needs. In addition, some electrical loads can be shifted from electrical service to thermal service, further reducing total consumption of electricity. As a result, the amount of electricity sourced from the power grid is reduced. CHP systems produce less NOx than central station generators because:
    - CHP systems do not create any transmission and distribution losses. These losses, which can amount to 7-10% of total electricity produced at a

[9] See the presentation by Austin Energy regarding NOx comparisons to their Dell Children's Hospital project at http://files.harc.edu/Sites/GulfCoastCHP/News/CHPEmissions2006/BusinessCaseForCHP.pdf. This site was last accessed on February 3, 2008.

central station generating facility, increase the amount of fuel that must be burnt to produce the same amount of electricity at the end-user's site.

- CHP systems are required to meet a more stringent NOx emission limit of 0.14 lbs/MWh, which is far less than the 1.07 lbs/MWh created by central station generators serving the Texas grid.[10]

Figure 1-3: Comparison of NOx Emissions



CCGT: Combined Cycle Gas Turbine
Source: Elliott, 2001

Even though CHP systems produce an overall decrease in NOx emissions, the technologies may still not create a viable strategy to reduce ozone in HGB. Widespread development of CHP projects would essentially relocate the source of some of the NOx emissions produced by the power generating sector from a few, very large point sources outside the city to many, small point sources inside the city. Implementation of CHP changes both the amount AND geographical distribution of NOx emissions, and the evaluation of this trade-off is the central goal of the study.

[10] NOx emissions produced by the Texas electrical grid are based on the EPA's Emissions & Generation Resource Integrated Database (eGRID), which is a comprehensive catalog of the air emissions (including NOx) and environmental attributes of US electric power systems. It integrates 24 different federal data sources on power plants and power companies, from three different federal agencies: EPA, the Energy Information Administration (EIA), and the Federal Energy Regulatory Commission (FERC). eGRID, which includes data for some 4,700 power plants, provides data at the plant/company, state, and power grid region levels. The "2007 Annual eGRID (25%)" and "2007 OSD eGRID (25%)" were used to establish utility NOx emissions in lbs per MWh consistent with protocols of the Texas Commission on Environmental Quality (TCEQ) and EPA.

1.5 Study Goals and Limitations

This study examines whether NOx emissions in the HGB region can be expected to increase or decrease with widespread implementation of Combined Heat and Power (CHP) technologies in HGB. CHP requires relatively small electrical generating units to be located near facilities that have a need for the thermal energy produced by the generating units. Because the technology is substantially more efficient than traditional energy supply methods, CHP adoption is anticipated to result in significantly less NOx emissions. However, development of CHP at facilities in the city would essentially relocate the sources of NOx emissions produced by the power generating sector from a few, very large point sources outside the city to many, small point sources inside the city. Initial quantification of the magnitude of the NOx change expected from CHP was a key goal of the study, while an assessment of the geographical impact on NOx emissions was largely beyond the study's scope.

This study compares NOx emissions resulting from a 'business as usual' baseline case to a scenario in which CHP systems are widely deployed in commercial and industrial applications. The study evaluates the quantity of NOx emissions only. No attempt has been made to employ air dispersion models or to consider the effects of exhaust stack heights or wind speeds in determining local NOx concentrations. In addition, the study does not address the complex chemistry of ozone formation and transport. An examination of NOx plume movement and the mechanics of ozone formation in each scenario are beyond the scope of this study, and further analysis is recommended that incorporates these phenomena.

In addition, the potential sites for CHP in HGB are based upon studies of technical potential done by other researchers, and the results presented here reflect the accuracy of those reports in determining CHP potential. The report does not specifically address the cost effectiveness of CHP systems and much of the technical potential for CHP may not be economically attractive to adopters without additional financial incentives. In the case of commercial systems, a maximum payback of ten years was used in the model to establish potential project size limits and performance requirements. The report also does not address the time delay that would be experienced to develop a large number of projects, which could impact the magnitude of the NOx savings achievable with CHP.

While the technical potential for CHP in HGB is large, the number of potential CHP projects and their NOx impacts are thought to be conservative. In the commercial sector analysis, additional potential for CHP system deployment could exist in a number of other building types including, for instance, refrigerated warehouses, prisons, airports, and food processing operations. These possible applications were not included in the study due to lack of firm data on the number of such facilities or details of exactly how CHP could be utilized. The results determined in the study are only a guideline of the magnitude of NOx emission changes that can be expected from a given amount of CHP system deployment.

1.6 Data Sources

The following databases and analytical tools were used in this study.

- **2006 infoUSA Business/Employer Database** – The database was used to obtain up-to-date and comprehensive information concerning area businesses. The database contains detailed information on more than 200,000 businesses in area, including location and North American Industry Classification System (NAICS) code.
- **ArcGIS** – This mapping software suite was used to compile and map data from infoUSA, HCAD, and power plant locations and characteristics.
- **Harris County Appraisal District (HCAD) Public Data** – These data were used to obtain detailed category and facility specific (building) area information for the region. HCAD data for every building in Harris County was downloaded from the HCAD public data site: http://pdata.hcad.org/.
- **BCHP Screening Tool** – This analytical tool, which was developed for the U.S. Department of Energy by Oak Ridge National Lab. It can be used to evaluate combined cooling, heating, and power in commercial buildings. In this study, it was used to analyze energy use and emissions impacts from implementation of CHP into prototypical commercial buildings under various operating strategies.
- **Emissions & Generation Resource Integrated Database (eGRID)** – This comprehensive database, which is maintained by the U.S. Environmental Protection Agency, provides data on the environmental characteristics of almost all electric power generated in the United States. The eGRID database was used to obtain the emissions and resource mix data for power plants in Texas and in HGB. In this project, eGRID database Version 2.1 (updated April 30, 2007) was utilized.
- **2002 Economic Census** – Information from the U.S. Census Bureau was used to obtain information on regional buildings and characteristics.
- **The Complete Economic and Demographic Data Source (CEDDS.)** – This data from Woods & Poole Economics (2006) was used to estimate and compare the level and types of industrial activity in HGB to Texas as a whole.
- **CHP Emissions Calculator, v1.1** - The analytical tool, which is provided and maintained by U.S. Environmental Protection Agency, was used to compare the anticipated emissions from a CHP system to the emissions from systems using separate heat and power (SHP).

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2.0. Commercial and Institutional Buildings

Many commercial and institutional facilities, because of their energy use profiles and needs, are potential candidates for CHP adoption. In particular, hospitals and hotels offer some of the greatest potential for CHP due to their need for hot water. Schools, office buildings, and large retail facilities can also be good CHP prospects, although typically with somewhat longer payback periods.

To estimate the potential NOx emissions impact from implementation of CHP across the commercial and institutional building stock in HGB, the existing building stock was evaluated and screened for CHP potential. A combination of general industry guidelines combined with computer modeling was used to determine the building types suitable for CHP and to estimate the size and configuration of the CHP system. Only those buildings thought to offer reasonable technical and financial justification to adopt CHP were considered in the study. The methodology used in the study includes the following steps:

- Survey and analyze the existing HGB building stock
- Select building types with reasonable CHP potential
- Establish prototypical building types and characteristics for selected buildings
- Model building energy use for baseline and CHP cases (multiple operating scenarios)
- Estimate a range of NOx emissions impacts expected for each prototype
- Estimate total NOx impact by considering the existing building type count

A detailed description of the methodology including models, tools, databases, assumptions, and scenarios used in the analysis is provided below.

2.1 Identifying Candidate Facilities

The identification of building types and facilities potentially suitable for CHP system development required a survey and analysis of the commercial and institutional building stock in HGB. The building stock was broadly considered and screened for CHP viability. Those building types that met the following criteria were selected for further analysis:

- The building type exhibited technical and operating requirements that are generally thought to provide reasonable justification in support of CHP development
- The building type exists in sufficient numbers in the HGB region such that a penetration of CHP systems would generate a meaningful impact

Commercial and institutional buildings within the greater Houston region were initially identified by examining the 2006 infoUSA Business/Employer database for the region. The database, which is licensed to the Houston-Galveston Area Council (H-GAC) and its Geographic Data Committee (GDC), of which HARC is a member, is the most up-to-date and comprehensive database of area businesses. It contains detailed information on more than 200,000 businesses in the region, including each business' geocoded location, for utilization within a geographic information system (GIS), along with its North American Industry Classification System (NAICS) code. NAICS codes were used to identify the most promising CHP candidate business types within the region.

The building stock was analyzed by building type. The viability of CHP in each building type was roughly estimated by considering building operation relative to the following factors. The viability of CHP development in a commercial or institutional building is enhanced by positive answers to these criteria.

- Does the facility have a need for hot water, steam, or other thermal energy?
- Do the building's electrical and thermal loads show strong coincidence?
- Does the facility operate continuously (24 hr x 365 days)?
- Do the loads have low seasonal variations?
- Does the facility need high power reliability?

After thoroughly examining all the area's commercial and institutional buildings via the infoUSA database, an initial list of roughly 200 facility types were identified where CHP was possible. Subsequent iterative analysis narrowed the number of facility types that both offered strong CHP viability and were well represented in the region to the following five broad categories:

- Healthcare
- Hotel and apartments
- Office buildings
- Schools
- Retail

A number of other building type categories or specific one-off buildings could potentially support attractive CHP projects, but were not included in this study due to difficulty estimating the size and characteristics of such systems. For example, the Houston Intercontinental Airport, Hobby Airport, the Ports of Houston and Galveston, certain waste water treatment facilities, refrigerated warehouses, area breweries, and other facilities could host viable CHP projects, potentially totaling to between 50-100 MW of electrical capacity.

2.2 Developing Prototype Buildings

The five building categories considered in the study were evaluated to further characterize actual building types existing in the HGB region. The evaluation involved examining the literature regarding building analysis and various data sources specific to HGB, such as the U.S. Census and County Appraisal District databases. Based upon the picture that emerged of the existing building stock, the five building categories were broken into sub-categories that fit to the actual building stock existing in the region. The overall categories and building quantities in HGB are shown in Table 2-1 below.

Table 2-1: Commercial & Institutional CHP Prospects

Master Category	Prototype	Existing Facilities
Healthcare Buildings	Fitness and Sports Centers	122
	Medical Labs	7
	Small Hospitals	53
	Medium Hospitals	47
	Large Hospitals	5
	Small Nursing and Retirement Homes	41
	Large Nursing and Retirement Homes	9
	Subtotal	284
Hotel and Apartment Buildings	Small Hotels	313
	Medium Hotels	41
	Large Hotel	15
	High-Rise Only Apartments/Condos	117
	Subtotal	486
Offices Buildings	High Rise Office	575
	Low-Rise Office	684
	Data Processing	96
	Large Libraries & Archives	75
	Subtotal	1430
School Buildings	High Schools	178
	Colleges – no on campus living	3
	Colleges – with on campus living	9
	Subtotal	190
Retail Buildings	Supermarkets and Retail w/refrigeration	186
	Big Box Retail	356
	Enclosed Shopping Malls	12
	Subtotal	554
ALL	**TOTAL**	**2,944**

While the infoUSA Business/Employer database contains fairly detailed information on the business itself, it unfortunately does not offer detailed facility (structure) specific area (size) information. Each business' facilities are simply classified into one of four broad area categories, with all facilities of 40,000 square feet or more identified under the same category. To ascertain more detailed category and facility specific (building) area information for the region, data from the Harris County Appraisal District (HCAD) was utilized. HCAD data for every building in Harris County was downloaded from the HCAD Public Data site. It was then processed, filtered, and summarized for each CHP candidate application type using SAS. The building database's Building Style Code field was used to group each structure with the corresponding NAICS code of interest.

Facility types were then summarized and aggregated into prototype groups within each candidate category, by square footage, based on their similar energy load profiles and operating scenarios. Groupings within building cluster types, such as hospitals (small, medium, and large), were determined by both the calculated minimum building sizes for feasible CHP adoption, as per the BCHP model, and the distribution of the building size data from the HCAD database. Based on initial BCHP runs, facilities of less than 40,000 square feet were generally excluded, with the exception of hospitals, fitness facilities, data processing centers, and libraries, where 20,000 square feet served as the cut-off threshold.

Using this process, building assumptions including building size, number of stories, building age, building envelope considerations, HVAC and boiler equipment size and age, and building electrical and thermal loads were established for each building sub-category, thereby creating a detailed prototype building with specific and detailed characteristics suitable for computer modeling. Also at this time, consideration was given to estimating the detailed equipment and operating strategy that an on-site CHP system would most likely employ. The detailed building assumptions used for each prototype is presented in Appendix A.

2.3 Modeling Building Performance

Computer modeling was used to determine the energy and environmental impacts resulting from adoption of CHP systems at each of the prototype buildings. Computer modeling was first used as part of an iterative process to establish the size and configuration of CHP systems likely for each prototype building type and to compare the energy and environmental impacts of the baseline and CHP alternatives. The NOx emission implications for each building type are an output of the computer model and discussed below and shown by prototype in Appendix A.

A detailed description of the modeling effort is provided below.

2.3.1 Prototype Building Models

The BCHP model and detailed spreadsheet models were used in the analysis of prototype buildings. BCHP incorporates the program DOE 2.1, which is a building simulator that uses detailed building characteristics and local weather data to generate hour-by-hour electrical and thermal load profiles. The model's algorithms automatically determined HVAC systems and plant sizes.

A total of eleven BCHP models were developed. Due to similarities between building types, these twelve models were considered to be suitable to model all of the desired prototype buildings, although in some cases minor modifications were made to the model to more accurately reflect anticipated building operation and use. For some prototypical buildings, spreadsheet analysis was used to modify the results of the BCHP model to improve accuracy across prototypical building types. The eleven BCHP models included:

- Healthcare (4): large, medium, and small hospitals, nursing homes
- Hotels (3): large, medium, and small
- Office Buildings (2): medium-rise office towers, colleges (with on-campus living)

- Retail Buildings (2): big box retail; supermarkets

2.3.2 CHP System Definition and Operating Strategies

The CHP operating strategy is central to defining its configuration, energy use, environmental impacts, and economic value. To provide a range of potential NOx savings from implementation of CHP systems, three specific operating cases were evaluated for each prototypical building type. All three of these cases assume all electrical and thermal energy is consumed by the project host, implying no exports and sale of electricity or thermal energy from the project. Even with this restriction, these three strategies are expected to cover the vast majority of CHP systems built to serve commercial and institutional buildings. Hence, the various cases will provide solid "bookends" for the NOx impacts likely to be achieved in HGB from CHP adoption. The three cases analyzed include:

- Case 1: Maximum Electrical Demand – In this case, CHP systems were sized to provide at least 90% (ideally 100%) of the electricity required by the building. The capacity of the prime mover was selected to meet the building's summer peak demand with the recovered thermal energy used to serve hot water, heating, and as required, cooling with absorption chillers. In cases where absorption cooling was used, the base chiller configuration was changed to allow for the use of an absorption chiller. The generator was operated to follow the electrical demand.
- Case 2: Maximum Thermal Demand -- In this case, CHP systems were sized to provide at least 90% (ideally 100%) of the thermal needs (hot water and heating) of the prototypical facility. The generator was operated to follow the thermal demand. In cases where this operating strategy could result in an excess (or export) of electricity, the generator was set to follow the lesser of the two demands. The chillers are the same as was used in the base case. In cases where this strategy resulted in paybacks of more than 10 years, the chiller sizes were allocated between absorption chiller and electric chiller iteratively so that the payback period fell below 10 years.
- Case 3: Optimal Thermal Utilization – In this case, CHP systems were sized to optimize the recovery and utilization of thermal energy produced by the system. The prime mover was selected and sized to ensure that about 85% or more of the thermal energy generated by it is utilized effectively. The generator was operated to follow the thermal demand, but used an auxiliary boiler to meet thermal demands exceeding CHP system capacity.

For each operating strategy, the BCHP software and spreadsheet analysis were used in an iterative process to define the size and configuration of CHP systems that could be supported by each prototypical building type. The prime mover selected for use in hypothetical CHP systems included reciprocating engines and microturbines. Microturbines were typically applied in cases where the capacity of the CHP system was anticipated to be 300 kW or less. The use of absorption chilling to provide chilled water for air conditioning and other uses was found to add value to the CHP solution, so it was included in the analysis in a number of cases. Detailed project scoping to include chilled water storage, operational redundancy, multi-fuel operation and similar design possibilities were beyond the scope of the study. CHP systems were configured and simulated to achieve operating conditions that resulted in an economic payback period of less than 10 years. Cost assumptions used in the model include:

- Electricity $0.08 / kWh
- Standby rate $1.12/kW/month
- Gas rate, base case $8.65 /MMBtu
- Gas rate for CHP cases $7.00 /MMBtu

Capital and installation cost assumptions were based upon the retrofit of existing structures with CHP systems, rather than the costs to incorporate CHP into new construction. Prototype buildings were then modeled in the BCHP software to generate the requisite load and unit profiles for each operating scenario and for a non-CHP baseline.

2.4 NOx Emissions Impact

The outputs for the baseline and CHP scenarios were then used to estimate a range of NOx emissions likely to arise through implementation of CHP systems in each prototypical building type. NOx impacts arise both on and off-site as follows:

1. On-site NOx Impacts – CHP systems provide some or all of a facility's thermal energy needs, thereby reducing the need to operate conventional boiler systems. As a result, on-site boilers are used much less frequently and NOx emissions are reduced or eliminated. In addition, the combustion of natural gas to operate the CHP system increases NOx emissions. With CHP adoption, NOx emissions at the facility site will increase.
2. Off-site NOx Impacts – CHP systems provide some or all of a facility's electrical energy needs. In addition, some electrical loads can be shifted from electrical service to thermal service, further reducing total consumption of electricity. As a result, the amount of electricity sourced from the power grid is reduced. CHP systems produce less NOx than central station generators because:
    - CHP systems are required to meet a more stringent NOx emission limit of 0.14 lbs/MWh, which is far less than the 1.07 lbs/MWh created by central station generators serving the Texas grid.[11]
    - CHP systems do not create any transmission and distribution losses. These losses, which can amount to 7-10% of total electricity produced at a central station generating facility, increase the amount of fuel that must be burnt to produce the same amount of electricity at the end-user's site.

[11] NOx emissions produced by the Texas electrical grid are based on the "2007 Annual eGRID (25%)" and "2007 OSD eGRID (25%)" databases using protocols consistent with those of the Texas Commission on Environmental Quality (TCEQ) and EPA.

To assess the NOx emissions impacts of potential CHP applications within the HGB commercial and institutional building sector, the base case (non-CHP) was modeled in BCHP for each prototypical building type and compared to the corresponding CHP cases. The BCHP model output includes calculations of the on-site NOx emissions and the amount of electricity supplied by the utility grid. On-site emissions were calculated based on each building cluster's general building characteristics and energy demands while the off-site NOx emissions were estimated from eGRID. The assumptions used to calculate the NOx impacts are summarized in Table 2-2.

Table 2-2: NOx Emissions Assumptions

Source	NOx Production	Unit
Commercial Boilers[a]	0.074	lbs per MMBtu
Reciprocating Engine Generator (< 2 MW)[b]	0.14	lbs per MWh
Microturbine[c]	0.036	lbs per MMBtu
Combustion Turbine (< 10 MW)[c]	0.167	lbs per MMBtu
Combustion Turbine (> 10 MW)[c]	0.099	lbs per MMBtu
Reciprocating Engine Generator (> 3MW)[c]	0.039	lbs per MMBtu
ERCOT Grid Electricity[d]	1.07	lbs per MWh

Notes:

a) EPA report #AP-42 which assumes 50% of boilers are uncontrolled and 50% are controlled
b) Assumes NOx controls are implemented to meet current HGB standard permit level, including value of thermal energy captured.
c) EPA CHP Emissions Calculator v1.1
d) EPA eGRID for ERCOT (2007)

In calculating off-site NOx emissions from utility generated electricity, a 7% factor is used to account for transmission and distribution losses. NOx impacts were calculated with respect to ERCOT-only utilities in the eight county HGB region. Generally, NOx production rate assumptions for prime movers used in commercial CHP systems were derived from the default values provided in the EPA CHP Emissions Calculator tool and those provided in the BCHP model, although CHP systems were forced to meet an emissions level of 0.14 lbs/MWh established in the standard permit. To establish the regional NOx impact, the total NOx emissions change for each building prototype and CHP case were multiplied by the actual number of existing buildings corresponding to the specific prototype.

2.4.1 CHP Operating Strategies

While CHP systems provide a number of benefits to host facilities, including for example improved power reliability, the decision to adopt CHP is most often based upon purely economic considerations. Acceptable payback periods ranging between 3-10 years are common, although institutional building owners are thought to have the longest time horizon. As a result of the short payback periods, the CHP design and operating strategy most likely to be implemented in commercial and institutional buildings is "Case 3:

Optimal Thermal Utilization." This is because Case 3 is designed to obtain maximum work from the input fuel, it results in a faster payback than either the "Case 1: Maximum Electrical Demand" or "Case 2: Maximum Thermal Demand."

Because the CHP system is designed to serve the building's thermal loads, Case 3 operation results in a relatively smaller system compared to Cases 1 and 2. The impact of this is that Case 3 CHP systems offset far less grid electricity. Because the bulk of the NOx savings from CHP is achieved by offsetting grid electricity, the net effect is that much less NOx savings is achievable using the Case 3 strategy. In fact, empirical data shows that Case 3 provides a reasonable and consistent lower bound of NOx savings from CHP.

Case 1 operation is desirable for some organizations like hospitals that are highly motivated to secure reliable electricity supplies. Because the generator is sized to meet the peak electrical load, Case 1 design and operation provides backup power to the whole facility in case of a general grid outage. Due to the relatively large prime mover used in the CHP system, Case I operation tends to result in the greatest aggregate NOx reductions at the regional level. For the same reason, it also leads to greater on-site NOx emissions as compared to the base non-CHP case. The goal was to approximate a NOx savings number that is closer to an upper bound. Empirical data shows that Case 1 provides a reasonable and consistent upper bound of NOx savings achievable with CHP.

Table 2-3: Potential NOx Emission Impacts from CHP – Existing Sites HGB Region

Commercial Sector	On-site NOx Change (tons/day)	Off-site NOx Change (tons/day)	Total NOx Change (tons/day)
Case 1: Maximum Electrical Load	0.8	-10.1	-9.4
Case 3: Optimal Thermal Utilization	0.0	-2.9	-2.9

The overall NOx impact from CHP in the commercial and institution building sector was determined by multiplying the modeled NOx results for each of the prototypical building types by the estimated number of buildings in the region. The summary data is shown in Table 2-3, where Cases 1 and 3 provide the upper and lower bounds of NOx impacts. As an intermediate case, the Case 2: Maximum Thermal Utilization is not considered in the final analysis.

