Building Integrated Cooling, Heat & Power

For Cost-Effective Carbon Mitigation

2005 Status and Prospects for Canada, China, India and the USA

December 2005

WADE
WORLD ALLIANCE FOR DECENTRALIZED ENERGY

THE CLIMATE GROUP

Table of Contents

About WADE

WADE is a non-profit research and advocacy organization that was established in June 2002 to accelerate the worldwide deployment of decentralized energy (DE) systems. WADE is now backed by national cogeneration and DE organizations, DE companies and providers, as well as a range of national governments. In total, WADE's direct and indirect membership support includes over 200 corporations around the world.

WADE believes that the wider use of DE is a key solution to bringing about the cost-effective modernization and development of the world's electricity systems. With inefficient central power systems holding a 93% share of the world's electricity generation, and with the DE share at only about 7.2%, WADE's overall mission is to bring about the doubling of this share to 14% by 2012. A more cost-effective, sustainable and robust electricity system will emerge as the share of DE increases.

To work towards its goal WADE undertakes a growing range of research and other actions on behalf of its supporters and members:

- WADE carries out promotional activities and research to document all aspects of DE, including policy, regulatory, economic and environmental aspects in key countries and regions.
- WADE works to extend the international network of national DE and cogeneration organizations. Current WADE network members represent Europe, the USA, India, China, Brazil Australia and Canada.
- WADE provides a forum for DE companies and organizations to convene and communicate.
- WADE jointly produces an industry journal: "Cogeneration and On-Site Power" (published by James and James in association with WADE).

About The Climate Group

The Climate Group is an independent, nonprofit organization dedicated to advancing business and government leadership on climate change. We are based in the UK, the USA and Australia and operate internationally.

The organization was founded in 2004 by a diverse group of companies, governments and supporters who saw the opportunity to create new momentum in the international effort to stop global warming.

Proactive companies, states and cities around the world are demonstrating that cuts in greenhouse gases required to stop climate change can be achieved whilst growing the bottom line. Using the work of these leaders as a catalyst, The Climate Group works to accelerate international action on global warming with a new, strong focus on practical solutions.

We promote the development and sharing of expertise on how business and government can lead the way towards a low carbon economy whilst boosting profitability and competitiveness.

The Climate Group represents a new approach. Focused on solutions and positive collaboration across the government, business and non-profit sectors, we act independently of special interests and political affiliations.

The Climate Group is a publicly supported 501(c)(3) nonprofit in the USA and holds equivalent charitable status in the United Kingdom (registered charity no. 1102909) and Australia (registration pending).

Acknowledgments

The author would like to thank the following individuals for their help in the researching and writing of this paper:

Hirohisa Aki, National Institute of Advanced Industrial Science and Technology,
Jan Berry, Oak Ridge National Laboratory,
Rob Brandon, Natural Resources Canada,
Sytze Dijkstra, the World Alliance for Decentralized Energy,
Mark Kenber, The Climate Group,
Chris Marnay, Lawrence Berkeley National Laboratory,
John Nyboer, Simon Fraser University,
Bob Obrien, WSU Energy Program,
Diana Profir, The Climate Group,
Bryn Sadownik, M.K. Jaccard & Associates,
Catherine Strickland, Strickland Energy Consulting,
Michael Totten, Conservation International,
Kuang Weida, Chinese Academy of Social Sciences,
Nan Zhou, Lawrence Berkeley National Laboratory.

All efforts have been made to ensure that the data contained in this report is the best available at the time of publication. If you are aware of any omissions or errors in the data used to make the calculations in this report, please contact WADE and bring the error(s) or omission(s) to our attention.

Lead Author:
Jeff Bell, the World Alliance for Decentralized Energy

This report was revised in June 2006.

Acronyms

BCHP	Building Integrated Cooling Heat and Power
CCGT	Combined Cycle Gas Turbine
CHP	Combined Heat and Power (cogeneration)
DE	Decentralized Energy
EIA	Energy Information Administration
ESCO	Energy Service Company
GDP	Gross Domestic Product
GHG	Greenhouse Gas(es)
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
T&D	Transmission and Distribution
USCHPA	United Stated Combined Heat and Power Association
WADE	The World Alliance for Decentralized Energy

Executive Summary

Report Objective

This WADE research report set out to explore the potential for the cost-effective development of carbon saving building-based cooling, heat and power (BCHP) systems in the US, Canada, China and India. These high efficiency systems, that deliver electricity, heat and/or cooling, are already applied widely in many parts of the world, but there is scope for greater use in most countries. Significantly, WADE's research indicates that BCHP expansion can not only make a major contribution to carbon emission reduction in the power sector, but can also deliver cost savings in energy generation and supply. If the various institutional and regulatory barriers to BCHP that exist in most countries today could be eliminated, then the full cost-saving potential of BCHP could be achieved in a relatively short period of time.