Widespread implementation of CHP into the five commercial and institutional building sectors is estimated to result in an overall NOx reduction in HGB of between 2.9 - 9.4 tons per day. A reduction in NOx production by wholesale electricity generators affecting the HGB region is found to dramatically offset a small increase in NOx at the sites where CHP is developed. Given the high potential for CHP development using the optimal thermal utilization strategy, the 2.9 tons per day NOx reductions estimated for Case 3 is likely to provide a conservative, but realistic estimate of NOx emissions benefits within HGB in the commercial sector.

2.4.2 Prototypical Building Types

The study identified a technical potential of between 274 MW to 1317 MW of CHP system development in commercial and institutional buildings in HGB. However, the optimal thermal energy utilization (Case 3) likely offers the best strategy to promote CHP into commercial and institutional buildings. This would imply the more realistic technical potential for CHP and the resulting NOx savings are closer to the lower numbers associated with Case 3. Table 2-4 shows the CHP potential by prototypical building type for the Case 3 scenario. Office buildings and office towers were found to provide over 60% of the total opportunity and about 40% of the NOx savings. While office buildings are not considered among the best site hosts for CHP, the large number of existing office buildings in HGB drive the large impact. Technical developments, financing, and policies that facilitate the implementation of CHP systems into commercial office buildings could be an important aid to expand the NOx benefits achievable in the commercial sector.

Table 2-4: Commercial and Institutional Sector for HGB Region (2007) Case 3: Optimal Thermal

Category	CHP Potential (MW)	On-site NOx Change (tons/day)	Off-site NOX Change (tons/day)	Total NOx Change (tons/day)
Office Buildings	173	0.0	-1.2	-1.2
Retail Buildings	37	0.0	-0.3	-0.3
Hotels & Apartments	25	0.1	-0.5	-0.5
Healthcare	24	0.0	-0.5	-0.5
School Buildings	16	0.0	-0.3	-0.3
Total	**274**	**0.0**	**-2.9**	**-2.9**

2.4.3 Peak Ozone Season Impacts

Due to summer air conditioning requirements, commercial and institutional buildings are anticipated to have strong summer electrical peak loads. Implementation of CHP systems can reduce summer electrical loads by shifting some existing electrical chiller loads to a thermally-driven absorption chiller. On-site electricity generation also reduces the need for wholesale electricity generators to operate inefficient (i.e., high NOx output) summer peaking units to serve these needs. Thus, NOx savings are anticipated to be greater during the peak ozone season.[12] Table 2-5 shows that emissions reductions during the peak ozone season are expected to be 40-80% more than average annual NOx emission reductions.

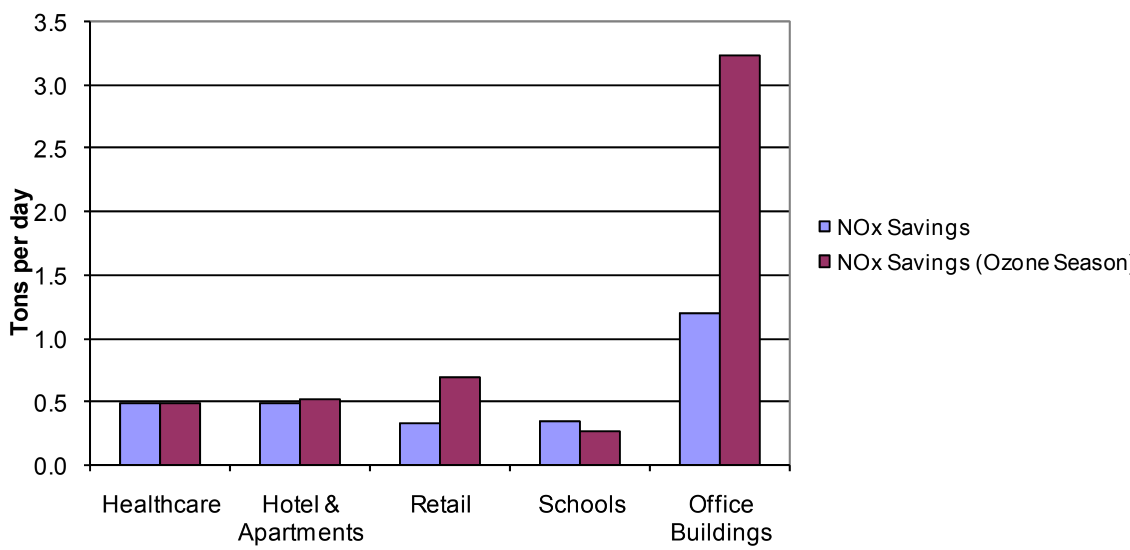
[12] TCEQ defines the ozone season as the period from March through September. In this report, we are focusing on the peak ozone season, which is a two-month subset of the ozone season running from July 15 to September 15.

Table 2-5: Potential NOx Emission Impacts from CHP – Existing Sites HGB Region

Commercial Sector	Total NOx Change Avg. Annual (tons/day)	Total NOx Change Peak Ozone Season (tons/day)
Case 1: Maximum Electrical Load	-9.4	-13.4
Case 3: Optimal Thermal Utilization	-2.9	-5.2

A comparison of NOx emissions reductions is provided in Figure 2-1, which breaks down the data by prototypical building type and by season. Again, office buildings are noted to offer the most substantial opportunities for NOx reductions through CHP implementation. By 2020, economic and population growth in HGB is anticipated to create additional CHP opportunities in the commercial sector, which could result in even greater NOx reductions.

Figure 2-1: NOx Emissions Savings from the CHP Prototype Categories (Case 3)



3.0 Industrial Facilities

Texas has a long and successful history implementing CHP in the state's industrial sector and is today considered to be the CHP capital of the United States. In 2005, CHP projects generated over 21% of the electricity used in the state, compared with a little over 8% nationally.[13] Today, an estimated 16,000 MW or about 20% of the total generating capacity of ERCOT comes from CHP. Of that capacity, over 98% is located at industrial locations like petroleum refineries and chemical plants, many of which are located in the greater Houston-Galveston-Brazoria (HBG) area.

Industrials are prime locations for CHP for a number of reasons. Most industrials require both electrical and thermal energy, so they are natural candidates for CHP. In addition, many operations meet the operating conditions, which are conducive to successful CHP development:

- Coincident electrical and thermal loads
- Continuous operation (24 hour x 365 days)
- Low seasonal variation in loads
- High power reliability needs

The large scale of many industrial operations helps to mitigate project development and engineering costs and supports sophisticated strategies for fuel procurement and risk management. Cost driven industrials have often found that CHP provides an economic value proposition sufficient to warrant investment in these systems.

3.1 Analytical Methodology

To estimate the potential emissions impact from widespread implementation of CHP in the industrial sector in the HGB region, emissions rates from various CHP options must be compared against the standard solution of separately obtaining electricity from the power grid and thermal energy (steam) from burning gas supplied from a natural gas pipeline. To accomplish this comparison, the following methodology was used.

- <u>CHP Technical Potential</u>

  The first step in the assessment is to establish the technical potential for CHP in the industrial sector of HGB. This is accomplished by using estimates already available in the published literature. A detailed, statewide study of the technical potential for CHP in Texas industrial facilities was recently completed (Elliott 2007) and these results are used herein. The technical potential provides a measure of the total electrical capacity expected from all CHP projects that could reasonably be anticipated to serve a market need. While no explicit economic

[13] Elliott, R. Neal, Maggie Eldridge, Anna M. Shipley, John "Skip" Laitner, Seven Nadel, Alison Silverstein, Bruce Hedman, Mike Sloan, "Potential for Energy Efficiency, Demand Response, and On-site Renewable Energy to Meet Texas's Growing Electricity Needs, American Council for an Energy-Efficient Economy, Report # E073, March 2007 (Elliott 2007)

filter is analytically included in the process of establishing this potential, consideration of factors generally known to be supportive of CHP development are considered. The technical potential results used here provide a breakdown of the data into project size categories. For this study, the statewide technical potential obtained from Elliott 2007 was reduced to estimate the CHP technical potential solely in the HGB industrial sector. The technical potential does not consider any CHP systems already developed and operating.

- Create CHP Prototypes

  Ten prototypical CHP configurations were created to meet the technical potential for project development. The prime mover technology used in each prototype was chosen based upon project size and needs, while operating strategies for the project were selected consistent with standard industry practice and economic drivers. While economic criteria are not explicitly modeled, the implementation and operation of proposed CHP projects is consistent with industry standards for such developments. NOx emissions produced by the prototypes were determined by modeling six representative projects using the EPA CHP Emission Calculator[14] v1.1 and extending the results to all ten prototypes by using an appropriate multiplier. The results produced by the Emission Calculator are provided in Appendix B.

- Characterize Potential CHP Projects

  The performance of the ten industrial CHP prototypes were modeled using detailed assumptions of operating hours, thermal energy utilization, and capacity factors. The model inputs and results for each of the six projects are provided in Appendix B.

A detailed description of the methodology and results is provided below.

3.2 Industrial CHP Potential (HGB Only)

While Texas industry has aggressively adopted CHP, significant potential remains for additional development. A number of recent studies have examined the potential for CHP (Onsite Energy 2000, Elliott 2001, Elliott 2007). In the oldest study completed in 2000, Onsite Energy projected the potential at over 20,000 MW, with about two-thirds of that potential (13,400 MW) existing in industry. Even with over 14 GW of capacity already implemented in the chemical and petroleum industries (SIC 28 & 29), CHP potential in these industries was thought to be about 7,500 MW or 56% of the remaining potential.

[14] The Combined Heat and Power (CHP) Emissions Calculator compares the anticipated emissions from a CHP system to the emissions from systems using separate heat and power (SHP). While the results generated by the CHP Emissions Calculator are not designed for use in developing emission inventories or preparing air permit applications, the emissions results are thought to provide sufficient accuracy for this report. At the time of the analysis, the EPA had issued an updated version of the eGRID database, which was not yet reflected in the current version of the Calculator. As a result, the NOx emissions values used to determine the amount of NOx saved by off-setting electricity that would otherwise be supplied from the utility grid were reduced from 2.31 lbs per MWh to 1.07 lbs per MWh.

The industrial technical potential estimate provided in the Onsite Energy report was broken out by project size as shown in Table 3-1 (Elliott 2001).

Table 3-1: Industrial Technical Potential by Project Size (Statewide)

Size	Potential (MW)
100 kW – 1 MW	2,050
1 – 5 MW	3,250
5 – 20 MW	1,800
> 20 MW	6,300
Total	13,400

Source: Elliott (2001)

The technical potential for CHP was recently updated (Elliott 2007). The work included an analysis of a wide range of industrial activities common in Texas.[15] The technical potential was updated by Energy and Environmental Analysis, Inc. (EEA) to include an assessment of the potential for thermally active cooling within CHP systems. With thermally activated cooling technologies such as absorption refrigeration, power and cooling are both produced by the CHP system. This application has the benefit of producing electricity to satisfy onsite power requirements while displacing electrically generated cooling during periods of peak demand. The basic approach used by EEA to update the technical potential was to:

- Identify applications where CHP provides a reasonable fit to the electric and thermal needs of the user
- Quantify the number and size distribution of target applications
- Estimate CHP potential in terms of MW capacity
- Estimate the growth of new facilities in the target market sectors.

In this study, the Texas-wide technical potential for CHP in the industrial sector was estimated at 4,962 MW, as shown in Table 3-2. This value is substantially lower than earlier Onsite Energy estimate and represents acknowledgement of a recent slowdown in the installation of CHP, which appears to be related to the volatility of natural gas prices in recent years. This situation was thought to be further complicated by uncertainty in the long-term viability of some domestic manufacturing facilities, which could lead some manufacturers to question whether a commitment to long-lived assets such as a CHP facility is warranted. The Texas-wide technical potential as presented in Elliott 2007 is shown in Table 3-2. To arrive at an industrial CHP technical potential figure specific to HGB, a factor derived from county level industrial employment and total wage data was

[15] Elliott, et.al included the following industries in their technical potential study: SIC 20 Food, 22 Textiles, 24 Lumber and wood, 25 Furniture, 26 Paper, 27 Printing/Publishing, 28 Chemicals, 29 Petroleum Refining, 30 Rubber/Misc Plastics, 32 Stone/Clay/Glass, 33 Primary Metals, 34 Fabricated Metals, 35 Machinery/Computer Equipment, 37 Transportation Equipment, 38 Instruments, and 39 Misc Manufacturing.

used to reduce Texas-wide CHP potential numbers.[16] Using this technique, the technical potential for additional CHP development in the HGB region is estimated at 1.178 GW.

Table 3-2: Current CHP Potential – Texas Industrial Sector

	Potential CHP Projects	Gross Capacity (MW)	Avg. Project Size (MW)
50-500 kW	2727	267	0.1
500-1 MW	686	347	0.5
1-5 MW	490	953	1.9
5-20 MW	53	553	10.4
>20 MW	29	2842	98.0
Total	3985	4962	

Source: Adapted from Elliott 2007

Table 3-3: Current CHP Potential – HGB Industrial Sector

	Potential CHP Projects	Gross Capacity (MW)	Avg. Project Size (MW)
50-500 kW	648	63	0.1
500-1 MW	163	82	0.5
1-5 MW	116	226	1.9
5-20 MW	13	131	10.4
>20 MW	7	675	98.0
Total	946	1178	

3.3 CHP Applications and System Characterization

The industrial CHP technical potential in HGB is broken out by size category and number of potential sites as shown in Table 3-3. This information is sufficient to calculate the average size of a CHP facility in each category. The average facility size is used to create the prototype CHP projects used for further analysis. For example, the prototype system chosen to model the 50-500 kW category is a CHP system sized at 100 kW (0.1 MW) of electrical capacity (MW). The prototype system size established for each category is presented in Table 3-4.

[16] The factor used to convert Texas-wide CHP potential numbers to HGB regional numbers is 23.75%, which is an average of industrial employment and total wages obtained from the U.S. Census Bureau (2002 Economic Census) and Woods & Poole Economics (2006).

Table 3-4: Ten CHP Prototypes and Frequency (by Prime Move Size)

Prototype Capacity	Microturbine	Recip Engine (rich burn)	GT* (no duct burner)	GT (duct burner)
0.1 MW	100%	-	-	-
0.5 MW	50%	50%	-	-
2.0 MW	-	50%	50%	-
10.0 MW	-	10%	40%	50%
100 MW	-	-	50%	50%

* GT = Gas Turbine

Each CHP prototype must have an associated prime mover technology and operating strategy to allow effective emissions modeling. Prime mover technologies used for CHP prototypes include microturbines, reciprocating engines, and gas turbines, with and without duct burners. Table 3-4 shows the frequency with which the various prime movers are anticipated to occur for each size of prototype.

This breakout of the CHP potential by prime mover and size creates ten unique prototype systems. Based upon the technical potential in HGB (Table 3-3) and the frequency of each prototypical project (Table 3-4), the estimated number of projects anticipated for each of the ten prototypes and the total electrical capacity can be calculated. The results, which are presented in Table 3-5, show that in 2007, an estimated 946 projects could be developed in the HGB industrial sector with a combined capacity of some 1,298 MW.

3.4 System Performance and Potential NOx Savings

In order to determine the NOx emission impacts from each of the ten prototypes, six CHP templates were developed to reflect the range of prime mover technologies employed in the ten prototype projects. The six templates include:

- 250 kW microturbine
- 750 kW rich burn reciprocating engine
- 3 MW rich burn reciprocating engine
- 3 MW gas turbine
- 10 MW gas turbine without duct burners
- 20 MW gas turbine with duct burners

In order to model the NOx emission impacts, information such as equipment configurations, performance assumptions, and operating strategies was needed for each template: in particular, required fuel type, the number of generating units, operating hours, heat rate, the use of duct burners, and the type of absorption chiller used in the project, if any. Templates were developed to align with practices and strategies commonly applicable for typical industrial CHP facilities. Generally, CHP systems with electrical capacity of less than 5 MW were assumed to operate only 5840 hours per year, while those greater than 5 MW were assumed to operate year round. All of the industrial prototypes were assumed to have year round cooling and heating loads, with both available simultaneously.

Table 3-5: Industrial CHP Prototype Projects

Technology	Unit Capacity (MW)	Potential Projects	Potential Capacity (MW)
Microturbine	0.1	647	64.7
Microturbine	0.5	82	41.0
Recip. Engine (rich burn)	0.5	81	40.5
Recip. Engine (rich burn)	2	58	116.0
Gas Turbine (no duct burner)	2	58	116.0
Recip. Engine (rich burn)	10	1	10.0
Gas Turbine (no duct burner)	10	5	50.0
Gas Turbine (duct burner)	10	6	60.0
Gas Turbine (no duct burner)	100	4	400.0
Gas Turbine (duct burner)	100	4	400.0
Total		**946**	**1,298**

Template information was input into the EPA CHP Emission Calculator. This tool calculates fuel consumption, duct burner fuel consumption, total fuel consumption, total CHP electricity generated, and the amount of useful thermal energy obtained from the system. The calculator compares that to a baseline system configured to purchase electricity from the Texas electrical grid and natural gas from the local natural gas distribution company to produce steam in a conventional boiler.

Detailed system performance and potential NOx emission impacts were calculated for each of the ten prototypes by adjusting the model output as appropriate. The Emissions Calculator tool defaults input settings for engine and chiller performance parameters were utilized. The Emissions Calculator estimates on-site NOx changes due to changes in boiler usage and due to operation of the prime mover used in the CHP system. It also estimates NOx changes due to changes in the consumption of grid-supplied electricity. Detailed assumptions and information used to model the industrial CHP templates is provided in Appendix B.

NOx savings produced by offsetting power from the electrical grid are calculated with the EPA's eGRID tool.[17] Generally, NOx production rate assumptions for CHP systems were adapted from the default values provided in the EPA CHP Emissions Calculator tool. However, as the most recent version of the Emissions Calculator had not been updated to include the latest eGRID information, the ERCOT NOx emissions information was manually updated in this study to reflect the latest eGRID information pertaining to ERCOT-only utilities operating in the eight county HGB region. Note also that a 7%

[17] NOx emissions produced by the Texas electrical grid are based on the "2007 Annual eGRID (25%)" and "2007 OSD eGRID (25%)" databases using protocols consistent with those of the TCEQ and EPA.

transmission/distribution loss is also considered. The NOx emissions are calculated for each prototype case and compared to the corresponding base case.

Table 3-6: NOx Emissions Assumptions

Source	NOx Production	Unit
Commercial Boilers[a]	0.074	lbs per MMBtu
Industrial Boiler/Duct Burners[b]	0.1	lbs per MMBtu
Reciprocating Engine Generator (< 2 MW)[c]	0.14	lbs per MWh
Microturbine[b]	0.036	lbs per MMBtu
Combustion Turbine (< 10 MW)[b]	0.167	lbs per MMBtu
Combustion Turbine (> 10 MW)[b]	0.099	lbs per MMBtu
Reciprocating Engine Generator (> 3MW)[b]	0.039	lbs per MMBtu
ERCOT Grid Electricity[d]	1.07	lbs per MWh

Notes:

a) EPA report #AP-42 which assumes 50% of boilers are uncontrolled and 50% are controlled
b) EPA CHP Emissions Calculator v1.1
c) Assumes NOx controls are implemented to meet current HGB standard permit level, including value of thermal energy captured.
d) EPA eGRID for ERCOT (2007)

3.5 NOx Emissions Impacts of Industrial CHP

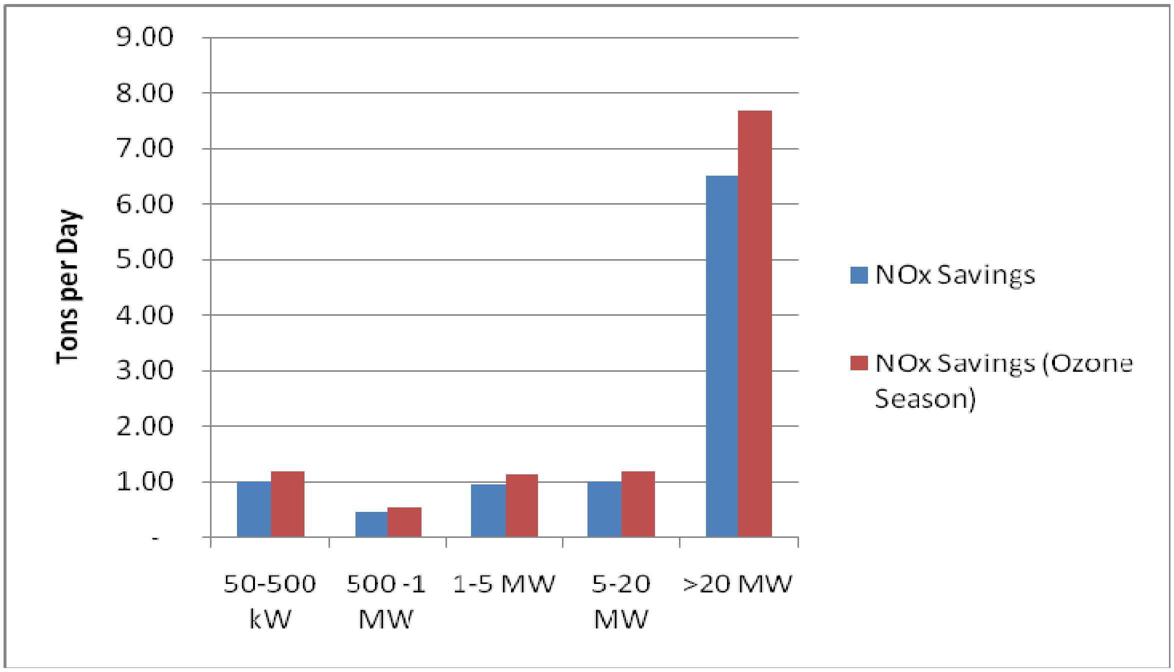
NOx emissions results estimated for the ten industrial CHP prototype configurations are presented in Table 3-7. The table compares NOx produced by the CHP system to that offset from reduced natural gas use in the onsite boiler and reduced consumption of grid supplied electricity. The analysis indicates that widespread implementation of CHP in the HGB industrial sector could decrease NOx by about 3,641 tons per year or about 10 tons per day. During the 62 day peak ozone season, NOx emissions will be reduced by an estimated 728 tons or about 11.7 tons per day. By 2020, economic and population growth in HGB is anticipated to create additional CHP opportunities in the industrial sector, which could result in even greater NOx reductions.

Table 3-7: Potential Impact of Industrial CHP Projects (Existing Sites)

CHP Prototype	On-site NOx Change (tons/day)	Off-site NOx Change (tons/day)	Total NOx Change Annual Average (tons/day)	Total NOx Change Peak Ozone Season (tons/day)
100 kW Microturbine	0.1	-0.7	-0.6	-0.72
500 kW Microturbine	0.1	-0.4	-0.4	-0.46
500 kW Recip. Engine (rich burn)	-0.0	-0.5	-0.5	-0.56
2 MW Recip. Engine (rich burn)	0.1	-1.4	-1.4	-1.63
2 MW Gas Turbine (no duct burner)	1.8	-1.4	0.4	0.49
10 MW Recip. Engine (rich burn)	0.0	-0.1	-0.1	-0.14
10 MW Gas Turbine (no duct burner)	0.5	-0.9	-0.4	-0.46
10 MW Gas Turbine (duct burner)	0.7	-1.2	-0.5	-0.59
100 MW Gas Turbine (no duct burner)	4.1	-7.2	-3.2	-3.71
100 MW Gas Turbine (duct burner)	4.6	-7.9	-3.4	-3.96
	11.8	**-21.8**	**-10.0**	**-11.74**

NOx emission impacts are proportional to the technical potential for CHP implementation in each project size category. While a large number of small projects are potentially possible, the total project capacity is about one-third of that at the largest facilities. This data is graphically presented in Figure 3-1, which shows that about 60% of the total NOx savings achievable in the industrial sector is created through the development of large CHP projects.

Figure 3-1: NOx Savings by Project Size – HGB Industrial Sector (Existing Sites)



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4.0 Results and Discussion

As shown in Table 4-1, the technical potential for additional CHP systems in HGB is large. In the commercial sector, potential exists today to develop CHP systems at about 2,944 facilities, which could amount to between 274 to 1,317 MW of electrical capacity. In the industrial sector, an estimated 946 additional CHP projects are technically possible, which could generate electrical capacity in excess of about 1,300 MW. In total, an estimated 1,600 – 2,600 MW of CHP capacity is possible at nearly 3,900 sites.

Table 4-1: CHP Potential in HGB

Sector	Number of Facilities	Capacity (MW)
Commercial	2,944	274 – 1,317
Industrial	946	1,298
Total	3,890	1,572 - 2,615

Note: Electrical capacity range for commercial CHP depends upon Case 1 or Case 3 operation.

Widespread CHP implementation of the magnitude suggested in Table 4-2 would likely produce a dramatic overall reduction in NOx emissions. Conservative estimates put the savings at between 2.9 to 9.4 tons per day from the commercial sector and about 10.0 tons per day from the industrial sector. Taken together, the total potential NOx impact from commercial and industrial CHP implementation is estimated to be between 12.9 and 19.4 tons per day, depending on operating strategy adopted in the commercial sector.

However, because the majority of CHP systems implemented in the commercial sector are anticipated to use small systems using an Optimal Thermal Utilization (Case 3) strategy, total NOx savings achievable in the commercial sector are most likely to be in the range of 3 to 5 tons per day. Consequently, the total potential for NOx savings from widespread adoption of CHP in HGB is estimated to be in the rage of 13 – 15 tons per day. Potential NOx savings during the peak ozone season are expected to amount to between 17-21 tons per day. By 2020, economic and population growth in HGB is anticipated to create additional CHP opportunities across the region, which could result in even greater NOx reductions.

Table 4-2: Potential NOx Emission Reductions

Likely NOx Impacts	Annual Average (tons/day)	Peak Ozone Season (tons/day)
Commercial	2.9 – 4.9	5 - 9
Industrial	10.0	11.7
Total HGB	12.9 – 14.9	17 - 21

4.1 Geographic Implications

Even though widespread CHP implementation across HGB would produce a substantial net reduction in NOx emissions, implementation of CHP system at commercial and industrial facilities in HGB would relocate the source of some of those emissions from outside of HGB to within the eight county region. Table 4.3 summarizes the anticipated on-site and off-site NOx changes.

Table 4-3: Potential NOx Emission Impacts from CHP – Existing Sites HGB Region

Commercial and Industrial Sectors	On-site NOx Change from CHP and Boiler Offset (tons/day)	Off-site NOx Change from Displaced Grid Electricity (tons/day)	On & Off Site Total Change in NOx Emissions (tons/day)
Commercial (Case 3 Impacts)	0.0	-2.9	-2.9
Industrial	11.8	-21.8	-10.0
Total HGB	11.8	-24.7	-12.9

Development of the full 1,300 MW of CHP potential in the industrial sector is anticipated to increase NOx emissions inside HGB by about 11.8 tons per day, while NOx emissions from power plants serving the electricity grid would reduce NOx emissions by about 21.8 tons per day. Considering full development of the commercial potential (274 MW) assuming use of the Optimal Thermal Utilization (Case 3) strategy, a net reduction of 2.9 tons per day is anticipated.

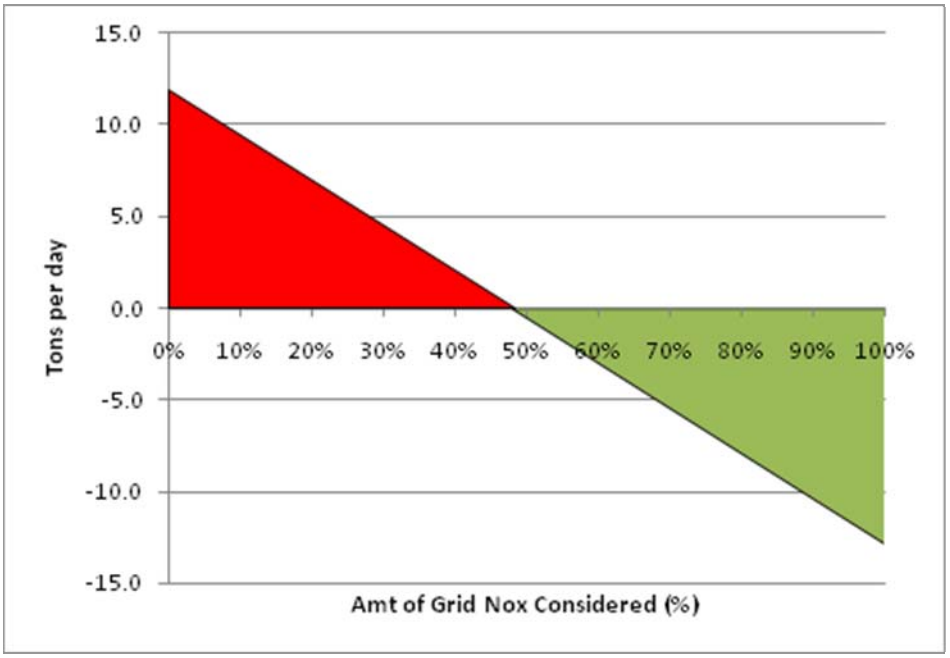
The NOx impact of CHP development within HGB is highly dependent on the location and impact of NOx emissions being produced by electric utility generators. The EPA's eGRID database, used in this study, attempts to estimate NOx impacts within the HGB region from each utility power plant located in ERCOT. However, to fully assess the impact of CHP on ozone concentrations in HGB, we would have to know which utility power plants operated at reduced output as a result of new CHP capacity. This would require knowledge of power plant dispatch tactics within ERCOT and the NOx emission profile for each plant. With the addition of NOx plume and dispersion modeling, this information could be used to generate detailed NOx concentration profiles for use in photochemical modeling of the region.

To the extent that NOx emissions from electric utility generators are created outside of the eight-county region, CHP implementation could increase NOx concentrations within the region. However, if the power plants operating at reduced output due to CHP implementation are located within the HGB air shed, their NOx emissions could have an impact on NOx concentrations.

Figure 4-1 illustrates the potential NOx impact in HGB due to the geographic location of emissions. If NOx reductions arising at electric utility generators are not considered in the analysis, widespread adoption of CHP in HGB may increase NOx by an anticipated 11.8 tons per day. However, if all of the NOx emission reductions occurring at utility power plants do impact HGB, then CHP implementation may decrease NOx by an estimated

12.9 tons per day. As seen in the graph, CHP becomes a net NOx reducing technology if about 50% of the utility NOx reductions actually occur within the HGB air shed.

Figure 4-1: Impact of Utility NOx Emissions



4.2 Further Needs and Recommendations

Recently, NOx emission reductions from energy efficiency and renewable energy were estimated by the Energy Systems Laboratory (ESL) at Texas A&M to be 5.05 tons/day in 2009.[18] While these estimates did not include the deployment of CHP in the Houston area, the methodology used by ESL for calculating NOx reductions from reductions in grid supplied electricity appear to be appropriate to analyze CHP impacts. Additional studies are warranted to verify the anticipated NOx savings from CHP.

Because widespread adoption of CHP systems, especially at commercial and institutional buildings, could result in various concentrated or distributed patterns across the region, the effects on air quality are likely to vary depending on how such systems are deployed in practice. The potential spatial variations, including the effects of stack heights and mixing layer, especially during the summer ozone season, should be examined further.

The existing NOx cap-and-trade system should be adapted to include energy efficiency and renewable energy NOx impacts. CHP deployment is discouraged by this same

[18] STATEWIDE AIR EMISSIONS CALCULATIONS FROM WIND AND OTHER RENEWABLES SUMMARY REPORT A Report to the Texas Commission on Environmental Quality, For the Period September 2006 – August 2007 Jeff Haberl, Ph.D., P.E.; Zi Liu, Ph.D.; Juan-Carlos Baltazar- Cervantes, Ph.D.; Kris Subbarao, Ph.D.; Don Gilman, P.E.; Charles Culp, Ph.D., P.E.; Bahman Yazdani, P.E.; Dan Turner, Ph.D., P.E. August 2007 ESL-TR-07-08-01. See http://www.tercairquality.org/AQR/Projects/T-01-2006. This link was last accessed on February 14, 2008.

system under the current air quality regulations. In addition, CHP projects are currently restricted from receiving TERP funding promoting NOx reductions, particularly in the HGB non-attainment region. The scientific basis for these restrictions should be further analyzed and quantified.

Potential opportunities to develop CHP in the commercial and institutional building sector are numerous, but the NOx impacts are highly dependent on the CHP operating strategy employed for such systems. Current market dynamics favor the development of small CHP systems designed and operated to serve facility thermal loads (Case 3). While such systems have a potentially beneficial NOx impact, the impact is anticipated to be only about one-third of the possible NOx reductions. Without additional incentives, a purely market based approach would under develop CHP capacity in the commercial market resulting in the realization of substantially lower NOx savings.

This study did not evaluate the impact of CHP development time, which can take one to three years for a single system. Widespread implementation of CHP of a magnitude similar to what is suggested here could conceivably take 10-15 years or longer. Additional study is needed to better quantify and forecast NOx impacts into the future.

4.3 Conclusions

In HGB today, the potential for additional CHP systems in both commercial and industrial sectors is large and growing. In the commercial sector, office buildings represent a large opportunity for CHP, although other building types like hospitals and hotel may be a better fit for CHP. In the industrial sector, large projects over 20 MW represent the best opportunities for NOx reductions, although many smaller projects are possible. Potential NOx savings anticipated from widespread adoption of CHP in existing structures in HGB is estimated to be in the rage of 13 - 15 tons per day.

Implementation of CHP reduces total NOx emissions, but shifts some of those emissions to those facilities adopting its use. Thus, the geographical distribution of NOx emissions is changed through CHP implementation. While total savings are achieved, NOx emissions at facilities adopting CHP is anticipated to increase. For HGB, this could mean that local NOx emissions could increase by about 11.8 tons per day. This study suggests that widespread adoption of CHP would reduce NOx concentrations in HGB if more than half of the NOx savings from decreased use of grid electricity actually lowered NOx concentrations in the eight-county region. Further studies of the NOx savings from CHP and the potential impacts on ozone formation are warranted.

In recent years, commercial real estate owners and developers are increasingly looking at CHP for economic and environmental reasons, and a few CHP projects are currently under construction in HGB. However, the adoption rate for CHP, especially among industrial facilities, has slowed due to volatile natural gas prices and uncertain economic conditions. If additional NOx savings are to be realized from CHP, a number of regulatory and market barriers will need to be addressed and incentive provided to value the NOx benefits.

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Appendix A
Large Hospital CHP Analysis For the Houston Galveston Brazoria (HGB)

General Building Characteristics & Assumptions

Size:	600,960 sq ft 300' x 400 x 5 (width x length x no.of floors)	Base Case -	Non CHP case
Building Characteristics	R-11 Wall R-17 Roof Single pane clear glass	Case I -	Maximum CHP Power to meet < 10 year CHP payback requirement and add absorption chillers to increase NOx savings
Building Loads	3,302 kW Peak electric demand 1,700 tons Peak cooling load 6.9 MMBtu/h Peak space heat and hot water load (includes laundry)	Case II -	Maximum CHP Thermal to meet < 10 year CHP payback requirement to approximate least NOx savings only add absorption if required to meet payback
HVAC Systems	Variable air volume with reheat	Case III -	Optimal CHP Thermal Utilization to meet < 10 year CHP payback requirement absorption for thermal balancing to approximate least NOx savings
Number of Buildings in Region	5		
2020 Projected # of Buildings	7		

Plant Characteristics and Assumptions

Average Per Building	Base Case		CHP Case I		CHP Case II		CHP Case III	
Lead Chillers	2 x 450 ton	Electric	2 x 525 ton	Electric	2 x 450 ton	Electric	2 x 375 ton	Electric
Lag Chillers	1 x 400 ton	Electric	2 x 125 ton	2 stage absorption	1 x 400 ton	Electric	2 x 275 ton	2 stage absorption
Boilers	3 x 105 HP	Boiler	3 x 105 HP	Boiler	3 x 105 HP	Boiler	3 x 105 HP	Boiler
Building Power	3302	Peak Electric kW	3184	Peak Electric kW	3302	Peak Electric kW	2590	Peak Electric kW
	21790	Electric MWh Load	21586	Electric MWh Load	21789	Electric MWh Load	19572	Electric MWh Load
	Cooling/heating always available		Cooling/heating always available		Cooling/heating available always		Cooling/heating always available	
			Generator following electric demand		Generator following thermal demand		Generator following lesser demand	
CHP Power			2 x 1651 kW	Recip engine	2 x 1150 kW	Recip engine	7 x 67 kW	Recip engine
			3302	Gen kW	2300	Gen kW	469	Gen kW
			21586	Gen MWh	5038	Gen MWh	7188	Gen MWh
			8760	Gen Run Hours Available	8760	Gen Run Hours Available	8760	Gen Run Hours Available
			189700	Gen Fuel MMBTU	69261	Gen Fuel MMBTU	89574	Gen Fuel MMBTU
CHP Performance			58%	CHP Efficiency	65%	CHP Efficiency	73%	CHP Efficiency
			100%	Power from CHP	23%	Power from CHP	25%	Power from CHP
			100%	Thermal from CHP	100%	Thermal from CHP	84%	Thermal from CHP
			75%	Power Utilization	25%	Power Utilization	100%	Power Utilization
			35%	Thermal Utilization	37%	Thermal Utilization	86%	Thermal Utilization

Building Energy Variables

	Base Case		CHP Case I		CHP Case II		CHP Case II	
Average Per Building	Annual	Peak Ozone Season	Annual	Peak Ozone Season	Annual	Peak Ozone Season	Annual	Peak Ozone Season
Electric from utility (kWh)	21,790,456	4,369,419	0	0	16,751,461	2,944,076	14,602,614	3,130,297
Gas for boiler (MMBtu)	37,560	5,603	50	0	0	0	9,980	3,284
Gas for generator (MMBtu)	0	0	189,700	37,603	69,267	15,981	89,574	14,648

Building NOx Emissions (tons/year)

Average Per Building								
Site NOx Emissions[2,3]	1.4	0.2	2.2	0.4	0.9	0.2	1.6	0.3
NOx Emissions from Grid Power[1]	12.5	2.5	0.0	0.0	9.6	1.7	8.4	1.8
Net NOx Emissions for HGB[1,2,3,4]	13.9	2.7	2.2	0.4	10.5	1.9	9.8	2.1
NOx Emissions Savings[1,2,3,4]	NA	NA	11.6	2.3	3.4	0.8	4.1	0.6
% Savings	**NA**	**NA**	**84%**	**84%**	**24%**	**30%**	**29%**	**23%**

2007 Regional NOx Emission Summary (tons/year)

Current Regional NOx Production								
Site NOx Emissions[2,3]	6.9	1.0	11.2	2.2	4.6	1.1	7.8	1.6
NOx Emissions from Grid Power[1]	62.4	12.5	0.0	0.0	47.9	8.4	41.8	9.0
Net NOx Emissions for HGB[1,2,3,4]	69.3	13.5	11.2	2.2	52.5	9.5	49.0	10.4
Current Regional NOx Impact								
Site NOx Emissions Impact[2,3]	NA	NA	4.3	1.2	-2.4	0.0	0.8	0.5
NOx Emissions from Grid Power[1]	NA	NA	-62.4	-12.5	-14.4	-4.1	-20.6	-3.5
Net NOx Emissions for HGB Impact[1,2,3,4]	NA	NA	-58.1	-11.3	-16.8	-4.0	-20.4	-3.1

Notes:

1 - Based on 2007 TCEQ E-Grid (25%) NOx Rates for Ercot utilities, Annual and Ozone Season Day, includes 70% Reliant Utility Factor, and 7% transmission loss effect. Peak Ozone Season for HGB from 7/15 - 9/15.

2 - Boiler NOx = 0.074 lbs/MMBtu, average of 0.098 and 0.049 from the AP-42 EPA report, assumption is that currently 50% boilers are uncontrolled and 50% are with controls

3 - Generators meeting NOx permit criteria of 0.14 lbs/mwh (including thermal)

4 - Net NOx of site increase and 2007 eGrid decrease

Appendix A
Medium Hospital CHP Analysis For the Houston Galveston Brazoria (HGB)

General Building Characteristics & Assumptions

Size:	215,346 sq ft 190' x 283 x 4 (width x length x no.of floors)	Base Case -	Non CHP case
Building Characteristics	R-11 Wall R-17 Roof Single pane clear glass	Case I -	Maximum CHP Power to meet < 10 year CHP payback requirement and add absorption chillers to increase NOx savings
Building Loads	1,257 kW Peak electric demand 650 tons Peak cooling load 2.6 MMBtu/h Peak space heat and hot water load	Case II -	Maximum CHP Thermal to meet < 10 year CHP payback requirement to approximate least NOx savings only add absorption if required to meet payback
HVAC Systems	Variable air volume with reheat	Case III -	Optimal CHP Thermal Utilization to meet < 10 year CHP payback requirement absorption for thermal balancing to approximate least NOx savings
Number of Buildings in Region	47		
2020 Projected # of Buildings	61		

Plant Characteristics and Assumptions

Average Per Building	Base Case		CHP Case I		CHP Case II		CHP Case III	
Lead Chillers	1 x 352 ton	Electric	2 x 235 ton	Electric	2 x 220 ton	Electric	1 x 312 ton	Electric
Lag Chillers	2 x 95 ton	Electric	1 x 70 ton	2 stage absorption	1 x 100 ton	2 stage absorption	2 x 115 ton	2 stage absorption
Boilers	3 x 37 HP	Boiler	3 x 37 HP	Boiler	3 x 37 HP	Boiler	3 x 37 HP	Boiler
Building Power	1257	Peak Electric kW	1223	Peak Electric kW	1223	Peak Electric kW	986	Peak Electric kW
	7866	Electric MWh Load	7848	Electric MWh Load	2403	Electric MWh Load	7065	Electric MWh Load
	Cooling/heating always available		Cooling/heating always available		Cooling/heating always available		Cooling/heating always available	
			Generator following electric demand		Generator following thermal demand		Generator following lesser demand	
CHP Power			1 x 817 kW	Recip	2 x 200 kW	Microturbine	3 x 60 kW	Microturbine
			817	Gen kW	400	Gen kW	180	Gen kW
			7179	Gen MWh	1476	Gen MWh	2595	Gen MWh
			8760	Gen Run Hours Available	8760	Gen Run Hours Available	8760	Gen Run Hours Available
			78858	Gen Fuel MMBTU	20858	Gen Fuel MMBTU	32333	Gen Fuel MMBTU
CHP Performance			43%	CHP Efficiency	68%	CHP Efficiency	73%	CHP Efficiency
			91%	Power from CHP	18%	Power from CHP	25%	Power from CHP
			100%	Thermal from CHP	100%	Thermal from CHP	84%	Thermal from CHP
			100%	Power Utilization	40%	Power Utilization	100%	Power Utilization
			31%	Thermal Utilization	40%	Thermal Utilization	86%	Thermal Utilization

Building Energy Variables

	Base Case		CHP Case I		CHP Case II		CHP Case II	
Average Per Building	Annual	Peak Ozone Season	Annual	Peak Ozone Season	Annual	Peak Ozone Season	Annual	Peak Ozone Season
Electric from utility (kWh)	7,865,622	1,589,553	669,239	239,652	6,485,945	1,397,025	5,271,053	1,129,932
Gas for boiler (MMBtu)	11,795	1,714	2	0	39	0	3,134	1,031
Gas for generator (MMBtu)	0	0	78,858	14,187	19,832	3,004	32,333	5,287

Building NOx Emissions (tons/year)

Average Per Building								
Site NOx Emissions[2,3]	0.4	0.1	0.7	0.1	0.3	0.0	0.5	0.1
NOx Emissions from Grid Power[1]	4.5	0.9	0.4	0.1	3.7	0.8	3.0	0.6
Net NOx Emissions for HGB[1,2,3,4]	4.9	1.0	1.1	0.3	4.0	0.8	3.5	0.7
NOx Emissions Savings[1,2,3,4]	NA	NA	3.86	0.71	0.95	0.13	1.45	0.23
% Savings	**NA**	**NA**	**78%**	**73%**	**19%**	**13%**	**29%**	**24%**

2007 Regional NOx Emission Summary (tons/year)

Current Regional NOx Production								
Site NOx Emissions[2,3]	20.5	3.0	32.9	5.9	13.1	2.0	23.0	4.6
NOx Emissions from Grid Power[1]	211.6	42.8	18.0	6.5	174.5	37.6	141.8	30.4
Net NOx Emissions for HGB[1,2,3,4]	232.1	45.7	50.9	12.4	187.6	39.6	163.9	34.9
Current Regional NOx Impact								
Site NOx Emissions Impact[2,3]	NA	NA	12.3	2.9	-7.4	-1.0	2.5	1.7
NOx Emissions from Grid Power[1]	NA	NA	-193.6	-36.3	-37.1	-5.2	-69.8	-12.4
Net NOx Emissions for HGB Impact[1,2,3,4]	NA	NA	-181.3	-33.4	-44.5	-6.2	-68.2	-10.9

Notes:

1 - Based on 2007 TCEQ E-Grid (25%) NOx Rates for Ercot utilities, Annual and Ozone Season Day, includes 70% Reliant Utility Factor, and 7% transmission loss effect. Peak Ozone Season for HGB from 7/15 - 9/15.