Background

The US, China, Canada and India are four of the world's heaviest energy users. In 2002 they were respectively the first, second, sixth and seventh overall users of electricity. Much of the power generated in these countries is fossil fuel-based and thus represents the source of large volumes of CO2 emissions.

In each country, commercial and residential buildings account for a large part of the total energy demand. This report examines the potential of one supply-side approach used for improving the sector's energy efficiency - BCHP. The full technical potential of using BCHP systems for carbon abatement in the buildings sector is great. The potential to save costs and increase profitability, which the report assesses for the above mentioned four countries, cannot be ignored as a viable and important option for cutting emissions and energy costs at the same time.

The BCHP Opportunity – Simultaneous Carbon and Cost Benefits

BCHP describes any technology that simultaneously generates both useful electrical and thermal (heat and/or cooling) energy in commercial or residential buildings. There is a wide variety of technologies that can be used in BCHP applications, ranging from 1 kWe micro-CHP systems to multi-MWe reciprocating engine and gas turbine installations. Similarly, fuels used in BCHP applications can also range widely, from fossil-fuel based to renewable sources.

The most established of the BCHP technologies, diesel- and gas-fired reciprocating engines, are already used around the world, including in many buildings, but often in power-only mode. The key to unlocking the substantial carbon mitigation potential of BCHP technologies is to optimise fuel use by utilizing both the thermal and the electrical energy.

In this way, BCHP can operate at efficiencies of 70% to 90%, displacing on-site boilers (used to provide both heating and cooling) and grid-based electricity. When the displaced fuels are fossil-based, which is usually the case, BCHP becomes the major source of carbon reductions. When a gas-fired BCHP system is displacing coal-based electricity and/or heat, the carbon savings are very significant.

Buildings provide an excellent opportunity for BCHP investment because there is often a steady demand for both thermal energy and power. The greater and more constant the thermal demand the better suited the building is for BCHP systems. Thus, hospitals and hotels are some of the best examples because of their constant use. In addition, office complexes, residential apartment buildings, shopping centres and other leisure facilities provide other clear opportunities for installing BCHP systems.

The economic benefit of BCHP is mainly driven by the avoided investment costs in transmission and distribution (T&D) networks associated with central, remote power stations. WADE has created a robust economic model, which has now been applied on behalf of customers in several countries, that quantifies these cost savings. In this way, WADE has been able to assess the degree to which the carbon savings that arise from BCHP can result in specific economic benefits for the country concerned.

Research Methodology

WADE has adapted a levelised cost model, developed by Delta Energy & Environment, to make a detailed comparison of a 1 MWe gas-fired CHP system, based on a reciprocating engine and serving an intermediate thermal load of 5,000 – 5,500 hours per year, with a boiler and grid-based electricity provision. In the cases of the US and Canada, these displaced supply systems have been assumed to be a gas-fired boiler and the current mix of fossil-based generation. In India and China, where natural gas supply is emerging rapidly, they have been assumed to be a coal-fired boilers and the current mix of fossil-based generation. Arguments can be made for alternative substitutions, some of which would result in lower carbon savings arising from BCHP, and some would result in higher savings. WADE has aimed to come to a balanced assessment.

The technical potential for BCHP may well account for all, if not more than the total national electricity demand in most countries, but this is normally only of academic interest. It is the *cost-effective* potential that WADE has sought to assess. In order to do this, it has created a series of scenarios for each of the four countries that relate to the share of new electricity demand in the residential and commercial sectors that could be taken by BCHP in the period to 2020. These shares vary according to sector and country based on the very different climatic and other factors that exist in the various countries. Table ES1. below summarises the scenarios:

Table ES1. BCHP Growth Scenarios

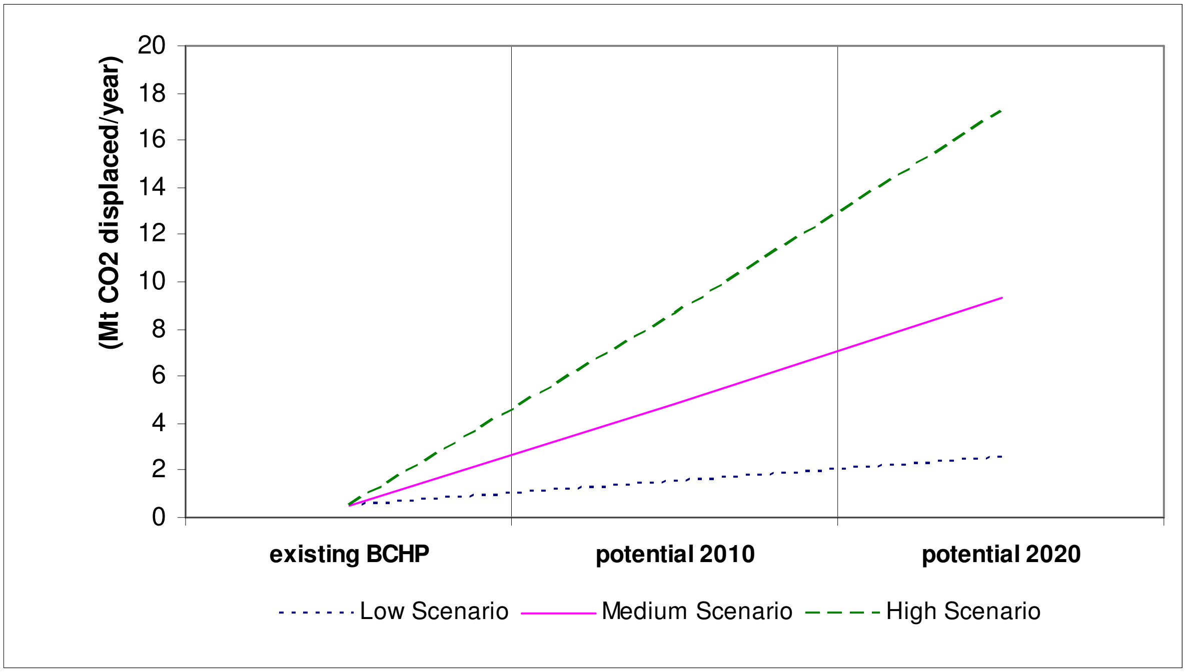
Country	Sector	BCHP Sector Growth Scenarios		
		Business-as-usual	Medium	High
Canada	Residential	5%	20%	40%
	Commercial	5%	25%	45%
China	Residential	5%	15%	35%
	Commercial	5%	20%	40%
India	Residential	5%	10%	30%
	Commercial	5%	15%	35%
USA	Residential	5%	20%	40%
	Commercial	5%	25%	45%

Source: WADE assumptions

Carbon Savings in Canada

In the case of Canada about 0.5 Mt CO_2 is saved every year as a result of the existing installations of BCHP. The economic potential for BCHP is summarized in Figure ES1.