2 - Boiler NOx = 0.074 lbs/MMBtu, average of 0.098 and 0.049 from the AP-42 EPA report, assumption is that currently 50% boilers are uncontrolled and 50% are with controls

3 - Generators meeting NOx permit criteria of 0.14 lbs/mwh (including thermal)

4 - Net NOx of site increase and 2007 eGrid decrease

Appendix A
Small Hospital CHP Analysis For the Houston Galveston Brazoria (HGB)

General Building Characteristics & Assumptions

Size:	59,163 sq ft 150 x 200 x 2 (width x length x no.of floors)	Base Case -	Non CHP case
Building Characteristics	R-11 Wall R-17 Roof Single pane clear glass	Case I -	Maximum CHP Power to meet < 10 year CHP payback requirement and add absorption chillers to increase NOx savings
Building Loads	422 kW Peak electric demand 186 tons Peak cooling load 0.71 MMBtu/h Peak space heat and hot water load	Case II -	Maximum CHP Thermal to meet < 10 year CHP payback requirement to approximate least NOx savings only add absorption if required to meet payback
HVAC Systems	Variable air volume with reheat	Case III -	Optimal CHP Thermal Utilization to meet < 10 year CHP payback requirement absorption for thermal balancing to approximate least NOx savings
Number of Buildings in Region	53		
2020 Projected # of Buildings	69		

Plant Characteristics and Assumptions

Average Per Building	Base Case		CHP Case I		CHP Case II		CHP Case III	
Lead Chillers	1 x 100 ton	Electric	3 x 60 ton	2 stage absorption	3 x 60 ton	2 stage absorption	1 x 104 ton	Electric
Lag Chillers	2 x 40 ton	Electric					2 x 38 ton	2 stage absorption
Boilers	3 x 10.5 HP	Boiler	3 x 10.5 HP	Boiler	3 x 10.5 HP	Boiler	3 x 10.5 HP	Boiler
Building Power	422	Peak Electric kW	274	Peak Electric kW	274	Peak Electric kW	331	Peak Electric kW
	2371	Electric MWh Load	1854	Electric MWh Load	1854	Electric MWh Load	2129	Electric MWh Load
	Cooling/heating always available		Cooling/heating always available		Cooling/heating always available		Cooling/heating always available	
			Generator following electric demand		Generator following thermal demand		Generator following lesser demand	
CHP Power			1 x 220 kW	Microturbine	2 x 95 kW	Microturbine	1x60	Microturbine
			220	Gen kW	190	Gen kW	60	Gen kW
			1747	Gen MWh	927	Gen MWh	541	Gen MWh
			8760	Gen Run Hours Available	8760	Gen Run Hours Available	8760	Gen Run Hours Available
			22482	Gen Fuel MMBTU	12819	Gen Fuel MMBTU	6738	Gen Fuel MMBTU
CHP Performance			55%	CHP Efficiency	75%	CHP Efficiency	73%	CHP Efficiency
			94%	Power from CHP	50%	Power from CHP	25%	Power from CHP
			100%	Thermal from CHP	100%	Thermal from CHP	84%	Thermal from CHP
			91%	Power Utilization	56%	Power Utilization	100%	Power Utilization
			53%	Thermal Utilization	56%	Thermal Utilization	86%	Thermal Utilization

Building Energy Variables

	Base Case		CHP Case I		CHP Case II		CHP Case III	
Average Per Building	Annual	Peak Ozone Season	Annual	Peak Ozone Season	Annual	Peak Ozone Season	Annual	Peak Ozone Season
Electric from utility (kWh)	2,370,813	503,496	106,951	46,116	926,387	148,365	1,588,772	340,578
Gas for boiler (MMBtu)	3,199	456	1	1	17	11	850	280
Gas for generator (MMBtu)	0	0	22,482	3,972	12,819	2,832	6,738	1,102

Building NOx Emissions (tons/year)

Average Per Building								
Site NOx Emissions[2,3]	0.1	0.0	0.3	0.0	0.2	0.0	0.1	0.03
NOx Emissions from Grid Power[1]	1.4	0.3	0.1	0.0	0.5	0.1	0.9	0.2
Net NOx Emissions for HGB[1,2,3,4]	1.5	0.3	0.3	0.1	0.7	0.1	1.0	0.2
NOx Emissions Savings[1,2,3,4]	NA	NA	1.2	0.2	0.7	0.2	0.4	0.1
% Savings	NA	NA	**79%**	**77%**	**51%**	**58%**	**29%**	**27%**

2007 Regional NOx Emission Summary (tons/year)

Current Regional NOx Production								
Site NOx Emissions[2,3]	6.3	0.9	13.5	2.4	10.5	2.3	7.0	1.4
NOx Emissions from Grid Power[1]	71.9	15.3	3.2	1.4	28.1	4.5	48.2	10.3
Net NOx Emissions for HGB[1,2,3,4]	78.2	16.2	16.7	3.8	38.6	6.8	55.2	11.8
Current Regional NOx Impact								
Site NOx Emissions Impact[2,3]	NA	NA	7.2	1.5	4.2	1.4	0.8	0.5
NOx Emissions from Grid Power[1]	NA	NA	-68.7	-13.9	-43.8	-10.8	-23.7	-4.9
Net NOx Emissions for HGB Impact[1,2,3,4]	NA	NA	-61.5	-12.4	-39.6	-9.3	-23.0	-4.4

Notes:

1 - Based on 2007 TCEQ E-Grid (25%) NOx Rates for Ercot utilities, Annual and Ozone Season Day, includes 70% Reliant Utility Factor, and 7% transmission loss effect. Peak Ozone Season for HGB from 7/15 - 9/15.
2 - Boiler NOx = 0.074 lbs/MMBtu, average of 0.098 and 0.049 from the AP-42 EPA report, assumption is that currently 50% boilers are uncontrolled and 50% are with controls
3 - Generators meeting NOx permit criteria of 0.14 lbs/mwh (including thermal)
4 - Net NOx of site increase and 2007 eGrid decrease

Appendix A

Large Nursing Home CHP Analysis For the Houston Galveston Brazoria (HGB)

General Building Characteristics & Assumptions

Size:	147,936 sq ft 224 x 220 x 3 (width x length x no.of floors)	Base Case -	Non CHP case
Building Characteristics	R-11 Wall R-17 Roof Single pane clear glass	Case I -	Maximum CHP Power to meet < 10 year CHP payback requirement and add absorption chillers to increase NOx savings
Building Loads	719 kW Peak electric demand, 488 kW with double-effect absorption chillers 375 tons Peak cooling load 1.97 MMBtu/h Peak space heat and hot water load	Case II -	Maximum CHP Thermal to meet < 10 year CHP payback requirement to approximate least NOx savings only add absorption if required to meet payback
HVAC Systems	Variable air volume with reheat	Case III -	Optimal CHP Thermal Utilization to meet < 10 year CHP payback requirement absorption for thermal balancing to approximate least NOx savings
Number of Buildings in Region	9		
2020 Projected # of Buildings	12		

Plant Characteristics and Assumptions

Average Per Building	Base Case		CHP Case I		CHP Case II		CHP Case III	
Lead Chillers	1 x 180 ton	Electric	3 x 124 ton	2 stage absorption	1 x 180 ton	Electric	1 x 214 ton	Electric
Lag Chillers	2 x 95 ton	Electric			2 x 95 ton	Electric	2 x 78 ton	2 stage absorption
Boilers	1 x 50 HP	Boiler	1 x 50 HP	Boiler	1 x 50 HP	Boiler	1 x 50 HP	Boiler
Building Power	719	Peak Electric kW	488	Peak Electric kW	739	Peak Electric kW	564	Peak Electric kW
	3296	Electric MWh Load	2746	Electric MWh Load	3316	Electric MWh Load	2961	Electric MWh Load
	Cooling/heating always available		Cooling/heating always available		Cooling/heating always available		Cooling/heating always available	
			Generator following electrical demand		Generator following thermal demand		Generator following lesser demand	
CHP Power			4 x 95 kW	Microturbine	4 x 60 kW	Microturbine	2 x 51 kW	Microturbine
			380	Gen kW	240	Gen kW	102	Gen kW
			2628	Gen MWh	766	Gen MWh	1087	Gen MWh
			8760	Gen Run Hours Available	8760	Gen Run Hours Available	8760	Gen Run Hours Available
			33946	Gen Fuel MMBTU	10427	Gen Fuel MMBTU	13549	Gen Fuel MMBTU
CHP Performance			63%	CHP Efficiency	76%	CHP Efficiency	73%	CHP Efficiency
			96%	Power from CHP	23%	Power from CHP	25%	Power from CHP
			100%	Thermal from CHP	100%	Thermal from CHP	84%	Thermal from CHP
			79%	Power Utilization	36%	Power Utilization	100%	Power Utilization
			54%	Thermal Utilization	37%	Thermal Utilization	86%	Thermal Utilization

Building Energy Variables

	Base Case		CHP Case I		CHP Case II		CHP Case III	
Average Per Building	Annual	Peak Ozone Season	Annual	Peak Ozone Season	Annual	Peak Ozone Season	Annual	Peak Ozone Season
Electric from utility (kWh)	3,296,073	707,238	117,549	55,566	2,550,544	600,768	2,208,824	473,496
Gas for boiler (MMBtu)	8,201	1,261	22	20	1	0	2,179	717
Gas for generator (MMBtu)	0	0	33,946	6,148	10,427	1,591	13,549	2,216

Building NOx Emissions (tons/year)

Average Per Building								
Site NOx Emissions[2,3]	0.3	0.0	0.4	0.1	0.2	0.0	0.3	0.1
NOx Emissions from Grid Power[1]	1.9	0.4	0.1	0.0	1.5	0.3	1.3	0.3
Net NOx Emissions for HGB[1,2,3,4]	2.2	0.5	0.5	0.1	1.6	0.4	1.5	0.3
NOx Emissions Savings[1,2,3,4]	NA	NA	1.7	0.3	0.6	0.1	0.6	0.1
% Savings	**NA**	**NA**	**77%**	**75%**	**26%**	**18%**	**29%**	**27%**

2007 Regional NOx Emission Summary (tons/year)

Current Regional NOx Production								
Site NOx Emissions[2,3]	2.7	0.4	3.9	0.7	1.5	0.2	3.1	0.6
NOx Emissions from Grid Power[1]	17.0	3.6	0.6	0.3	13.1	3.1	11.4	2.4
Net NOx Emissions for HGB[1,2,3,4]	19.7	4.1	4.5	1.0	14.6	3.3	13.9	3.0
Current Regional NOx Impact								
Site NOx Emissions Impact[2,3]	NA	NA	1.2	0.3	-1.3	-0.2	0.3	0.2
NOx Emissions from Grid Power[1]	NA	NA	-16.4	-3.4	-3.8	-0.5	-5.6	-1.2
Net NOx Emissions for HGB Impact[1,2,3,4]	NA	NA	-15.2	-3.1	-5.1	-0.7	-5.8	-1.1

Notes:

1 - Based on 2007 TCEQ E-Grid (25%) NOx Rates for Ercot utilities, Annual and Ozone Season Day, includes 70% Reliant Utility Factor, and 7% transmission loss effect. Peak Ozone Season for HGB from 7/15 - 9/15.

2 - Boiler NOx = 0.074 lbs/MMBtu, average of 0.098 and 0.049 from the AP-42 EPA report, assumption is that currently 50% boilers are uncontrolled and 50% are with controls

3 - Generators meeting NOx permit criteria of 0.14 lbs/mwh (including thermal)

4 - Net NOx of site increase and 2007 eGrid decrease

Appendix A
Large Hotel CHP Analysis For the Houston Galveston Brazoria (HGB)

General Building Characteristics & Assumptions

Size:	516,600 sq ft 206 x 250 x 10 (width x length x no.of floors)	Base Case -	Non CHP case
Building Characteristics	R-11 Wall R-17 Roof Single pane clear glass	Case I -	Maximum CHP Power to meet < 10 year CHP payback requirement and add absorption chillers to increase NOx savings
Building Loads	1712 kW Peak electric demand 1103 tons Peak cooling load 9.62 MMBtu/h Peak space heat and hot water load	Case II -	Maximum CHP Thermal to meet < 10 year CHP payback requirement to approximate least NOx savings only add absorption if required to meet payback
HVAC Systems	Variable air volume with reheat	Case III -	Optimal CHP Thermal Utilization to meet < 10 year CHP payback requirement absorption for thermal balancing to approximate least NOx savings
Number of Buildings in Region	15		
2020 Projected # of Buildings	20		

Plant Characteristics and Assumptions

Average Per Building	Base Case		CHP Case I		CHP Case II		CHP Case III	
Lead Chillers	2 x 350 ton	Electric	2 x 360 ton	Electric	2 x 350 ton	Electric	1 x 364 ton	Electric
Lag Chillers	1 x 100 ton	Electric	1 x 80 ton	1 stage absorption	1 x 100 ton	Electric	3 x 112 ton	2 stage absorption
Boilers	1 x 244 HP	Boiler	1 x 244 HP	Boiler	1 x 244 HP	Boiler	1 x 244 HP	Boiler
Building Power	1712	Peak Electric kW	1650	Peak Electric kW	1712	Peak Electric kW	1343	Peak Electric kW
	7,611	Electric MWh Load	7,566	Electric MWh Load	7,587	Electric MWh Load	6,836	Electric MWh Load
	Cooling/heating always available		Cooling/heating always available		Cooling/heating always available		Cooling/heating always available	
			Generator following electric demand		Generator following lesser demand		Generator following lesser demand	
CHP Power			2 x 856 kW	Recip	4 x 425 kW	Recip	4 x 60 kW	Microturbine
			1712	Gen kW	1700	Gen kW	243	Gen kW
			7566	Gen MWh	4673	Gen MWh	2510	Gen MWh
			8760	Gen Run Hours Available	8760	Gen Run Hours Available	8760	Gen Run Hours Available
			96442	Gen Fuel MMBTU	57332	Gen Fuel MMBTU	31285	Gen Fuel MMBTU
CHP Performance			56%	CHP Efficiency	75%	CHP Efficiency	73%	CHP Efficiency
			100%	Power from CHP	62%	Power from CHP	25%	Power from CHP
			91%	Thermal from CHP	92%	Thermal from CHP	84%	Thermal from CHP
			50%	Power Utilization	33%	Power Utilization	100%	Power Utilization
			43%	Thermal Utilization	38%	Thermal Utilization	86%	Thermal Utilization

Building Energy Variables

	Base Case		CHP Case I		CHP Case II		CHP Case III	
Average Per Building	Annual	Peak Ozone Season	Annual	Peak Ozone Season	Annual	Peak Ozone Season	Annual	Peak Ozone Season
Electric from utility (kWh)	7,610,662	1,661,373	1	0	2,913,761	851,697	5,100,194	1,093,306
Gas for boiler (MMBtu)	43,822	7,237	4,819	114	4,246	258	11,644	3,832
Gas for generator (MMBtu)	0	0	96,442	20,214	57,332	9,884	31,285	5,116

Building NOx Emissions (tons/year)

Average Per Building								
Site NOx Emissions[2,3]	1.6	0.3	1.3	0.2	1.0	0.2	1.8	0.4
NOx Emissions from Grid Power[1]	4.4	1.0	0.0	0.0	1.7	0.5	2.4	0.5
Net NOx Emissions for HGB[1,2,3,4]	6.0	1.2	1.3	0.2	2.7	0.7	4.2	0.9
NOx Emissions Savings[1,2,3,4]	NA	NA	4.7	1.0	3.3	0.6	1.8	0.3
% Savings	**NA**	**NA**	**79%**	**81%**	**55%**	**47%**	**29%**	**26%**

2007 Regional NOx Emission Summary (tons/year)

Current Regional NOx Production								
Site NOx Emissions[2,3]	24.3	4.0	19.2	3.5	15.6	2.4	27.2	5.5
NOx Emissions from Grid Power[1]	65.4	14.3	0.0	0.0	25.1	7.4	36.0	7.7
Net NOx Emissions for HGB[1,2,3,4]	89.7	18.3	19.2	3.5	40.7	9.8	63.3	13.5
Current Regional NOx Impact								
Site NOx Emissions Impact[2,3]	NA	NA	-5.1	-0.5	-8.7	-1.6	2.9	1.5
NOx Emissions from Grid Power[1]	NA	NA	-65.4	-14.3	-40.3	-6.9	-29.4	-6.5
Net NOx Emissions for HGB Impact[1,2,3,4]	NA	NA	-70.4	-14.7	-49.0	-8.5	-26.3	-4.8

Notes:
1 - Based on 2007 TCEQ E-Grid (25%) NOx Rates for Ercot utilities, Annual and Ozone Season Day, includes 70% Reliant Utility Factor,
and 7% transmission loss effect. Peak Ozone Season for HGB from 7/15 - 9/15.
2 - Boiler NOx = 0.074 lbs/MMBtu, average of 0.098 and 0.049 from the AP-42 EPA report, assumption is that currently 50% boilers are uncontrolled and 50% are with controls
3 - Generators meeting NOx permit criteria of 0.14 lbs/mwh (including thermal)
4 - Net NOx of site increase and 2007 eGrid decrease

Appendix A
Medium Hotel CHP Analysis For the Houston Galveston Brazoria (HGB)

General Building Characteristics & Assumptions

Size:	272,280 sq ft 181 x 250 x 6 (width x length x no.of floors)	Base Case -	Non CHP case
Building Characteristics	R-11 Wall R-17 Roof Single pane clear glass	Case I -	Maximum CHP Power to meet < 10 year CHP payback requirement and add absorption chillers to increase NOx savings
Building Loads	884 kW Peak electric demand 378 tons Peak cooling load 5.53 MMBtu/h Peak space heat and hot water load	Case II -	Maximum CHP Thermal to meet < 10 year CHP payback requirement to approximate least NOx savings only add absorption if required to meet payback
HVAC Systems	Variable air volume with reheat	Case III -	Optimal CHP Thermal Utilization to meet < 10 year CHP payback requirement absorption for thermal balancing to approximate least NOx savings
Number of Buildings in Region	41		
2020 Projected # of Buildings	53		

Plant Characteristics and Assumptions

Average Per Building	Base Case		CHP Case I		CHP Case II		CHP Case III	
Lead Chillers	2 x 153 ton	Electric	2 x 153 ton	Electric	2 x 153 ton	Electric	1 x 212 ton	Electric
Lag Chillers	1 x 60 ton	Electric	1 x 60 ton	1 stage absorption	1 x 60 ton	Electric	2 x 77 ton	2 stage absorption
Boilers	1 x 165 HP	Boiler	1 x 165 HP	Boiler	1 x 165 HP	Boiler	1 x 165 HP	Boiler
Building Power	884	Peak Electric kW	840	Peak Electric kW	884	Peak Electric kW	693	Peak Electric kW
	3936	Electric MWh Load	3875	Electric MWh Load	4077	Electric MWh Load	3,536	Electric MWh Load
	Cooling/heating always available		Cooling/heating always available		Cooling/heating always available		Cooling/heating always available	
			Generator following electric demand		Generator following lesser demand		Generator following lesser demand	
CHP Power			2 x 442 kW	Recip	4 x 200 kW	Microturbine	2 x 63 kW	Microturbine
			884	Gen kW	800	Gen kW	126	Gen kW
			3875	Gen MWh	2712	Gen MWh	1299	Gen MWh
			8760	Gen Run Hours Available	8760	Gen Run Hours Available	8760	Gen Run Hours Available
			47009	Gen Fuel MMBTU	36930	Gen Fuel MMBTU	16182	Gen Fuel MMBTU
CHP Performance			64%	CHP Efficiency	71%	CHP Efficiency	73%	CHP Efficiency
			100%	Power from CHP	65%	Power from CHP	25%	Power from CHP
			92%	Thermal from CHP	94%	Thermal from CHP	84%	Thermal from CHP
			50%	Power Utilization	36%	Power Utilization	100%	Power Utilization
			43%	Thermal Utilization	36%	Thermal Utilization	86%	Thermal Utilization

Building Energy Variables

	Base Case		CHP Case I		CHP Case II		CHP Case III	
Average Per Building	Annual	Peak Ozone Season	Annual	Peak Ozone Season	Annual	Peak Ozone Season	Annual	Peak Ozone Season
Electric from utility (kWh)	3,936,499	863,793	1	0	1,365,127	409,815	2,637,998	565,496
Gas for boiler (MMBtu)	25,460	3,902	2,895	147	1,927	27	6,765	2,226
Gas for generator (MMBtu)	0	0	47,009	10,037	34,899	6,133	16,182	2,646

Building NOx Emissions (tons/year)

Average Per Building								
Site NOx Emissions[2,3]	0.9	0.1	0.7	0.1	0.6	0.1	1.1	0.2
NOx Emissions from Grid Power[1]	2.3	0.5	0.0	0.0	0.8	0.2	1.2	0.3
Net NOx Emissions for HGB[1,2,3,4]	3.2	0.6	0.7	0.1	1.4	0.3	2.3	0.5
NOx Emissions Savings[1,2,3,4]	NA	NA	2.5	0.5	1.8	0.3	0.9	0.2
% Savings	**NA**	**NA**	**77%**	**78%**	**57%**	**49%**	**29%**	**25%**

2007 Regional NOx Emission Summary (tons/year)

Current Regional NOx Production								
Site NOx Emissions[2,3]	38.6	5.9	29.8	5.7	23.7	3.7	43.2	8.7
NOx Emissions from Grid Power[1]	92.4	20.3	0.0	0.0	32.0	9.6	49.2	10.5
Net NOx Emissions for HGB[1,2,3,4]	131.0	26.2	29.8	5.7	55.8	13.3	92.5	19.7
Current Regional NOx Impact								
Site NOx Emissions Impact[2,3]	NA	NA	-8.8	-0.3	-14.9	-2.2	4.6	2.8
NOx Emissions from Grid Power[1]	NA	NA	-92.4	-20.3	-60.4	-10.7	-43.2	-9.7
Net NOx Emissions for HGB Impact[1,2,3,4]	NA	NA	-101.2	-20.5	-75.3	-12.9	-38.5	-6.5

Notes:

1 - Based on 2007 TCEQ E-Grid (25%) NOx Rates for Ercot utilities, Annual and Ozone Season Day, includes 70% Reliant Utility Factor, and 7% transmission loss effect. Peak Ozone Season for HGB from 7/15 - 9/15.