Figure ES1. CO2 Mitigation Potential from the Canadian Building Sector



Source: WADE projections

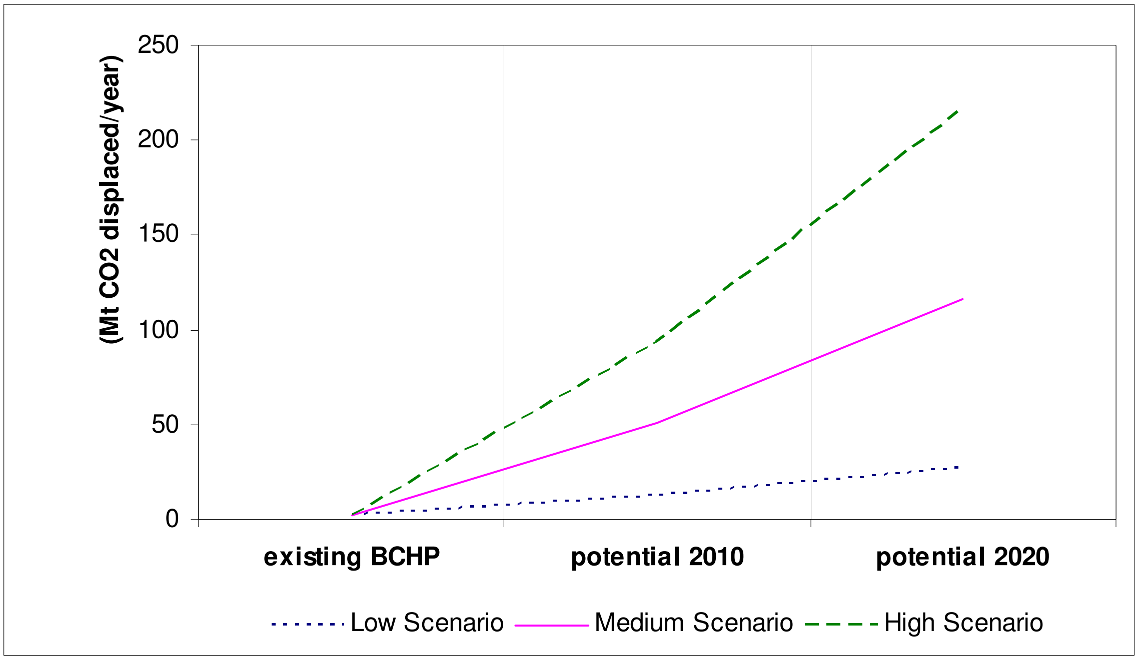
With only 5% BCHP uptake there is a potential to annually eliminate 2% of the total emissions resulting from stationary sources during the first Kyoto commitment period (2008-2012). In the high scenario, BCHP alone could cut total projected emissions growth in 2020 by 16%, and could achieve around 10% of the total emissions cuts required to achieve Canada's Kyoto target during the same 2008 – 2012 period.

In order to realize the carbon mitigation promised by the high scenario, federal and provincial governments will have to take more assertive steps to remove barriers and streamline grid interconnection arrangements for BCHP.

Carbon Savings in the United States

In the United States, there is already more than 3,500 MW of BCHP currently installed which displaces some 2 million tons of CO_2 annually. Figure ES2 below highlights the carbon savings arising from the three growth scenarios.

Figure ES2. CO_2 Mitigation Potential from BCHP in the US Building Sector



Source: WADE projections

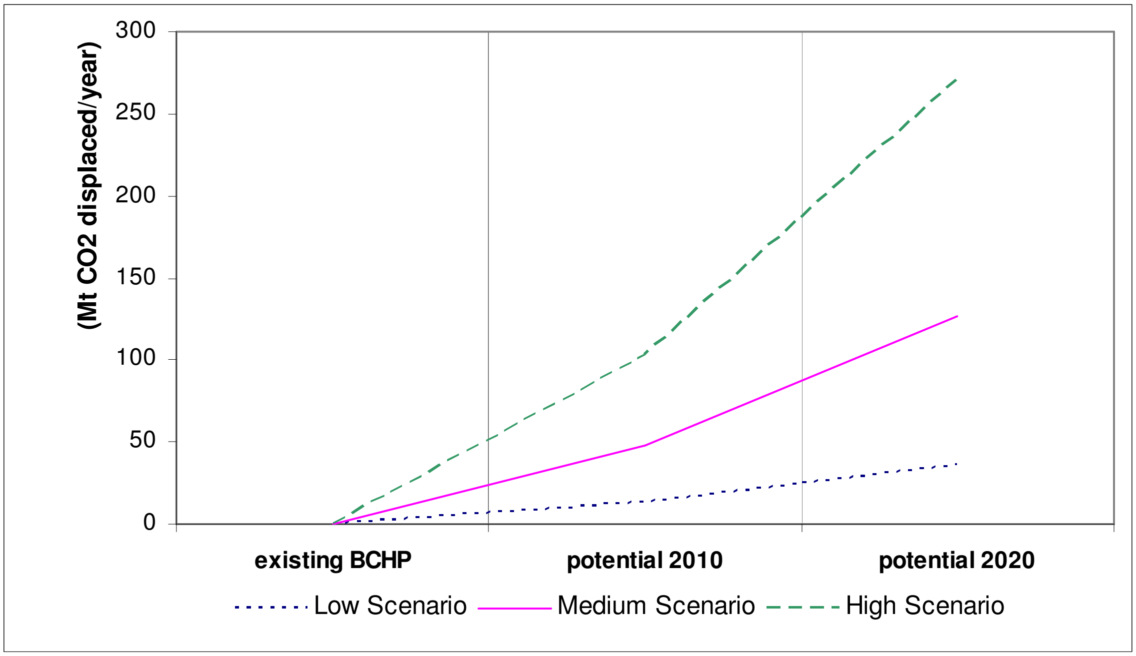
Based on CO_2 emissions projections of the International Energy Agency, the WADE projections suggest that in the low scenario, BCHP has the potential to displace close to 3% of the projected growth of total emissions. In the high scenario about 20% of total emissions growth (in all sectors) could be displaced.

The US BCHP market will largely be driven by energy security and cost issues. These two important drivers plus an improving regulatory landscape, together with an established history of BCHP projects, suggest a promising future for widescale BCHP investment in the US.

Carbon Savings in China

BCHP is a new phenomenon for China, where large municipal scale CHP is the conventional form of energy delivery at present. In recent years, however, China has installed about 21 MW of BCHP in a wide array of buildings, ranging from hotels and hospitals to offices and retail outlets. The installations are already displacing some 101 thousand tons of CO_2 every year. Regardless of the the encouraging nature of the recently emerging trend, enormous unrealised potential for BCHP applications to cut carbon emissions from buildings still exists. Figure ES3. below shows the WADE projections of what could be achieved economically in the near- and medium-term under the three different scenarios.

Figure ES3. CO_2 Mitigation Potential from BCHP in the Chinese Building Sector



Source: WADE projections

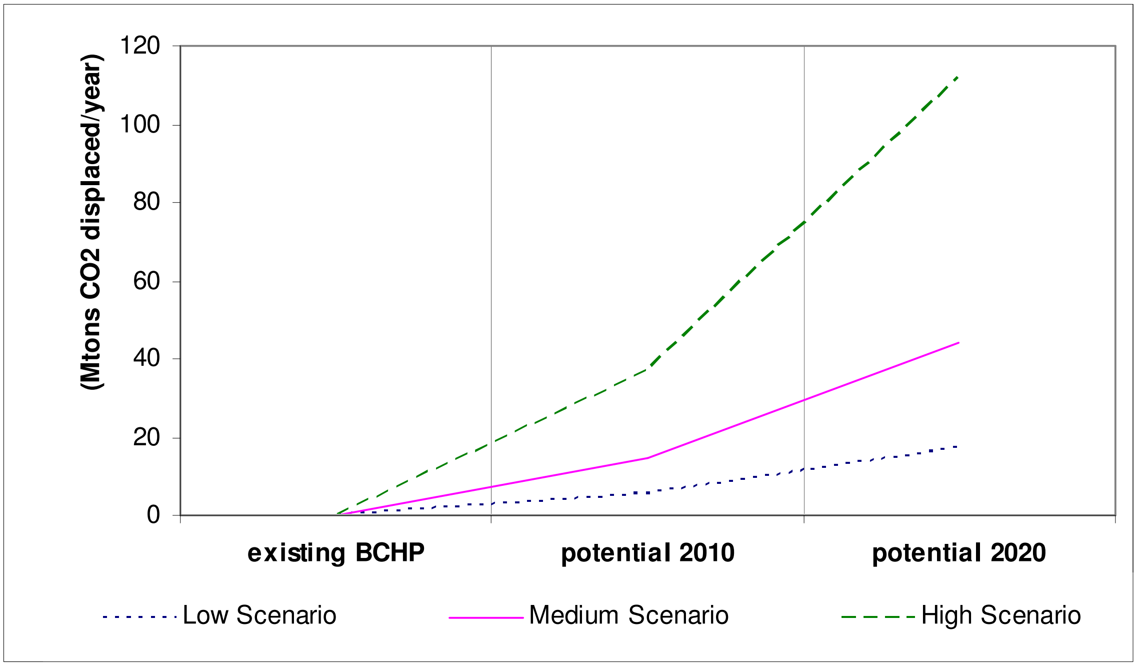
Based on the high BCHP uptake scenario, which some might regard as conservative, about 11% of the projected growth in CO_2 emissions in all sectors for 2020 could be displaced by BCHP alone.

The key challenge for BCHP in China is recognition. The concept of local scale on-site generation is relatively new, and demonstration projects have an important role to play. With national energy policy targeting efficiency as a central objective, there is every chance that some of the obstacles facing BCHP can be removed in the short term.

Carbon Savings in India

Like in the case of China above, the concept of generating power and thermal energy on-site is little known in India. However, approximately 30 MW of BCHP is currently installed, which already displace some 160 thousand tons of CO2 every year. Figure ES4. shows the various projections for carbon savings based on the three different scenarios assumed for the development of cost-effective projects.