2 - Boiler NOx = 0.074 lbs/MMBtu, average of 0.098 and 0.049 from the AP-42 EPA report, assumption is that currently 50% boilers are uncontrolled and 50% are with controls

3 - Generators meeting NOx permit criteria of 0.14 lbs/mwh (including thermal)

4 - Net NOx of site increase and 2007 eGrid decrease

Appendix A

Small Hotel CHP Analysis For the Houston Galveston Brazoria (HGB)

General Building Characteristics & Assumptions

Size:	73,684 sq ft 184 x 200 x 2 (width x length x no.of floors)	Base Case -	Non CHP case
Building Characteristics	R-11 Wall R-17 Roof Single pane clear glass	Case I -	Maximum CHP Power to meet < 10 year CHP payback requirement and add absorption chillers to increase NOx savings
Building Loads	257 kW Peak electric demand 109 tons Peak cooling load 1.716 MMBtu/h Peak space heat and hot water load	Case II -	Maximum CHP Thermal to meet < 10 year CHP payback requirement to approximate least NOx savings only add absorption if required to meet payback
HVAC Systems	Variable air volume with reheat	Case III -	Optimal CHP Thermal Utilization to meet < 10 year CHP payback requirement absorption for thermal balancing to approximate least NOx savings
Number of Buildings in Region	313		
2020 Projected # of Buildings	403		

Plant Characteristics and Assumptions

Average Per Building	Base Case		CHP Case I		CHP Case II		CHP Case III	
Lead Chillers	2 x 37 ton	Electric	3x37 ton	2 stage absorption	2 x 37 ton	Electric	2 x 32 ton	Electric
Lag Chillers	1 x 37 ton	Electric			1 x 37 ton	2 stage absorption	1 x 47 ton	2 stage absorption
Boilers	1 x 50 HP	Boiler	1 x 50 HP	Boiler	1 x 50 HP	Boiler	1 x 50 HP	Boiler
Building Power	257	Peak Electric kW	190	Peak Electric kW	257	Peak Electric kW	202	Peak Electric kW
	1,096	Electric MWh Load	856	Electric MWh Load	1,098	Electric MWh Load	985	Electric MWh Load
	Cooling/heating always available		Cooling/heating always available		Cooling/heating always available		Cooling/heating always available	
			Generator following electric demand		Generator following lesser demand		Generator following lesser demand	
CHP Power			4 x 57 kW	Microturbine	3 x 60 kW	Microturbine	1 x 37 kW	Microturbine
			228	Gen kW	180	Gen kW	37	Gen kW
			855	Gen MWh	631	Gen MWh	362	Gen MWh
			8760	Gen Run Hours Available	8197	Gen Run Hours Available	8760	Gen Run Hours Available
			11492	Gen Fuel MMBTU	8657	Gen Fuel MMBTU	4507	Gen Fuel MMBTU
CHP Performance			76%	CHP Efficiency	75%	CHP Efficiency	73%	CHP Efficiency
			100%	Power from CHP	57%	Power from CHP	25%	Power from CHP
			80%	Thermal from CHP	94%	Thermal from CHP	84%	Thermal from CHP
			43%	Power Utilization	43%	Power Utilization	100%	Power Utilization
			42%	Thermal Utilization	43%	Thermal Utilization	86%	Thermal Utilization

Building Energy Variables

	Base Case		CHP Case I		CHP Case II		CHP Case III	
Average Per Building	Annual	Peak Ozone Season	Annual	Peak Ozone Season	Annual	Peak Ozone Season	Annual	Peak Ozone Season
Electric from utility (kWh)	1,096,311	253,764	797	630	467,234	146,664	734,680	157,490
Gas for boiler (MMBtu)	6,658	756	2,748	653	596	34	1,769	582
Gas for generator (MMBtu)	0	0	11,492	2,305	8,657	1,503	4,507	737

Building NOx Emissions (tons/year)

Average Per Building								
Site NOx Emissions[2,3]	0.3	0.0	0.3	0.1	0.2	0.0	0.3	0.1
NOx Emissions from Grid Power[1]	0.6	0.2	0.0	0.0	0.3	0.1	0.3	0.1
Net NOx Emissions for HGB[1,2,3,4]	0.9	0.2	0.3	0.1	0.4	0.1	0.6	0.1
NOx Emissions Savings[1,2,3,4]	NA	NA	0.6	0.1	0.5	0.1	0.3	0.05
% Savings	**NA**	**NA**	**68%**	**67%**	**51%**	**44%**	**29%**	**27%**

2007 Regional NOx Emission Summary (tons/year)

Current Regional NOx Production								
Site NOx Emissions[2,3]	78.3	9.4	87.6	18.8	50.1	6.3	87.6	17.7
NOx Emissions from Grid Power[1]	197.2	47.0	0.0	0.0	84.5	25.0	106.9	22.9
Net NOx Emissions for HGB[1,2,3,4]	275.4	56.3	87.6	18.8	134.6	31.3	194.5	41.4
Current Regional NOx Impact								
Site NOx Emissions Impact[2,3]	NA	NA	9.4	9.4	-28.2	-3.1	9.4	8.3
NOx Emissions from Grid Power[1]	NA	NA	-197.2	-47.0	-112.7	-21.9	-90.3	-24.0
Net NOx Emissions for HGB Impact[1,2,3,4]	NA	NA	-187.8	-37.6	-140.9	-25.0	-80.9	-14.9

Notes:

1 - Based on 2007 TCEQ E-Grid (25%) NOx Rates for Ercot utilities, Annual and Ozone Season Day, includes 70% Reliant Utility Factor, and 7% transmission loss effect. Peak Ozone Season for HGB from 7/15 - 9/15.

2 - Boiler NOx = 0.074 lbs/MMBtu, average of 0.098 and 0.049 from the AP-42 EPA report, assumption is that currently 50% boilers are uncontrolled and 50% are with controls

3 - Generators meeting NOx permit criteria of 0.14 lbs/mwh (including thermal)

4 - Net NOx of site increase and 2007 eGrid decrease

Appendix A
Colleges (with on campus living) CHP Analysis For the Houston Galveston Brazoria (HGB)

General Building Characteristics & Assumptions

Size (sq.ft) of Average Campus:	2,065,230	Base Case -	Non CHP case
Building Characteristics		Case I -	Maximum CHP Power to meet < 10 year CHP payback requirement and add absorption chillers to increase NOx savings
Building Loads	8,376 kW Peak electric demand 49233 mWh for campus 29303 therms for campus	Case II -	Maximum CHP Thermal to meet < 10 year CHP payback requirement to approximate least NOx savings only add absorption if required to meet payback
HVAC Systems		Case III -	Optimal CHP Thermal Utilization to meet < 10 year CHP payback requirement absorption for thermal balancing to approximate least NOx savings
Campuses in Region	8		

Plant Characteristics and Assumptions

Average Per Building	Base Case		CHP Case I		CHP Case II		CHP Case III	
Lead Chillers	yes	Electric	yes	Electric	yes	Electric	yes	Electric
Lag Chillers	yes	Electric	1 x 500 ton	1 stage absorption	yes	Electric	yes	2 stage absorption
Boilers	yes	Boiler	yes	Boiler	yes	Boiler	yes	Boiler
Building Power	8376	Peak Electric kW	8000	Peak Electric kW	8376	Peak Electric kW	6570	Peak Electric kW
	49234	Electric MWh Load	48264	Electric MWh Load	49234	Electric MWh Load	44,222	Electric MWh Load
	Cooling/heating always available		Cooling/heating always available		Cooling/heating available always		Cooling/heating always available	
			Generator following electric demand		Generator following thermal demand		Generator following lesser demand	
CHP Power			4 x 2100 kW	Recip engine	3 x 1860 kW	Recip engine	5 x 238 kW	Microturbine
			8000	Gen kW	5580	Gen kW	1190	Gen kW
			48264	Gen MWh	24986	Gen MWh	16240	Gen MWh
			8760	Gen Run Hours Available	8760	Gen Run Hours Available	8760	Gen Run Hours Available
			520150	Gen Fuel MMBTU	221516	Gen Fuel MMBTU	202385	Gen Fuel MMBTU
CHP Performance			83%	CHP Efficiency	67%	CHP Efficiency	73%	CHP Efficiency
			100%	Power from CHP	51%	Power from CHP	25%	Power from CHP
			100%	Thermal from CHP	100%	Thermal from CHP	84%	Thermal from CHP
			66%	Power Utilization	51%	Power Utilization	100%	Power Utilization
			64%	Thermal Utilization	51%	Thermal Utilization	86%	Thermal Utilization

Building Energy Variables

	Base Case		CHP Case I		CHP Case II		CHP Case III	
Average Per Building	Annual	Peak Ozone Season	Annual	Peak Ozone Season	Annual	Peak Ozone Season	Annual	Peak Ozone Season
Electric from utility (kWh)	49,233,635	9,477,423	0	0	24,247,596	7,042,543	32,993,332	7,072,634
Gas for boiler (MMBtu)	109,650	10,710	0	0	0	0	29,135	9,588
Gas for generator (MMBtu)	0	0	520,150	72,310	221,516	21,586	202,385	33,096

Building NOx Emissions (tons/year)

Average Per Building								
Site NOx Emissions[2,3]	4.1	0.4	5.4	0.7	3.5	0.3	4.5	0.9
NOx Emissions from Grid Power[1]	28.2	5.4	0.0	0.0	13.9	4.0	18.3	3.9
Net NOx Emissions for HGB[1,2,3,4]	32.2	5.8	5.4	0.7	17.4	4.4	22.8	4.8
NOx Emissions Savings[1,2,3,4]	NA	NA	26.9	5.1	14.8	1.4	9.5	1.0
% Savings	**NA**	**NA**	**83%**	**87%**	**46%**	**25%**	**29%**	**17%**

2007 Regional NOx Emission Summary (tons/year)

Current Regional NOx Production								
Site NOx Emissions[2,3]	32.5	3.2	42.9	6.0	28.4	2.8	36.3	7.3
NOx Emissions from Grid Power[1]	225.5	43.4	0.0	0.0	111.0	32.3	146.4	31.4
Net NOx Emissions for HGB[1,2,3,4]	257.9	46.6	42.9	6.0	139.4	35.0	182.1	0.0
Current Regional NOx Impact								
Site NOx Emissions Impact[2,3]	NA	NA	10.4	2.8	-4.1	-0.4	3.9	4.2
NOx Emissions from Grid Power[1]	NA	NA	-225.5	-43.4	-114.4	-11.2	-79.1	-12.0
Net NOx Emissions for HGB Impact[1,2,3,4]	NA	NA	-215.1	-40.6	-118.5	-11.6	-75.8	-46.6

Notes:

1 - Based on 2007 TCEQ E-Grid (25%) NOx Rates for Ercot utilities, Annual and Ozone Season Day, includes 70% Reliant Utility Factor, and 7% transmission loss effect. Peak Ozone Season for HGB from 7/15 - 9/15.

2 - Boiler NOx = 0.074 lbs/MMBtu, average of 0.098 and 0.049 from the AP-42 EPA report, assumption is that currently 50% boilers are uncontrolled and 50% are with controls

3 - Generators meeting NOx permit criteria of 0.14 lbs/mwh (including thermal)

4 - Net NOx of site increase and 2007 eGrid decrease

Appendix A
Super Market CHP Analysis For the Houston Galveston Brazoria (HGB)

General Building Characteristics & Assumptions

Size:	62786 sq ft 314 x 200 x 1 (width x length x no.of floors)	Base Case -	Non CHP case
Building Characteristics	R-11 Wall R-17 Roof Single pane clear glass	Case I -	Maximum CHP Power to meet < 10 year CHP payback requirement and add absorption chillers to increase NOx savings
Building Loads	317 kW Peak electric demand 124 tons Peak cooling load 0.8 MMBtu/h Peak space heat and hot water load	Case II -	Maximum CHP Thermal Did not meet criteria
HVAC Systems	Variable air volume with reheat	Case III -	Optimal CHP Thermal Utilization to meet < 10 year CHP payback requirement absorption for thermal balancing to approximate least NOx savings
Number of Buildings in Region	186		
2020 Projected # of Buildings	240		

Plant Characteristics and Assumptions

Average Per Building	Base Case		CHP Case I		CHP Case II		CHP Case III	
Lead Chillers	1 x 120 ton	Electric	1 x 120 ton	2 stage absorption			1 x 70 ton	Electric
Lag Chillers							1 x 50 ton	2 stage absorption
Boilers	1 x 36 HP	Boiler	1 x 36 HP	Boiler			1 x 36 HP	Boiler
Building Power	317	Peak Electric kW	251	Peak Electric kW	NA		272	Peak Electric kW
	1330	Electric MWh Load	1077	Electric MWh Load	NA		1286	Electric MWh Load
			Cooling/heating always available		NA		Cooling/heating always available	
	Cooling/heating always available		Generator following electric demand		NA		Generator following lessor demand	
CHP Power			4 x 45 kW	Microturbine	NA		1 x 45 kW	Microturbine
			180	Gen kW	NA		45	Gen kW
			920	Gen MWh	NA		135	Gen MWh
			7458	Gen Run Hours Available			3000	Gen Run Hours Available
			8836	Gen Fuel MMBTU			1768	Gen Fuel MMBTU
CHP Performance			63%	CHP Efficiency			74%	CHP Efficiency
			85%	Power from CHP			5%	Power from CHP
			91%	Thermal from CHP			58%	Thermal from CHP
			58%	Power Utilization			83%	Power Utilization
			49%	Thermal Utilization			83%	Thermal Utilization

Building Energy Variables

	Base Case		CHP Case I		CHP Case II		CHP Case III	
Average Per Building	Annual	Peak Ozone Season	Annual	Peak Ozone Season	Annual	Peak Ozone Season	Annual	Peak Ozone Season
Electric from utility (kWh)	1,330,357	276,633	157,876	46,746			1,195,357	215,707
Gas for boiler (MMBtu)	743	79	472	201			451	174
Gas for generator (MMBtu)	0	0	8,836	1,569			1,768	446

Building NOx Emissions (tons/year)

Average Per Building								
Site NOx Emissions [2,3]	0.03	0.00	0.13	0.03			0.03	0.01
NOx Emissions from Grid Power [1]	0.76	0.16	0.09	0.03			0.7	0.13
Net NOx Emissions for HGB [1,2,3,4]	0.8	0.2	0.2	0.1			0.7	0.14
NOx Emissions Savings [1,2,3,4]	NA	NA	0.6	0.1	NA	NA	0.1	0.02
% Savings	**NA**	**NA**	**72%**	**66%**	**NA**	**NA**	**8%**	**14%**

2007 Regional NOx Emission Summary(tons/year)

Current Regional NOx Production								
Site NOx Emissions [2,3]	5.1	0.5	24.6	5.2			4.8	1.3
NOx Emissions from Grid Power [1]	141.7	29.5	16.8	5.0			130.3	23.5
Net NOx Emissions for HGB [1,2,3,4]	146.8	30.0	41.4	10.2			135.1	25.8
Current Regional NOx Impact								
Site NOx Emissions Impact [2,3]	NA	NA	19.5	4.7	NA	NA	-0.4	0.7
NOx Emissions from Grid Power [1]	NA	NA	-124.8	-24.5	NA	NA	-11.3	-5.9
Net NOx Emissions for HGB Impact [1,2,3,4]	NA	NA	-105.4	-19.8	NA	NA	-11.7	-4.2

Notes:

1 - Based on 2007 TCEQ E-Grid (25%) NOx Rates for Ercot utilities, Annual and Ozone Season Day, includes 70% Reliant Utility Factor, and 7% transmission loss effect. Peak Ozone Season for HGB from 7/15 - 9/15.

2 - Boiler NOx = 0.074 lbs/MMBtu, average of 0.098 and 0.049 from the AP-42 EPA report, assumption is that currently 50% boilers are uncontrolled and 50% are with controls

3 - Generators meeting NOx permit criteria of 0.14 lbs/mwh (including thermal)

4 - Net NOx of site increase and 2007 eGrid decrease

Appendix A
Medium High-Rise Office CHP Analysis For the Houston Galveston Brazoria (HGB)

General Building Characteristics & Assumptions

Size:	620032 sq ft 206 x 200 x 15 (width x length x no.of floors)	Base Case -	Non CHP case
Building Characteristics	R-11 Wall R-17 Roof Single pane clear glass	Case I -	Maximum CHP Power Did not meet Criteria
Building Loads	2617 kW Peak electric demand 1251 tons Peak cooling load 6.5 MMBtu/h Peak space heat and hot water load	Case II -	Maximum CHP Thermal to meet < 10 year CHP payback requirement to approximate least NOx savings only add absorption if required to meet payback
HVAC Systems	Variable air volume with reheat	Case III -	Optimal CHP Thermal Utilization to meet < 10 year CHP payback requirement absorption for thermal balancing to approximate least NOx savings
Number of Buildings in Region	61		
2020 Projected # of Buildings	79		

Plant Characteristics and Assumptions

Average Per Building	Base Case		CHP Case I	CHP Case II		CHP Case III	
Lead Chillers	1 x 364 ton	Electric		3 x 343 ton	2 stage absorption	2 x 432 ton	Electric
Lag Chillers	1 x 676 ton	Electric				1 x 200 ton	2 stage absorption
Boilers	1 x 585 HP	Boiler		1 x 585 HP	Boiler	1 x 585 HP	Boiler
Building Power	2617	Peak Electric kW	NA	2086	Peak Electric kW	2530	Peak Electric kW
	7993	Electric MWh Load	NA	6744	Electric MWh Load	7723	Electric MWh Load
	Cooling/heating always available		NA	Cooling/heating always available		Cooling/heating always available	
			NA	Generator following electric demand		Generator following lessor demand	
CHP Power			NA	5 x 150 kW	Microturbine	1 x 150 kW	Microturbine
			NA	750	Gen kW	150.00	Gen kW
			NA	1820	Gen MWh	370	Gen MWh
				4736	Gen Run Hours Available	2985	Gen Run Hours Available
				23983	Gen Fuel MMBTU	4845	Gen Fuel MMBTU
CHP Performance				74%	CHP Efficiency	74%	CHP Efficiency
				27%	Power from CHP	5%	Power from CHP
				97%	Thermal from CHP	58%	Thermal from CHP
				51%	Power Utilization	83%	Power Utilization
				51%	Thermal Utilization	83%	Thermal Utilization

Building Energy Variables

	Base Case		CHP Case I		CHP Case II		CHP Case III	
Average Per Building	Annual	Peak Ozone Season	Annual	Peak Ozone Season	Annual	Peak Ozone Season	Annual	Peak Ozone Season
Electric from utility (kWh)	7,992,631	1,731,647			4,924,306	888,612	7,353,382	1,326,949
Gas for boiler (MMBtu)	6,154	690			818	316	3,737	1,442
Gas for generator (MMBtu)	0	0			23,983	6,057	4,845	1,224

Building NOx Emissions (tons/year)

Average Per Building								
Site NOx Emissions[2,3]	0.23	0.03			0.39	0.10	0.2	0.1
NOx Emissions from Grid Power[1]	4.58	0.99			2.82	0.51	4.2	0.8
Net NOx Emissions for HGB[1,2,3,4]	4.80	1.02			3.21	0.61	4.4	0.8
NOx Emissions Savings[1,2,3,4]	NA	NA	NA	NA	1.6	0.4	0.4	0.2
% Savings	**NA**	**NA**	**NA**	**NA**	**33%**	**40%**	**8%**	**17%**

2007 Regional NOx Emission Summary (tons/year)

Current Regional NOx Production								
Site NOx Emissions[2,3]	13.9	1.6			23.9	6.3	12.9	3.4
NOx Emissions from Grid Power[1]	279.1	60.5			171.9	31.0	256.8	46.3
Net NOx Emissions for HGB[1,2,3,4]	293.0	62.0			195.8	37.3	269.7	51.4
Current Regional NOx Impact								
Site NOx Emissions Impact[2,3]	NA	NA	NA	NA	10.0	4.7	-1.0	1.8
NOx Emissions from Grid Power[1]	NA	NA	NA	NA	-107.2	-29.4	-22.3	-14.1
Net NOx Emissions for HGB Impact[1,2,3,4]	NA	NA	NA	NA	-97.1	-24.7	-23.3	-10.6

Notes:
1 - Based on 2007 TCEQ E-Grid (25%) NOx Rates for Ercot utilities, Annual and Ozone Season Day, includes 70% Reliant Utility Factor,
and 7% transmission loss effect. Peak Ozone Season for HGB from 7/15 - 9/15.
2 - Boiler NOx = 0.074 lbs/MMBtu, average of 0.098 and 0.049 from the AP-42 EPA report, assumption is that currently 50% boilers are uncontrolled and 50% are with controls
3 - Generators meeting NOx permit criteria of 0.14 lbs/mwh (including thermal)
4 - Net NOx of site increase and 2007 eGrid decrease

Appendix A
Big Box Retail CHP Analysis For the Houston Galveston Brazoria (HGB)

General Building Characteristics & Assumptions

Size:	155600 sq ft 389 x 400 x 1 (width x length x no.of floors)	Base Case -	Non CHP case
Building Characteristics	R-11 Wall R-17 Roof Single pane clear glass	Case I -	Maximum CHP Power Did not meet criteria
Building Loads	1527 kW Peak electric demand 699 tons Peak cooling load 2.82 MMBtu/h Peak space heat and hot water load	Case II -	Maximum CHP Thermal to meet < 10 year CHP payback requirement to approximate least NOx savings only add absorption if required to meet payback
HVAC Systems	Variable air volume with reheat	Case III -	Optimal CHP Thermal Utilization to meet < 10 year CHP payback requirement absorption for thermal balancing to approximate least NOx savings
Number of Buildings in Region	368		
2020 Projected # of Buildings	475		

Plant Characteristics and Assumptions

Average Per Building	Base Case		CHP Case I	CHP Case II		CHP Case III	
Lead Chillers	1 x 550 ton	Electric		1 x 400 ton	Electric	1 x 450 ton	Electric
Lag Chillers			Did Not Meet Criteria	1 x 150	2 stage absorption	1 x 100 ton	2 stage absorption
Boilers	1 x 170 HP	Boiler		1 x 170 HP	Boiler	1 x 170 HP	Boiler
Building Power	1527	Peak Electric kW	NA	1441	Peak Electric kW	1452	Peak Electric kW
	5996	Electric MWh Load	NA	9584	Electric MWh Load	5794	Electric MWh Load
	Cooling/heating always available		NA	Cooling/heating always available		Cooling/heating always available	
			NA	Generator following electric demand		Generator following lessor demand	
			NA	2 x 60 kW	Microturbine	1 x 75 kW	Microturbine
			NA	120	Gen kW	75	Gen kW
			NA	4792	Gen MWh	225	Gen MWh
				8760	Gen Run Hours Available	3000	Gen Run Hours Available
				11022	Gen Fuel MMBTU	2946	Gen Fuel MMBTU
				51%	CHP Efficiency	74%	CHP Efficiency
				15%	Power from CHP	5%	Power from CHP
				93%	Thermal from CHP	58%	Thermal from CHP
				82%	Power Utilization	83%	Power Utilization
				37%	Thermal Utilization	83%	Thermal Utilization

Building Energy Variables

	Base Case		CHP Case I		CHP Case II		CHP Case III	
Average Per Building	Annual	Peak Ozone Season	Annual	Peak Ozone Season	Annual	Peak Ozone Season	Annual	Peak Ozone Season
Electric from utility (kWh)	5,995,521	1,255,522			4,791,752	685,010	5,770,521	1,041,315
Gas for boiler (MMBtu)	2,296	84			420	486	1,394	538
Gas for generator (MMBtu)	0	0			11,022	3,862	2,946	744

Building NOx Emissions (tons/year)

Average Per Building								
Site NOx Emissions[2,3]	0.1	0.0			0.1	0.1	0.1	0.02
NOx Emissions from Grid Power[1]	3.4	0.7			2.7	0.4	3.2	0.57
Net NOx Emissions for HGB[1,2,3,4]	3.5	0.7			2.9	0.5	3.2	0.62
NOx Emissions Savings[1,2,3,4]	NA	NA	NA	NA	0.6	0.3	0.3	0.10
% Savings	**NA**	**NA**	**NA**	**NA**	**18%**	**38%**	**8%**	**14%**

2007 Regional NOx Emission Summary (tons/year)

Current Regional NOx Production								
Site NOx Emissions[2,3]	31.3	1.1			47.8	21.3	29.1	7.7
NOx Emissions from Grid Power[1]	1,263.0	264.5			1009.4	144.3	1162.0	209.7
Net NOx Emissions for HGB[1,2,3,4]	1,294.3	265.6			1057.3	165.6	1191.4	227.1
Current Regional NOx Impact								
Site NOx Emissions Impact[2,3]	NA	NA	NA	NA	16.6	20.2	-2.2	6.5
NOx Emissions from Grid Power[1]	NA	NA	NA	NA	-253.6	-120.2	-101.0	-54.7
Net NOx Emissions for HGB Impact[1,2,3,4]	NA	NA	NA	NA	-237.0	-100.0	-102.9	-38.5

Notes:
1 - Based on 2007 TCEQ E-Grid (25%) NOx Rates for Ercot utilities, Annual and Ozone Season Day, includes 70% Reliant Utility Factor, and 7% transmission loss effect. Peak Ozone Season for HGB from 7/15 - 9/15.
2 - Boiler NOx = 0.074 lbs/MMBtu, average of 0.098 and 0.049 from the AP-42 EPA report, assumption is that currently 50% boilers are uncontrolled and 50% are with controls
3 - Generators meeting NOx permit criteria of 0.14 lbs/mwh (including thermal)
4 - Net NOx of site increase and 2007 eGrid decrease

CHP Results

The results generated by the CHP Emissions Calculator are intended for eductional and outreach purposes only; it is not designed for use in developing emission inventories or preparing air permit applications.