Figure ES4. CO_2 Mitigation Potential from BCHP in the Indian Building Sector



Source: WADE projections

The low growth scenario results in 5.7 Mt of displaced CO_2 by 2010, around 2.3% of the projected CO_2 emissions growth of all sectors. The high scenario shows BCHP could displace 16.1% of the total CO_2 emissions growth projected for 2020 based on a 2002 baseline.

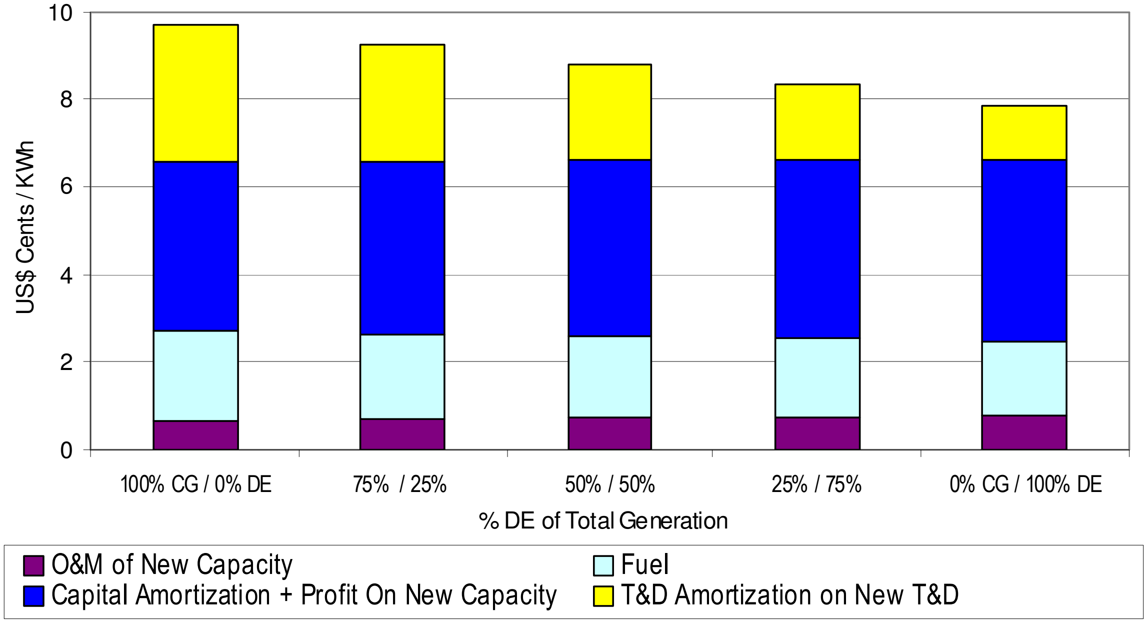
The Economic Benefits of BCHP

BCHP is a major part of the overall sectoral spread of decentralised energy (DE). The other main category is industrial-based CHP. In order to quantify the extent to which DE, including BCHP, can reduce overall system costs, WADE has developed an economic model that is able to compare the relative costs of DE and conventional central generation in meeting the new capacity requirements in any country, city or region. The model has been applied to both the US (in 2002) and to China (2004).

The model takes into account all aspects of system development and operation, including the transmission and distribution network (T&D). When these costs are taken into account, as the two output charts below indicate, the costs of newly developed DE are significantly lower than those for conventional central generation.

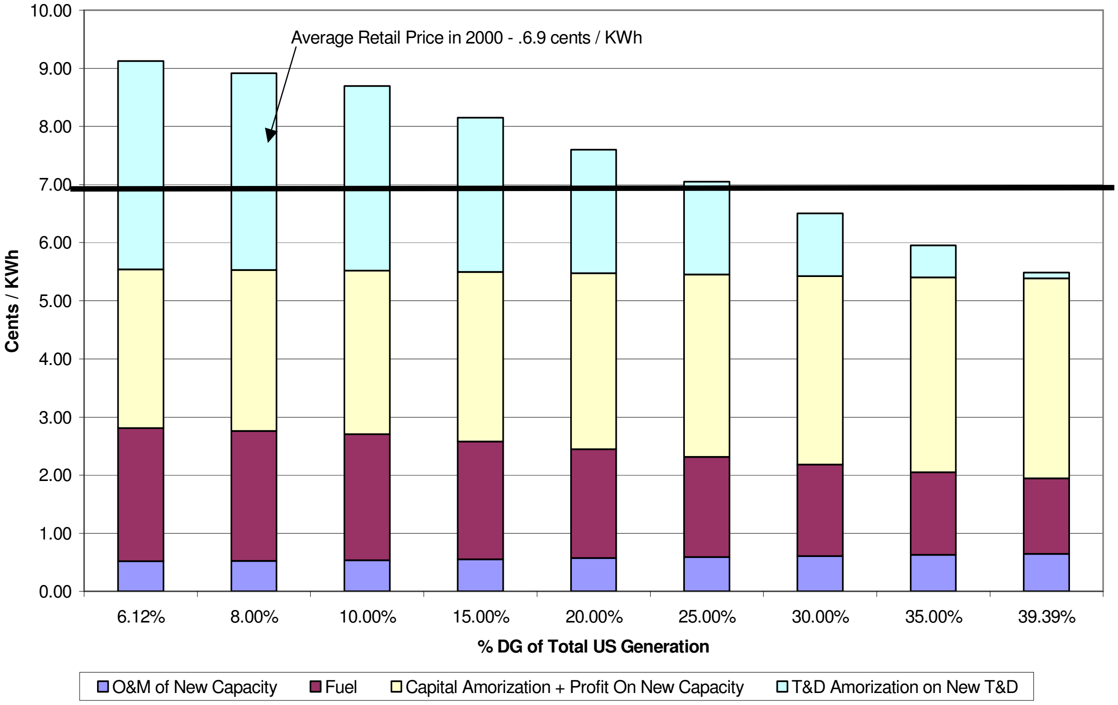
Figure ES5 below shows the outputs of the model that was run for China. It shows the average electricity retail costs that would result from five different scenarios of capacity development over the next 20 years, ranging from 100% new central generation (and no new DE) to 100% new DE development (and no new central generation). Figure ES6 shows the outputs of the model that was run for the US. Again, the two extreme example reflect either 100% new central generation development, or 100% new DE development taking place over the next 20 years. In this portrayal of the data, the columns reflect different shares of DE in the whole power market after year 20, and highlights that even in the 100% DE scenario, the overall share of central generation in year 20 continues to exceed 50%.

Figure ES5.
Retail Price of Electricity in China as Function of Penetration of DE in New Investment (2021)



Source: 103

Figure ES6.
Retail Price of Electricity in The USA as Function of Penetration of DE in New Investment (2021)



Source: WADE

Introduction

Need for Carbon Reductions

The Intergovernmental Panel on Climate Change (IPCC), in its latest report, concluded that the global mean temperature has increased by 0.6ºC during the 20th century. This increase is thought to be a result of increasing greenhouse gases in the atmosphere and has resulted in a corresponding loss of snow and ice cover, more frequent & severe storms, changes in precipitation patterns, increases in drought, and rising sea levels[1]. The same IPCC report concludes that there exists robust evidence that human activities are intensifying the problem. In the words of the publication's authors: "There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities" [1].

Regardless of the cause of climate change there is a strong argument for taking steps to reduce atmospheric pollution including greenhouse gases such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), chlorofluorocarbons (CFCs) and their substitutes. Most steps to reduce GHG will also have the added benefit of reducing other air pollutants such as SO_2, NO_x and particulates. Reducing emissions can have enormous environmental benefits in terms of clean air but there is also much evidence to show that reducing emissions can be quite profitable. This report will discuss one method for reducing carbon emissions in where concentrating efforts could prove very effective: in residential and commercial buildings.

Potential in Building Sector

A large percentage of the total global carbon emissions can be attributed to the building sector. Based on an extrapolation of IPCC data (Table 1.) WADE estimates that 1.8 billion tons of carbon resulted from heating, cooling and powering commercial and residential buildings globally in 2005 (including power generation emissions for power used in buildings). This equals about a third of total global carbon emissions. There is also evidence that the building sector represents a growing percentage of the overall total emissions[1].

Needless to say that in any sector responsible for such a high percentage of GHG emissions enormous potential for improvement exists. There are many practical methods for reducing emissions in the building sector, including improved insulation, passive heating and cooling design, and energy efficient appliances among many others. In order to realize the full potential for emissions reductions in the building sector, all these options, as well as others not mentioned here, will have to be applied together as part of a an overall, all-encompassing solution. The purpose of this report, however, is to estimate the potential of using only one such method, namely BCHP or building integrated cooling heat and power technology, for achieving cost-effective carbon emission reductions in the buildings sector.