Annual Emissions Analysis	CHP System	Displaced Electricity Production	Displaced Thermal Production	Emissions/Fuel Reduction	Percent Reduction
NOx (tons/year)	0.34	2.12	0.22	2.00	85%
SO2 (tons/year)	0.01	2.80	0.00	2.79	100%
CO2 (tons/year)	1,117	1,350	261	493	31%
Carbon (metric tons/year)	305	368	71	134	31%
Fuel Consumption (MMBtu/year)	19,102	17,042	4,454	2,394	11%
Acres of Forest Equivalent				134	
Number of Cars Removed				84	

This CHP project will reduce emissions of Carbon Dioxide (CO2) by 493 tons per year

This is equal to 134 metric tons of carbon equivalent (MTCE) per year

This reduction is equal to removing the carbon that would be absorbed by 134 acres of forest

OR

This reduction is equal to removing the carbon emissions of 84 cars

CHP Results

CHP Technology:	Microturbine	
Fuel:	Natural Gas	
Unit Capacity:	250	kW
Number of Units:	1	
Total CHP Capacity:	250	kW
Operation:	5,840	hours per year
Heat Rate:	13,084	Btu/kWh HHV
CHP Fuel Consumption:	19,102	MMBtu/year
Duct Burner Fuel Consumption:	-	MMBtu/year
Total Fuel Consumption:	**19,102**	**MMBtu/year**
Total CHP Generation:	**1,460**	**MWh/year**
Useful CHP Thermal Output:	3,563	MMBtu/year for thermal applications (non-cooling)
	1,851	MMBtu/year for electric applications (cooling and electric heating)
	5,415	**MMBtu/year Total**
Displaced On-Site Production for		Existing Gas Boiler
Thermal (non-cooling) Applications:	0.10	lb/MMBtu NOx
	0.00%	sulfur content
Displaced Electric Service (cooling and electric heating):	54	tons of cooling capacity from CHP system
CHP:	Single-Effect Absorption Chiller	
Replaces:	1.60 kW/ton (COP=2.2) 1980-vintage, Roof-top unit <150 tons capacity	
	2.20	COP
Displaced Electricity Profile:	Egrid State Average All Sources 2000	
Egrid State:	TX	
Distribution Losses:	7%	
Displaced Electricity Production:	1,460	MWh/year CHP generation
	173	MWh/year Displaced Electric Demand (cooling)
	-	MWh/year Displaced Electric Demand (electric heating)
	206	MWh/year Transmission Losses
	1,838	**MWh/year Total**

CHP Results

Annual Analysis for CHP

	CHP System: Microturbine			Total Emissions from CHP System
NOx (tons/year)	0.34	-		0.34
SO2 (tons/year)	0.01	-		0.01
CO2 (tons/year)	1,117	-		1,117
Carbon (metric tons/year)	305	-		305
Fuel Consumption (MMBtu/year)	19,102	-		19,102

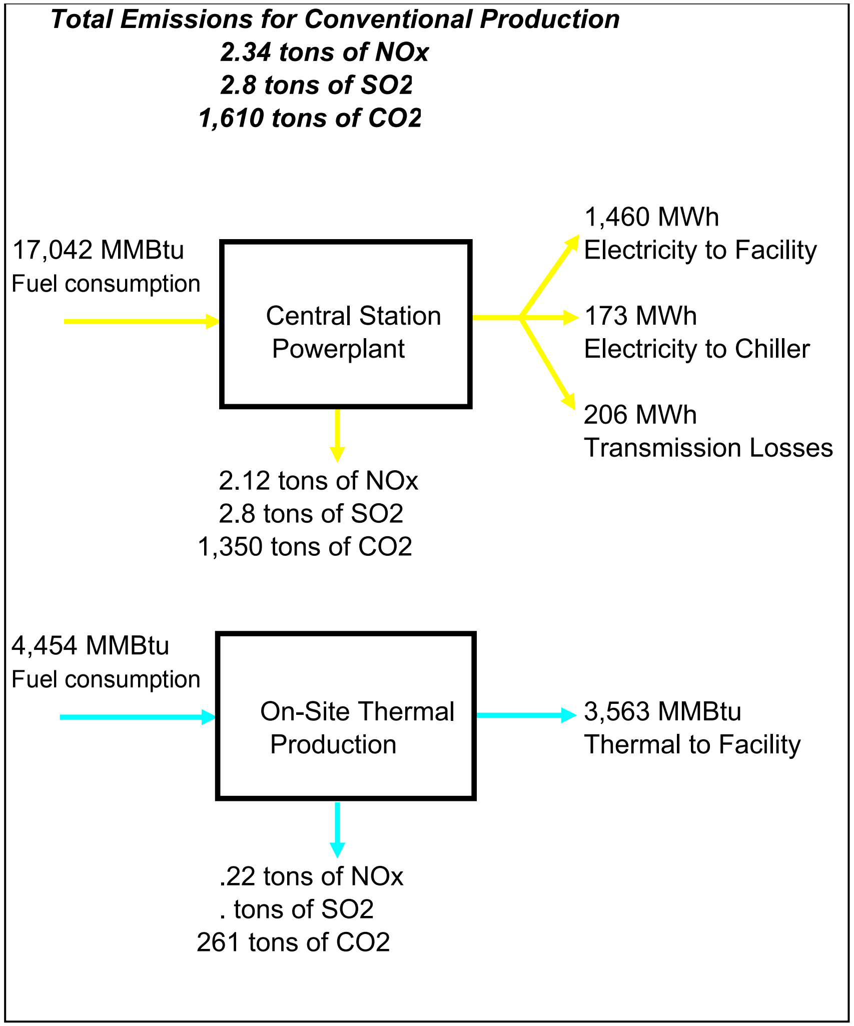
Annual Analysis for Displaced Production for Thermal (non-cooling) Applications

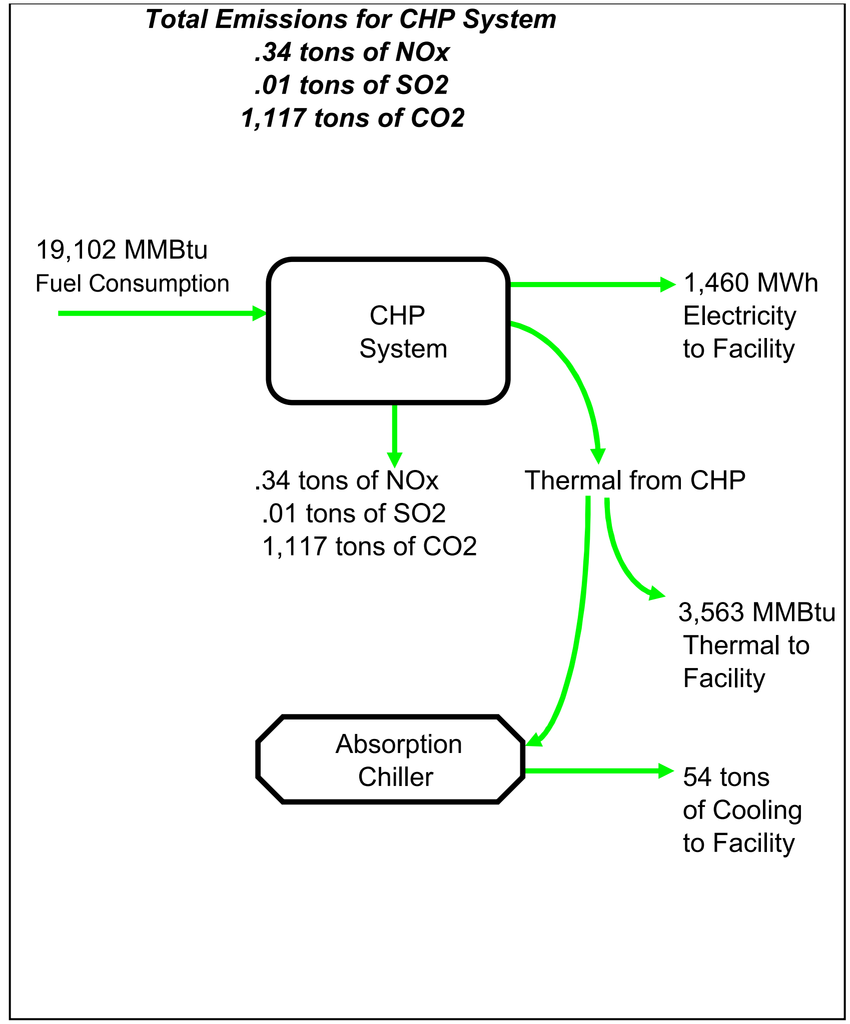
				Total Displaced Emissions from Thermal Production
NOx (tons/year)				0.22
SO2 (tons/year)				0.00
CO2 (tons/year)				261
Carbon (metric tons/year)				71
Fuel Consumption (MMBtu/year)				4,454

Annual Analysis for Displaced Electricity Production

	Displaced CHP Electricity Generation	Displaced Electricity for Cooling	Displaced Electricity for Heating	Transmission Losses	Total Displaced Emissions from Electricity Generation
NOx (tons/year)	1.68	0.20	-	0.24	2.12
SO2 (tons/year)	2.22	0.26	-	0.31	2.80
CO2 (tons/year)	1,072	126.88	-	151.02	1,350
Carbon (metric tons/year)	292	35	-	41	368
Fuel Consumption (MMBtu/year)	13,534	1,602	-	1,907	17,042

CHP Results


Total Emissions for Conventional Production
2.34 tons of NOx
2.8 tons of SO2
1,610 tons of CO2
17,042 MMBtu
Fuel consumption
Central Station Powerplant
1,460 MWh
Electricity to Facility
173 MWh
Electricity to Chiller
206 MWh
Transmission Losses
2.12 tons of NOx
2.8 tons of SO2
1,350 tons of CO2
4,454 MMBtu
Fuel consumption
On-Site Thermal Production
3,563 MMBtu
Thermal to Facility
.22 tons of NOx
. tons of SO2
261 tons of CO2


Total Emissions for CHP System
.34 tons of NOx
.01 tons of SO2
1,117 tons of CO2
19,102 MMBtu
Fuel Consumption
CHP System
1,460 MWh
Electricity
to Facility
.34 tons of NOx
.01 tons of SO2
1,117 tons of CO2
Thermal from CHP
3,563 MMBtu
Thermal to
Facility
Absorption Chiller
54 tons
of Cooling
to Facility

CHP Results

Emission Rates

	CHP System including Duct Burners	Microturbine Alone	Displaced Electricity
NOx (lb/MWh)	0.47	0.47	2.31
SO2 (lb/MWh)	0.01	0.01	3.05
CO2 (lb/MWh)	1,531	1,531	1,469

Note: Actual NOx value used in the calculation was 1.07 lbs. per MWh consistent with the value in Table 3-6 on Page 26 of main report.

Emission Rates

	Displaced Thermal Production
NOx (lb/MMBtu)	0.10
SO2 (lb/MMBtu)	0.00059
CO2 (lb/MMBtu)	117

CHP Results

The results generated by the CHP Emissions Calculator are intended for eductional and outreach purposes only; it is not designed for use in developing emission inventories or preparing air permit applications.

Annual Emissions Analysis

	CHP System	Displaced Electricity Production	Displaced Thermal Production	Emissions/Fuel Reduction	Percent Reduction
NOx (tons/year)	0.97	6.85	1.01	6.89	88%
SO2 (tons/year)	0.02	9.04	0.01	9.03	100%
CO2 (tons/year)	3,096	4,358	1,180	2,442	44%
Carbon (metric tons/year)	844	1,189	322	666	44%
Fuel Consumption (MMBtu/year)	52,930	55,022	20,167	22,259	30%
Acres of Forest Equivalent				666	
Number of Cars Removed				416	

This CHP project will reduce emissions of Carbon Dioxide (CO2) by 2,442 tons per year

This is equal to 666 metric tons of carbon equivalent (MTCE) per year

This reduction is equal to removing the carbon that would be absorbed by 666 acres of forest

OR

This reduction is equal to removing the carbon emissions of 416 cars

CHP Results

CHP Technology:	Recip Engine - Rich Burn	
Fuel:	Natural Gas	
Unit Capacity:	750	kW
Number of Units:	1	
Total CHP Capacity:	750	kW
Operation:	5,840	hours per year
Heat Rate:	12,085	Btu/kWh HHV
CHP Fuel Consumption:	52,930	MMBtu/year
Duct Burner Fuel Consumption:	-	MMBtu/year
Total Fuel Consumption:	**52,930**	**MMBtu/year**
Total CHP Generation:	**4,380**	**MWh/year**
Useful CHP Thermal Output:	16,134	MMBtu/year for thermal applications (non-cooling)
	8,366	MMBtu/year for electric applications (cooling and electric heating)
	24,499	**MMBtu/year Total**
Displaced On-Site Production for Thermal (non-cooling) Applications:		Existing Gas Boiler
	0.10	lb/MMBtu NOx
	0.00%	sulfur content
Displaced Electric Service (cooling and electric heating):	244	tons of cooling capacity from CHP system
CHP:	Single-Effect Absorption Chiller	
Replaces:	1.60 kW/ton (COP=2.2) 1980-vintage, reciprocating compressor, air-cooled, <150 tons capacity	
	2.20	COP
Displaced Electricity Profile:	Egrid State Average All Sources 2000	
Egrid State:	TX	
Distribution Losses:	7%	
Displaced Electricity Production:	4,380	MWh/year CHP generation
	781	MWh/year Displaced Electric Demand (cooling)
	-	MWh/year Displaced Electric Demand (electric heating)
	775	MWh/year Transmission Losses
	5,936	**MWh/year Total**

CHP Results

Annual Analysis for CHP

	CHP System: Recip Engine - Rich Burn			Total Emissions from CHP System
NOx (tons/year)	0.97	-		0.97
SO2 (tons/year)	0.02	-		0.02
CO2 (tons/year)	3,096	-		3,096
Carbon (metric tons/year)	844	-		844
Fuel Consumption (MMBtu/year)	52,930	-		52,930

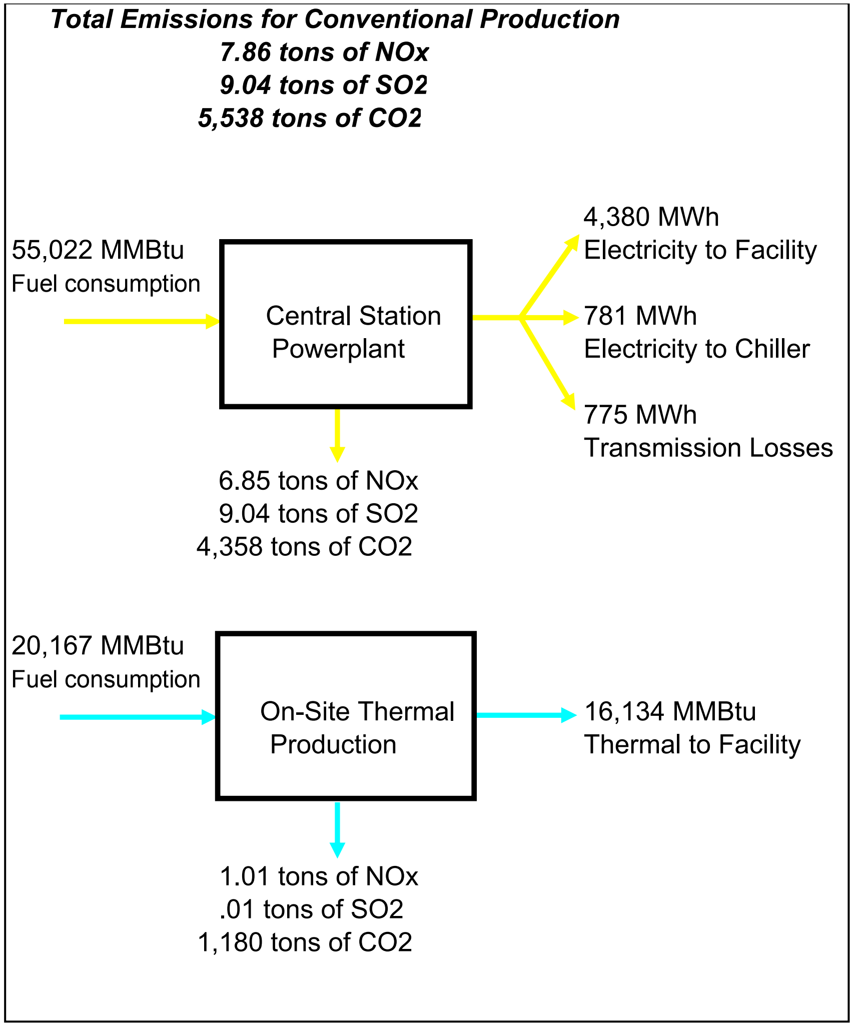
Annual Analysis for Displaced Production for Thermal (non-cooling) Applications

				Total Displaced Emissions from Thermal Production
NOx (tons/year)				1.01
SO2 (tons/year)				0.01
CO2 (tons/year)				1,180
Carbon (metric tons/year)				322
Fuel Consumption (MMBtu/year)				20,167

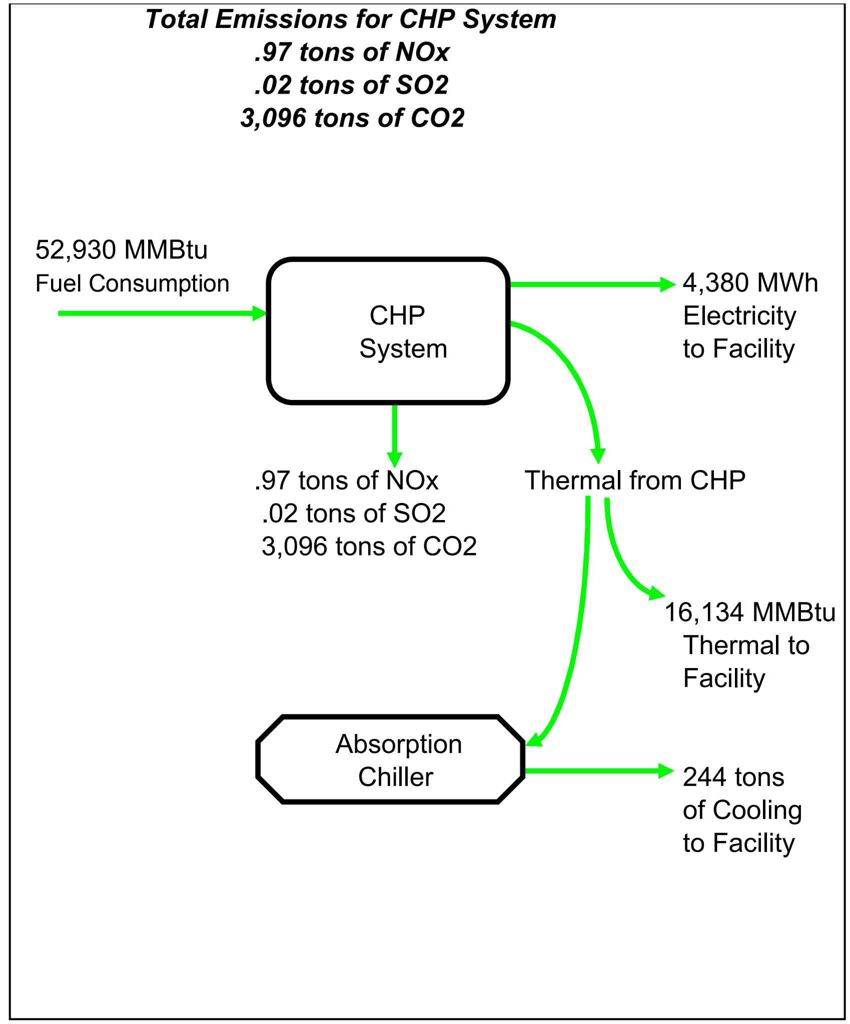
Annual Analysis for Displaced Electricity Production

	Displaced CHP Electricity Generation	Displaced Electricity for Cooling	Displaced Electricity for Heating	Transmission Losses	Total Displaced Emissions from Electricity Generation
NOx (tons/year)	5.05	0.90	-	0.89	6.85
SO2 (tons/year)	6.67	1.19	-	1.18	9.04
CO2 (tons/year)	3,216	573.30	-	569.04	4,358
Carbon (metric tons/year)	877	156	-	155	1,189
Fuel Consumption (MMBtu/year)	40,601	7,238	-	7,184	55,022

CHP Results



Total Emissions for Conventional Production
7.86 tons of NOx
9.04 tons of SO2
5,538 tons of CO2
55,022 MMBtu
Fuel consumption
Central Station Powerplant
4,380 MWh
Electricity to Facility
781 MWh
Electricity to Chiller
775 MWh
Transmission Losses
6.85 tons of NOx
9.04 tons of SO2
4,358 tons of CO2
20,167 MMBtu
Fuel consumption
On-Site Thermal Production
16,134 MMBtu
Thermal to Facility
1.01 tons of NOx
.01 tons of SO2
1,180 tons of CO2



Total Emissions for CHP System
.97 tons of NOx
.02 tons of SO2
3,096 tons of CO2
52,930 MMBtu
Fuel Consumption
CHP System
4,380 MWh
Electricity
to Facility
.97 tons of NOx
.02 tons of SO2
3,096 tons of CO2
Thermal from CHP
16,134 MMBtu
Thermal to
Facility
Absorption Chiller
244 tons
of Cooling
to Facility

CHP Results

Emission Rates

	CHP System including Duct Burners	Recip Engine - Rich Burn Alone	Displaced Electricity
NOx (lb/MWh)	0.44	0.44	2.31
SO2 (lb/MWh)	0.01	0.01	3.05
CO2 (lb/MWh)	1,414	1,414	1,469

Note: Actual NOx value used in the calculation was 1.07 lbs per MWh consistent with the value in Table 3-6 on Page 26 of main report.

Emission Rates

	Displaced Thermal Production
NOx (lb/MMBtu)	0.10
SO2 (lb/MMBtu)	0.00059
CO2 (lb/MMBtu)	117

CHP Results

*The results generated by the CHP Emissions Calculator are intended for eductional and outreach purposes only;
it is not designed for use in developing emission inventories or preparing air permit applications.*

Annual Emissions Analysis	CHP System	Displaced Electricity Production	Displaced Thermal Production	Emissions/Fuel Reduction	Percent Reduction
NOx (tons/year)	3.88	29.34	3.34	28.80	88%
SO2 (tons/year)	0.06	38.71	0.02	38.67	100%
CO2 (tons/year)	12,188	18,670	3,909	10,392	46%
Carbon (metric tons/year)	3,324	5,092	1,066	2,834	46%
Fuel Consumption (MMBtu/year)	208,339	235,700	66,826	94,187	31%
Acres of Forest Equivalent				2,834	
Number of Cars Removed				1,771	

This CHP project will reduce emissions of Carbon Dioxide (CO2) by 10,392 tons per year

This is equal to 2,834 metric tons of carbon equivalent (MTCE) per year

This reduction is equal to removing the carbon that would be absorbed by 2,834 acres of forest

OR

This reduction is equal to removing the carbon emissions of 1,771 cars

CHP Results

CHP Technology:	Recip Engine - Rich Burn	
Fuel:	Natural Gas	
Unit Capacity:	1,000	kW
Number of Units:	3	
Total CHP Capacity:	3,000	kW
Operation:	5,840	hours per year
Heat Rate:	11,891	Btu/kWh HHV
CHP Fuel Consumption:	208,339	MMBtu/year
Duct Burner Fuel Consumption:	-	MMBtu/year
Total Fuel Consumption:	**208,339**	**MMBtu/year**
Total CHP Generation:	**17,520**	**MWh/year**
Useful CHP Thermal Output:	53,461	MMBtu/year for thermal applications (non-cooling)
	39,943	MMBtu/year for electric applications (cooling and electric heating)
	93,404	**MMBtu/year Total**
Displaced On-Site Production for Thermal (non-cooling) Applications:		Existing Gas Boiler
	0.10	lb/MMBtu NOx
	0.00%	sulfur content
Displaced Electric Service (cooling and electric heating):	932	tons of cooling capacity from CHP system
CHP:	Single-Effect Absorption Chiller	
Replaces:	1.03 kW/ton (COP=3.4) 1980-vintage centrifugal compressor, water-cooled, >=150 tons capacity	
	3.41	COP
Displaced Electricity Profile:	Egrid State Average All Sources 2000	
Egrid State:	TX	
Distribution Losses:	7%	
Displaced Electricity Production:	17,520	MWh/year CHP generation
	2,400	MWh/year Displaced Electric Demand (cooling)
	-	MWh/year Displaced Electric Demand (electric heating)
	5,507	MWh/year Transmission Losses
	25,427	**MWh/year Total**

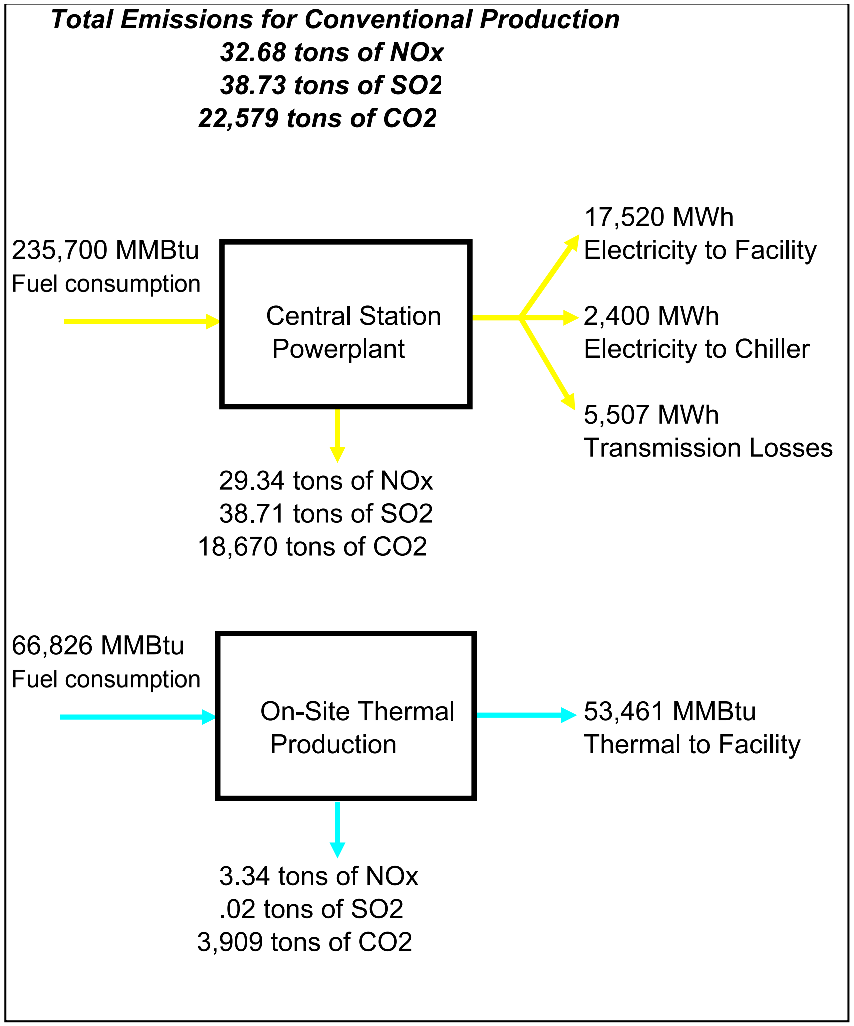
CHP Results

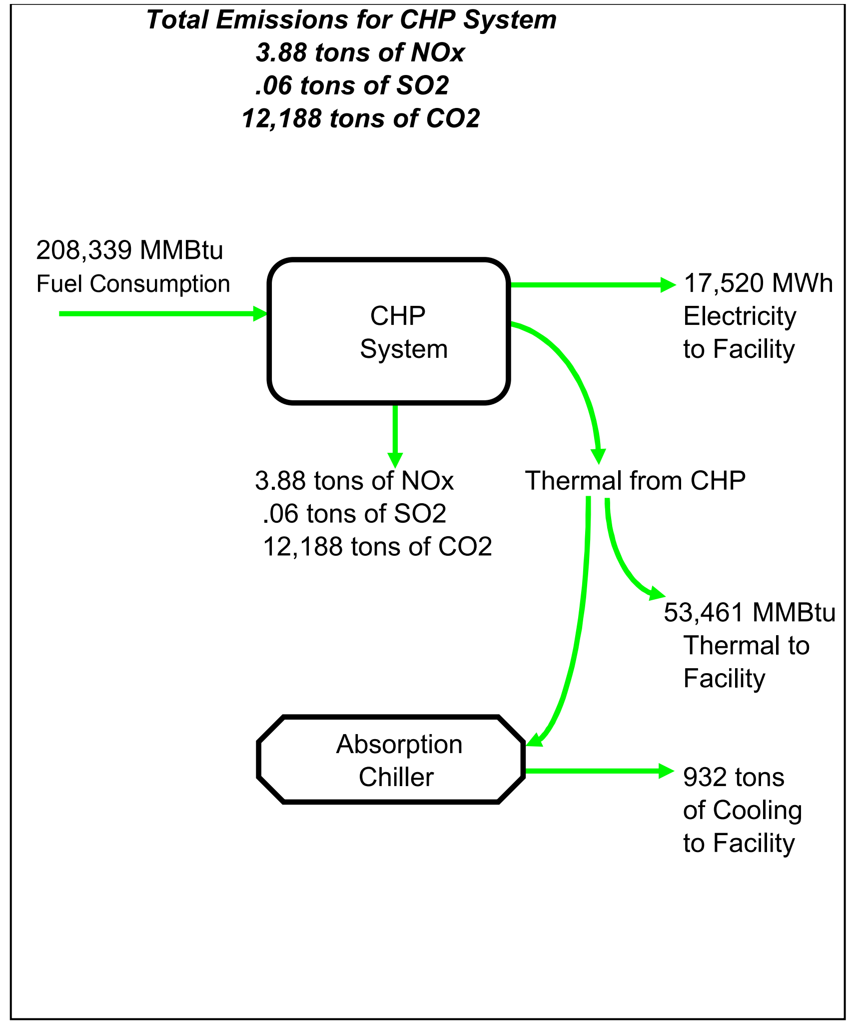
Annual Analysis for CHP				
	CHP System: Recip Engine - Rich Burn			Total Emissions from CHP System
NOx (tons/year)	3.88	-		3.88
SO2 (tons/year)	0.06	-		0.06
CO2 (tons/year)	12,188	-		12,188
Carbon (metric tons/year)	3,324	-		3,324
Fuel Consumption (MMBtu/year)	208,339	-		208,339

Annual Analysis for Displaced Production for Thermal (non-cooling) Applications				
				Total Displaced Emissions from Thermal Production
NOx (tons/year)				3.34
SO2 (tons/year)				0.02
CO2 (tons/year)				3,909
Carbon (metric tons/year)				1,066
Fuel Consumption (MMBtu/year)				66,826

Annual Analysis for Displaced Electricity Production					
	Displaced CHP Electricity Generation	Displaced Electricity for Cooling	Displaced Electricity for Heating	Transmission Losses	Total Displaced Emissions from Electricity Generation
NOx (tons/year)	20.22	2.77	-	6.36	29.34
SO2 (tons/year)	26.67	3.65	-	8.38	38.71
CO2 (tons/year)	12,864	1,762.13	-	4,043.79	18,670
Carbon (metric tons/year)	3,508	481	-	1,103	5,092
Fuel Consumption (MMBtu/year)	162,403	22,246	-	51,051	235,700

CHP Results


Total Emissions for Conventional Production
32.68 tons of NOx
38.73 tons of SO2
22,579 tons of CO2
235,700 MMBtu
Fuel consumption
Central Station Powerplant
17,520 MWh
Electricity to Facility
2,400 MWh
Electricity to Chiller
5,507 MWh
Transmission Losses
29.34 tons of NOx
38.71 tons of SO2
18,670 tons of CO2
66,826 MMBtu
Fuel consumption
On-Site Thermal Production
53,461 MMBtu
Thermal to Facility
3.34 tons of NOx
.02 tons of SO2
3,909 tons of CO2


Total Emissions for CHP System
3.88 tons of NOx
.06 tons of SO2
12,188 tons of CO2
208,339 MMBtu
Fuel Consumption
CHP System
17,520 MWh
Electricity
to Facility
3.88 tons of NOx
.06 tons of SO2
12,188 tons of CO2
Thermal from CHP
53,461 MMBtu
Thermal to
Facility
Absorption Chiller
932 tons
of Cooling
to Facility

CHP Results

Emission Rates

	CHP System including Duct Burners	Recip Engine - Rich Burn Alone	Displaced Electricity
NOx (lb/MWh)	0.44	0.44	2.31
SO2 (lb/MWh)	0.01	0.01	3.05
CO2 (lb/MWh)	1,391	1,391	1,469

Note: Actual NOx value used in the calculation was 1.07 lbs. per MWh consistent with the value in Table 3-6 on Page 26 of main report.

Emission Rates

	Displaced Thermal Production
NOx (lb/MMBtu)	0.10
SO2 (lb/MMBtu)	0.00059
CO2 (lb/MMBtu)	117

CHP Results

The results generated by the CHP Emissions Calculator are intended for eductional and outreach purposes only; it is not designed for use in developing emission inventories or preparing air permit applications.

Annual Emissions Analysis					
	CHP System	Displaced Electricity Production	Displaced Thermal Production	Emissions/Fuel Reduction	Percent Reduction
NOx (tons/year)	22.75	27.65	5.99	10.88	32%
SO2 (tons/year)	0.08	36.48	0.04	36.43	100%
CO2 (tons/year)	15,973	17,591	7,004	8,622	35%
Carbon (metric tons/year)	4,356	4,798	1,910	2,352	35%
Fuel Consumption (MMBtu/year)	273,042	222,081	119,730	68,769	20%
Acres of Forest Equivalent				2,352	
Number of Cars Removed				1,470	

This CHP project will reduce emissions of Carbon Dioxide (CO2) by 8,622 tons per year

This is equal to 2,352 metric tons of carbon equivalent (MTCE) per year

This reduction is equal to removing the carbon that would be absorbed by 2,352 acres of forest

OR

This reduction is equal to removing the carbon emissions of 1,470 cars

CHP Results

CHP Technology:	Combustion Turbine	
Fuel:	Natural Gas	
Unit Capacity:	3,000	kW
Number of Units:	1	
Total CHP Capacity:	3,000	kW
Operation:	5,840	hours per year
Heat Rate:	15,585	Btu/kWh HHV
CHP Fuel Consumption:	273,042	MMBtu/year
Duct Burner Fuel Consumption:	-	MMBtu/year
Total Fuel Consumption:	**273,042**	**MMBtu/year**
Total CHP Generation:	**17,520**	**MWh/year**
Useful CHP Thermal Output:	95,784	MMBtu/year for thermal applications (non-cooling)
	21,429	MMBtu/year for electric applications (cooling and electric heating)
	117,212	**MMBtu/year Total**
Displaced On-Site Production for		Existing Gas Boiler
Thermal (non-cooling) Applications:	0.10	lb/MMBtu NOx
	0.00%	sulfur content
Displaced Electric Service (cooling and electric heating):	1,000	tons of cooling capacity from CHP system
CHP:	Double-Effect Absorption Chiller	
Replaces:	1.03 kW/ton (COP=3.4) 1980-vintage centrifugal compressor, water-cooled, >=150 tons capacity	
	3.41	COP
Displaced Electricity Profile:	Egrid State Average All Sources 2000	
Egrid State:	TX	
Distribution Losses:	7%	
Displaced Electricity Production:	17,520	MWh/year CHP generation
	2,575	MWh/year Displaced Electric Demand (cooling)
	-	MWh/year Displaced Electric Demand (electric heating)
	3,863	MWh/year Transmission Losses
	23,958	**MWh/year Total**

CHP Results

Annual Analysis for CHP

	CHP System: Combustion Turbine			Total Emissions from CHP System
NOx (tons/year)	22.75	-		22.75
SO2 (tons/year)	0.08	-		0.08
CO2 (tons/year)	15,973	-		15,973
Carbon (metric tons/year)	4,356	-		4,356
Fuel Consumption (MMBtu/year)	273,042	-		273,042

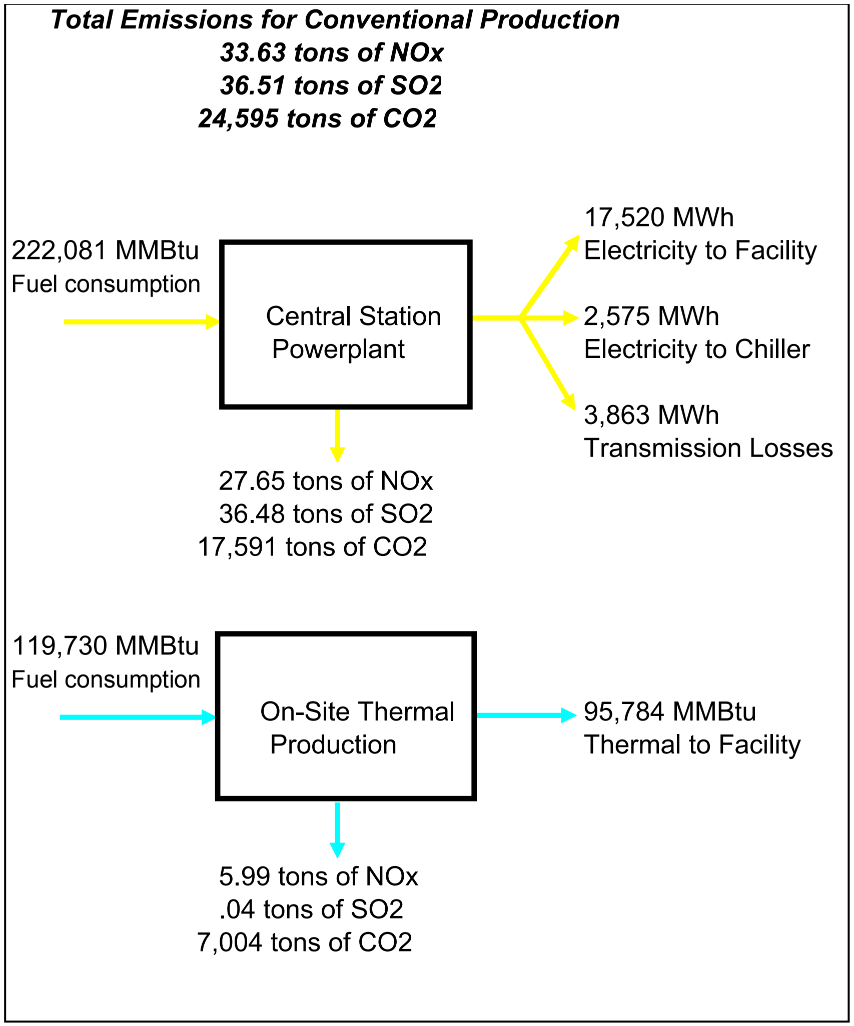
Annual Analysis for Displaced Production for Thermal (non-cooling) Applications

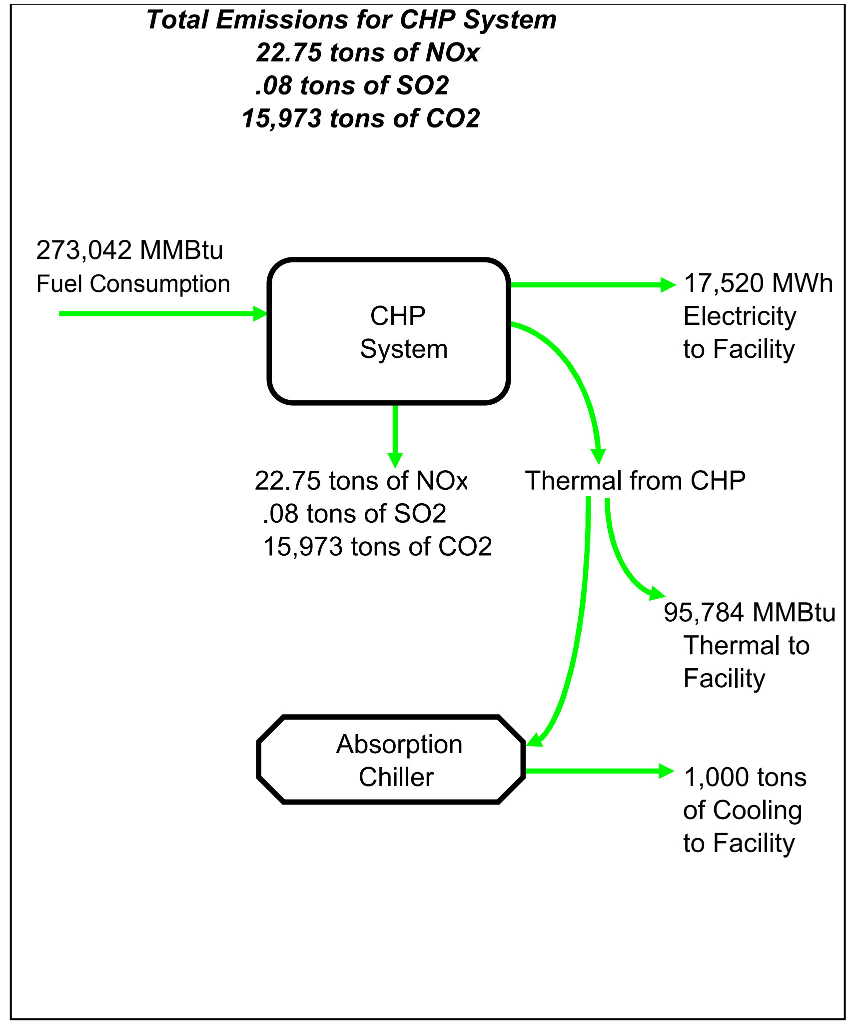
				Total Displaced Emissions from Thermal Production
NOx (tons/year)				5.99
SO2 (tons/year)				0.04
CO2 (tons/year)				7,004
Carbon (metric tons/year)				1,910
Fuel Consumption (MMBtu/year)				119,730

Annual Analysis for Displaced Electricity Production

	Displaced CHP Electricity Generation	Displaced Electricity for Cooling	Displaced Electricity for Heating	Transmission Losses	Total Displaced Emissions from Electricity Generation
NOx (tons/year)	20.22	2.97	-	4.46	27.65
SO2 (tons/year)	26.67	3.92	-	5.88	36.48
CO2 (tons/year)	12,864	1,890.70	-	2,836.42	17,591
Carbon (metric tons/year)	3,508	516	-	774	4,798
Fuel Consumption (MMBtu/year)	162,403	23,869	-	35,808	222,081

CHP Results


Total Emissions for Conventional Production
33.63 tons of NOx
36.51 tons of SO2
24,595 tons of CO2
222,081 MMBtu
Fuel consumption
Central Station Powerplant
17,520 MWh
Electricity to Facility
2,575 MWh
Electricity to Chiller
3,863 MWh
Transmission Losses
27.65 tons of NOx
36.48 tons of SO2
17,591 tons of CO2
119,730 MMBtu
Fuel consumption
On-Site Thermal Production
95,784 MMBtu
Thermal to Facility
5.99 tons of NOx
.04 tons of SO2
7,004 tons of CO2


Total Emissions for CHP System
22.75 tons of NOx
.08 tons of SO2
15,973 tons of CO2
273,042 MMBtu
Fuel Consumption
CHP System
17,520 MWh
Electricity
to Facility
22.75 tons of NOx
.08 tons of SO2
15,973 tons of CO2
Thermal from CHP
95,784 MMBtu
Thermal to
Facility
Absorption Chiller
1,000 tons
of Cooling
to Facility

CHP Results

Emission Rates

	CHP System including Duct Burners	Combustion Turbine Alone	Displaced Electricity
NOx (lb/MWh)	2.60	2.60	2.31
SO2 (lb/MWh)	0.01	0.01	3.05
CO2 (lb/MWh)	1,823	1,823	1,469

Emission Rates

	Displaced Thermal Production
NOx (lb/MMBtu)	0.10
SO2 (lb/MMBtu)	0.00059
CO2 (lb/MMBtu)	117

Note: Actual NOx value used in the calculation was 1.07 lbs per MWh consistent with the value in Table 3-6 on Page 26 of the main report.

CHP Results

The results generated by the CHP Emissions Calculator are intended for eductional and outreach purposes only; it is not designed for use in developing emission inventories or preparing air permit applications.

Annual Emissions Analysis					
	CHP System	Displaced Electricity Production	Displaced Thermal Production	Emissions/Fuel Reduction	Percent Reduction
NOx (tons/year)	51.14	142.37	13.97	105.20	67%
SO2 (tons/year)	0.30	187.84	0.08	187.62	100%
CO2 (tons/year)	60,309	90,588	16,342	46,621	44%
Carbon (metric tons/year)	16,448	24,706	4,457	12,715	44%
Fuel Consumption (MMBtu/year)	1,030,916	1,143,627	279,343	392,054	28%
Acres of Forest Equivalent				12,715	
Number of Cars Removed				7,947	

This CHP project will reduce emissions of Carbon Dioxide (CO_2) by 46,621 tons per year

This is equal to 12,715 metric tons of carbon equivalent (MTCE) per year

This reduction is equal to removing the carbon that would be absorbed by 12,715 acres of forest

OR

This reduction is equal to removing the carbon emissions of 7,947 cars

CHP Results

CHP Technology:	Combustion Turbine	
Fuel:	Natural Gas	
Unit Capacity:	10,000	kW
Number of Units:	1	
Total CHP Capacity:	10,000	kW
Operation:	8,760	hours per year
Heat Rate:	11,768	Btu/kWh HHV
CHP Fuel Consumption:	1,030,916	MMBtu/year
Duct Burner Fuel Consumption:	-	MMBtu/year
Total Fuel Consumption:	**1,030,916**	**MMBtu/year**
Total CHP Generation:	**87,600**	**MWh/year**
Useful CHP Thermal Output:	223,474	MMBtu/year for thermal applications (non-cooling)
	185,966	MMBtu/year for electric applications (cooling and electric heating)
	409,440	**MMBtu/year Total**
Displaced On-Site Production for		Existing Gas Boiler
Thermal (non-cooling) Applications:	0.10	lb/MMBtu NOx
	0.00%	sulfur content
Displaced Electric Service (cooling and electric heating):	5,424	tons of cooling capacity from CHP system
CHP:	Double-Effect Absorption Chiller	
Replaces:	1.03 kW/ton (COP=3.4) 1980-vintage centrifugal compressor, water-cooled, >=150 tons capacity	
	3.41	COP
Displaced Electricity Profile:	Egrid State Average All Sources 2000	
Egrid State:	TX	
Distribution Losses:	7%	
Displaced Electricity Production:	87,600	MWh/year CHP generation
	22,347	MWh/year Displaced Electric Demand (cooling)
	-	MWh/year Displaced Electric Demand (electric heating)
	13,427	MWh/year Transmission Losses
	123,374	**MWh/year Total**

CHP Results

Annual Analysis for CHP

	CHP System: Combustion Turbine			Total Emissions from CHP System
NOx (tons/year)	51.14	-		51.14
SO2 (tons/year)	0.30	-		0.30
CO2 (tons/year)	60,309	-		60,309
Carbon (metric tons/year)	16,448	-		16,448
Fuel Consumption (MMBtu/year)	1,030,916	-		1,030,916

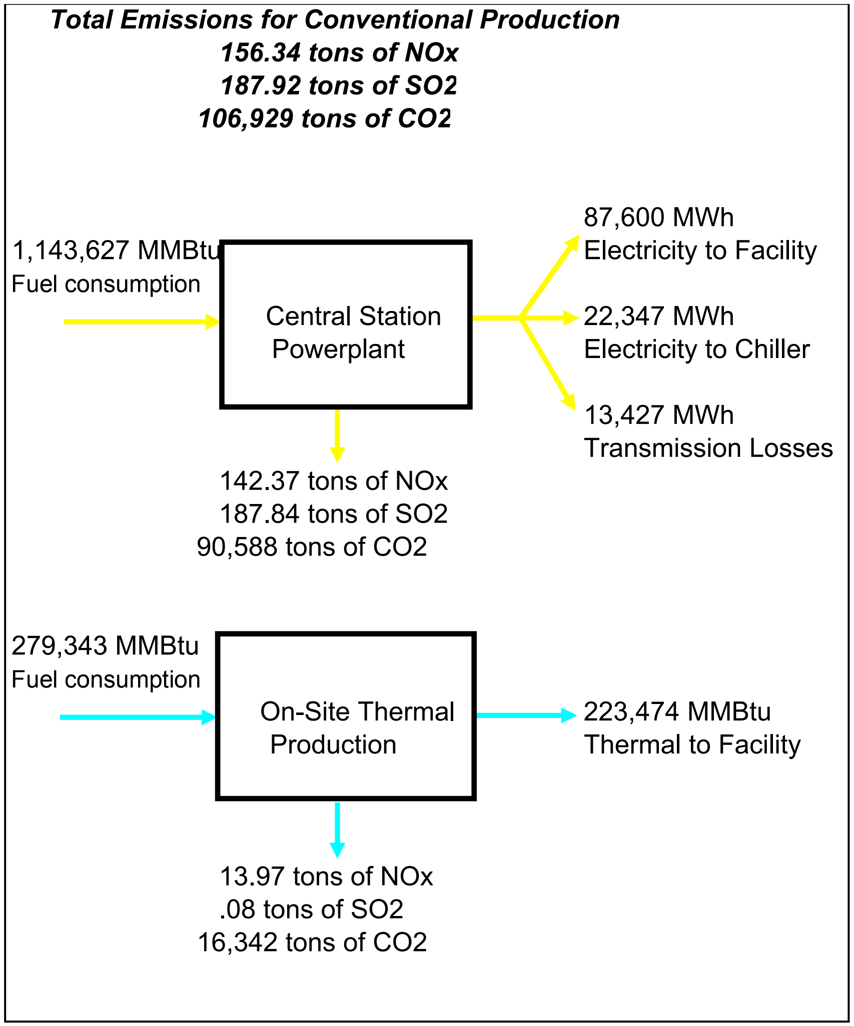
Annual Analysis for Displaced Production for Thermal (non-cooling) Applications

				Total Displaced Emissions from Thermal Production
NOx (tons/year)				13.97
SO2 (tons/year)				0.08
CO2 (tons/year)				16,342
Carbon (metric tons/year)				4,457
Fuel Consumption (MMBtu/year)				279,343

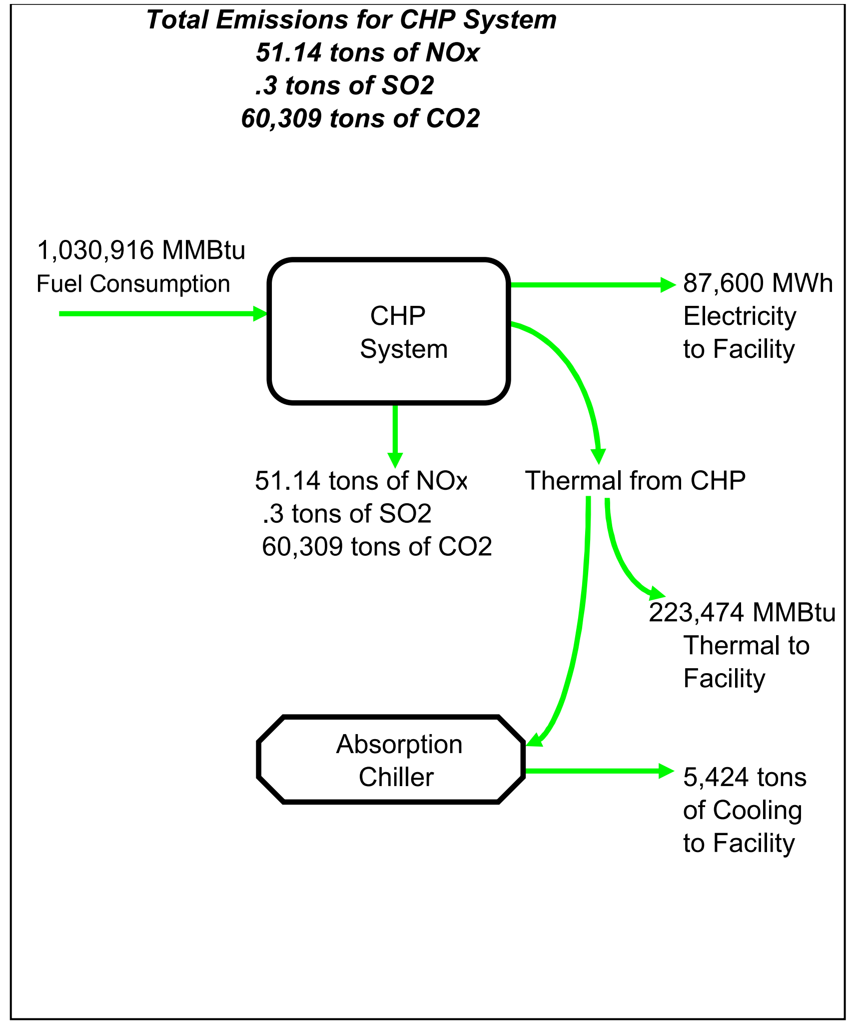
Annual Analysis for Displaced Electricity Production

	Displaced CHP Electricity Generation	Displaced Electricity for Cooling	Displaced Electricity for Heating	Transmission Losses	Total Displaced Emissions from Electricity Generation
NOx (tons/year)	101.09	25.79	-	15.50	142.37
SO2 (tons/year)	133.37	34.02	-	20.44	187.84
CO2 (tons/year)	64,321	16,408.27	-	9,858.99	90,588
Carbon (metric tons/year)	17,542	4,475	-	2,689	24,706
Fuel Consumption (MMBtu/year)	812,016	207,146	-	124,465	1,143,627

CHP Results



Total Emissions for Conventional Production
156.34 tons of NOx
187.92 tons of SO2
106,929 tons of CO2
1,143,627 MMBtu
Fuel consumption
Central Station Powerplant
87,600 MWh
Electricity to Facility
22,347 MWh
Electricity to Chiller
13,427 MWh
Transmission Losses
142.37 tons of NOx
187.84 tons of SO2
90,588 tons of CO2
279,343 MMBtu
Fuel consumption
On-Site Thermal Production
223,474 MMBtu
Thermal to Facility
13.97 tons of NOx
.08 tons of SO2
16,342 tons of CO2



Total Emissions for CHP System
51.14 tons of NOx
.3 tons of SO2
60,309 tons of CO2
1,030,916 MMBtu
Fuel Consumption
CHP System
87,600 MWh
Electricity
to Facility
51.14 tons of NOx
.3 tons of SO2
60,309 tons of CO2
Thermal from CHP
223,474 MMBtu
Thermal to
Facility
Absorption Chiller
5,424 tons
of Cooling
to Facility

CHP Results

Emission Rates

	CHP System including Duct Burners	Combustion Turbine Alone	Displaced Electricity
NOx (lb/MWh)	1.17	1.17	2.31
SO2 (lb/MWh)	0.01	0.01	3.05
CO2 (lb/MWh)	1,377	1,377	1,469

Note: Actual NOx value used in the calculation was 1.07lbs per MWh consistent with the value in Table 3-6 on Page 26 of main report.

Emission Rates

	Displaced Thermal Production
NOx (lb/MMBtu)	0.10
SO2 (lb/MMBtu)	0.00059
CO2 (lb/MMBtu)	117

CHP Results

The results generated by the CHP Emissions Calculator are intended for eductional and outreach purposes only; it is not designed for use in developing emission inventories or preparing air permit applications.

Annual Emissions Analysis

	CHP System	Displaced Electricity Production	Displaced Thermal Production	Emissions/Fuel Reduction	Percent Reduction
NOx (tons/year)	112.27	313.07	28.64	229.44	67%
SO2 (tons/year)	0.67	413.05	0.17	412.55	100%
CO2 (tons/year)	132,317	199,199	33,514	100,396	43%
Carbon (metric tons/year)	36,087	54,327	9,140	27,381	43%
Fuel Consumption (MMBtu/year)	2,261,832	2,514,789	572,886	825,842	27%
Acres of Forest Equivalent				27,381	
Number of Cars Removed				17,113	

This CHP project will reduce emissions of Carbon Dioxide (CO2) by 100,396 tons per year

This is equal to 27,381 metric tons of carbon equivalent (MTCE) per year

This reduction is equal to removing the carbon that would be absorbed by 27,381 acres of forest

OR

This reduction is equal to removing the carbon emissions of 17,113 cars

CHP Results

CHP Technology:	Combustion Turbine	
Fuel:	Natural Gas	
Unit Capacity:	20,000	kW
Number of Units:	1	
Total CHP Capacity:	20,000	kW
Operation:	8,760	hours per year
Heat Rate:	11,768	Btu/kWh HHV
CHP Fuel Consumption:	2,061,832	MMBtu/year
Duct Burner Fuel Consumption:	200,000	MMBtu/year
Total Fuel Consumption:	**2,261,832**	**MMBtu/year**
Total CHP Generation:	**175,200**	**MWh/year**
Useful CHP Thermal Output:	458,309	MMBtu/year for thermal applications (non-cooling)
	560,571	MMBtu/year for electric applications (cooling and electric heating)
	1,018,880	**MMBtu/year Total**
Displaced On-Site Production for		Existing Gas Boiler
Thermal (non-cooling) Applications:	0.10	lb/MMBtu NOx
	0.00%	sulfur content
Displaced Electric Service (cooling and electric heating):	10,900	tons of cooling capacity from CHP system
CHP:	Double-Effect Absorption Chiller	
Replaces:	1.03 kW/ton (COP=3.4) 1980-vintage centrifugal compressor, water-cooled, >=150 tons capacity	
	3.41	COP
Displaced Electricity Profile:	Egrid State Average All Sources 2000	
Egrid State:	TX	
Distribution Losses:	7%	
Displaced Electricity Production:	175,200	MWh/year CHP generation
	67,362	MWh/year Displaced Electric Demand (cooling)
	-	MWh/year Displaced Electric Demand (electric heating)
	28,733	MWh/year Transmission Losses
	271,295	**MWh/year Total**

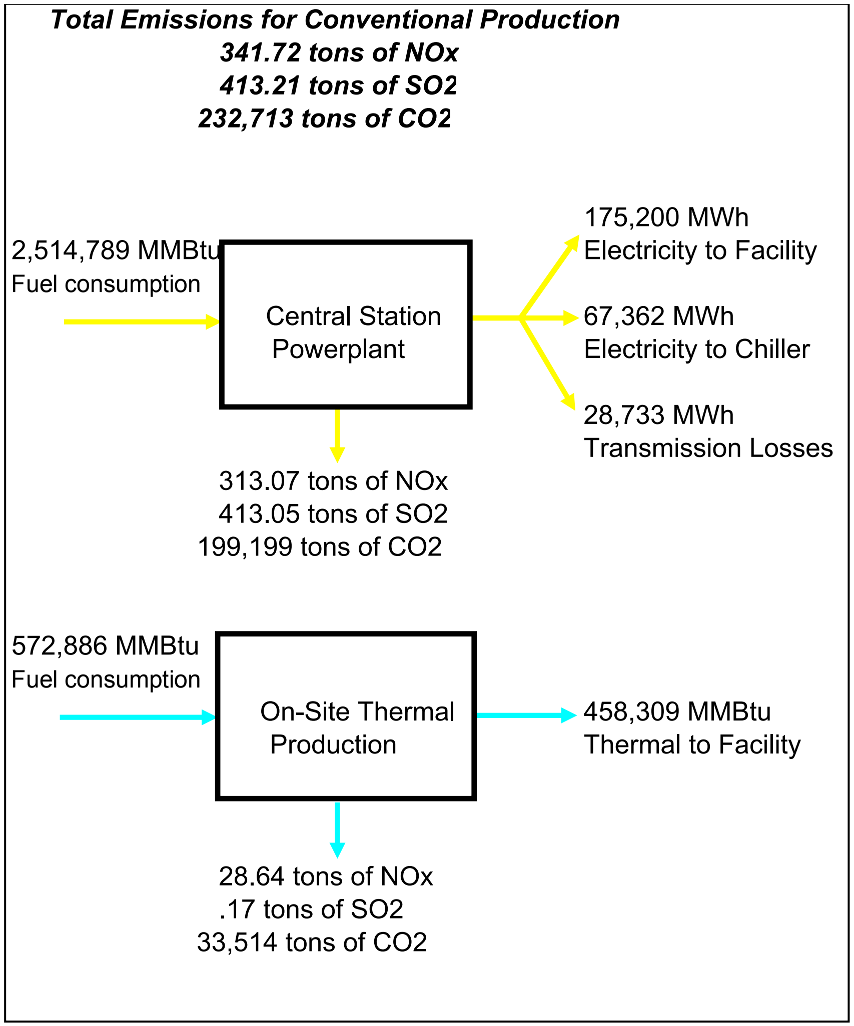
CHP Results

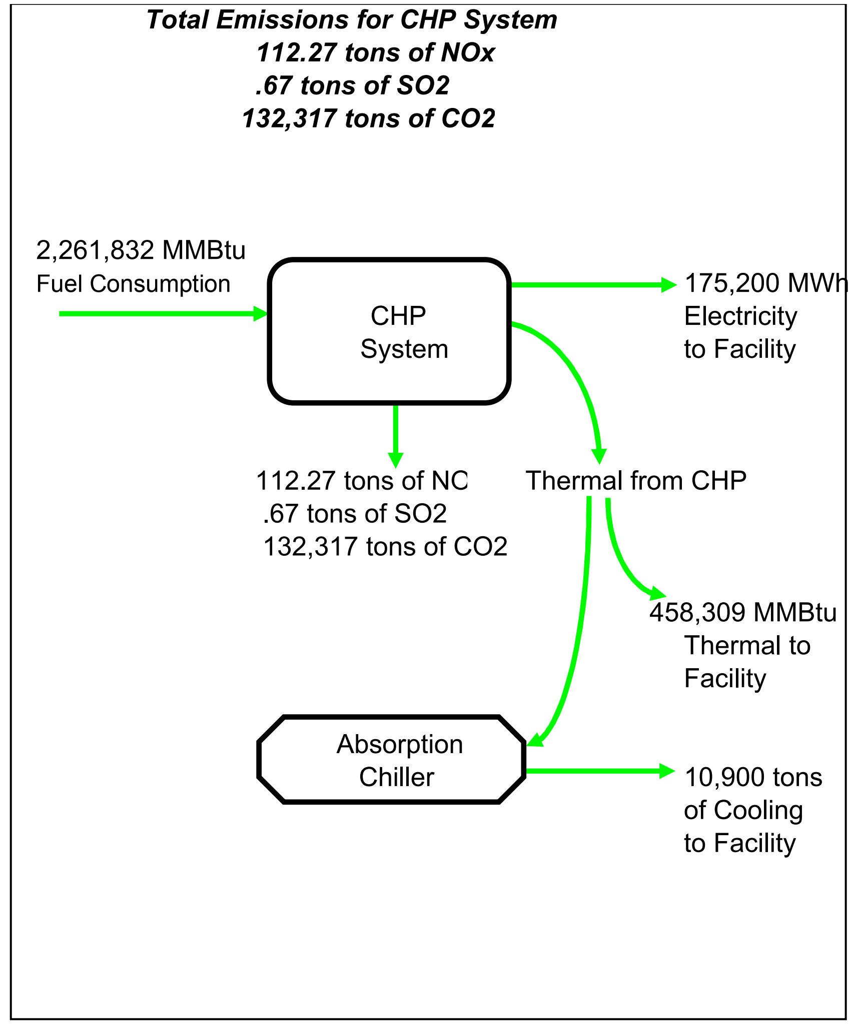
Annual Analysis for CHP				
	CHP System: Combustion Turbine	CHP System: Duct Burners		Total Emissions from CHP System
NOx (tons/year)	102.27	10.00		112.27
SO2 (tons/year)	0.61	0.06		0.67
CO2 (tons/year)	120,617	11,700		132,317
Carbon (metric tons/year)	32,896	3,191		36,087
Fuel Consumption (MMBtu/year)	2,061,832	200,000		2,261,832

Annual Analysis for Displaced Production for Thermal (non-cooling) Applications				
				Total Displaced Emissions from Thermal Production
NOx (tons/year)				28.64
SO2 (tons/year)				0.17
CO2 (tons/year)				33,514
Carbon (metric tons/year)				9,140
Fuel Consumption (MMBtu/year)				572,886

Annual Analysis for Displaced Electricity Production					
	Displaced CHP Electricity Generation	Displaced Electricity for Cooling	Displaced Electricity for Heating	Transmission Losses	Total Displaced Emissions from Electricity Generation
NOx (tons/year)	202.18	77.74	-	33.16	313.07
SO2 (tons/year)	266.74	102.56	-	43.75	413.05
CO2 (tons/year)	128,641	49,460.77	-	21,096.98	199,199
Carbon (metric tons/year)	35,084	13,489	-	5,754	54,327
Fuel Consumption (MMBtu/year)	1,624,032	624,418	-	266,339	2,514,789

CHP Results


Total Emissions for Conventional Production
341.72 tons of NOx
413.21 tons of SO2
232,713 tons of CO2
2,514,789 MMBtu
Fuel consumption
Central Station Powerplant
175,200 MWh
Electricity to Facility
67,362 MWh
Electricity to Chiller
28,733 MWh
Transmission Losses
313.07 tons of NOx
413.05 tons of SO2
199,199 tons of CO2
572,886 MMBtu
Fuel consumption
On-Site Thermal Production
458,309 MMBtu
Thermal to Facility
28.64 tons of NOx
.17 tons of SO2
33,514 tons of CO2


Total Emissions for CHP System
112.27 tons of NOx
.67 tons of SO2
132,317 tons of CO2
2,261,832 MMBtu
Fuel Consumption
CHP System
175,200 MWh
Electricity to Facility
112.27 tons of NC
.67 tons of SO2
132,317 tons of CO2
Thermal from CHP
458,309 MMBtu
Thermal to Facility
Absorption Chiller
10,900 tons
of Cooling
to Facility

CHP Results

Emission Rates

	CHP System including Duct Burners	Combustion Turbine Alone	Displaced Electricity
NOx (lb/MWh)	1.28	1.17	2.31
SO2 (lb/MWh)	0.01	0.01	3.05
CO2 (lb/MWh)	1,510	1,377	1,469

Note: Actual NOx value used in the calculation was 1.07 lbs. per MWh consistent with the value in Table 3-6 on Page 26 of main report.

Emission Rates

	Displaced Thermal Production
NOx (lb/MMBtu)	0.10
SO2 (lb/MMBtu)	0.00059
CO2 (lb/MMBtu)	117