Table 1. Projected Proportion of Overall GHG emissions from the Building Sector

Sector	Carbon emissions		Average annual growth rate (%)				Projected carbon emissions	
	(MtC) 1995	percent share, 1995	1971-1990	1990-1995	1995-2000 [a]	2000-2005 [a]	(MtC) 2005	percent share, 2005
Industry	2370	43%	1.7	0.4	0.4	0.4	2389	42%
Buildings Residential	1172	21%	1.8	1.0	1.0	1.0	1196	21%
Buildings Commercial	584	10%	2.2	1.0	1.0	1.0	596	10%
Transport	1227	22%	2.6	2.4	2.4	2.4	1287	23%
Agriculture	223	4%	3.8	0.8	0.8	0.8	227	4%
Total	5577	100%	2.0	1.0	1.0	1.0	5693	100%
Electricity [b]	1762	32%	2.3	1.7	1.7	1.7	1822	32%

a assumed

b including residential and commercial use and all other sectors

Source: WADE projection based on 1

What is BCHP?

BCHP can greatly reduce the carbon impact of the building sector by efficiently generating electricity on the building site. Onsite generation displaces the need to generate electricity (via fossil fuels) remotely in order to meet a building's power demand. Because BCHP burns the fuel for generation on-site the heat from the combustion can be used to provide space or water heating or drive chillers for cooling. This added efficiency is most often unavailable to large remote plants because thermal loads (or in other words places that could utilize the heat) are located too far away from the generation facility. As a result total fuel used to meet the heating, cooling and power demands can easily be reduced by about 25% with BCHP. Twenty five percent less fuel to provide the same services means twenty five percent less emissions.

The Technologies

There are many technologies that can and are already being used in BCHP applications today. Below is a short description of the main technologies[*]:

Reciprocating Engines

Typical Scale: 0.015MW-60MW
Fuels: (heavy oil, diesel, gas, biogas)
Comments: A very common and mass produced generation unit, reciprocating engines currently account for most BCHP applications around the world. Both compression ignition types and spark ignition types can be used in BCHP applications.
Typical Cost: 900-1500$/kW + operation and maintenance (0.005 to 0.02$/kWh)

Gas Turbines

Typical Scale: 0.1MW-200MW
Fuels: usually natural gas

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[*] For a detailed description of the various BCHP technologies see 2

Comments: Gas Turbines are the technology of choice in areas where gas prices compare favourably to the prices of other fuels. These turbines have high efficiencies and high environmental performance. Possible configurations include: cogeneration, simple cycle, recuperated cycle, combined cycle.
Typical Cost: 800-1800$/kW + operation and maintenance (0.003 to 0.01$/kWh)

Steam Turbines
Typical Scale: 0.05MW-500MW
Fuels: various (coal, oil, gas, biomass)
Comments: This is a very common and well established technology, also known as Rankin cycle plant. Steam turbines can be of either back pressure or condensing type.
Typical Cost: 400-1500$/kW + operation and maintenance (<0.004$/kWh)

Microturbines
Typical Scale: 0.025MW- 0.5MW
Fuels: usually natural gas
Comments: An important emerging option for BCHP applications on smaller scales.
Typical Cost: 1300-2500$/kW + operation and maintenance (<0.005 to 0.016 $/kWh)

Sterling Engines
Typical Scale: 0.001MW- 0.025MW
Fuels: usually natural gas
Comments: Sterling engines, an emerging external combustion technology, already have captured an important market share of the BCHP units installed in the single-family dwellings.
Typical Cost: 2000-5000$/kW + operation and maintenance (<0.001 to 0.035 $/kWh)

Drivers of BCHP

Today many factors are converging that promise to increase the popularity of BCHP systems and make them more accessible to a growing number of residential and commercial property owners:

- Public interest in BCHP is increasing;
- Economics are improving;
- Access to a suitable fuel is becoming more widespread;
- Policy barriers are being overcome;
- Emerging business opportunities abound;
- Demand for reliability is increasing; and
- Demand for thermal energy is also growing.

The sections below address each of these trends and their impact on the increased BCHP utilization.

Public Appeal

Awareness of the environmental and economic benefits of BCHP is increasing the appeal of BCHP to both policy makers and the general public. Word is getting around. Increased awareness is rapidly becoming a key driver behind an increased demand for BCHP system.

Economics

The economics of BCHP are improving as technologies mature and the environmental benefits of the technologies are recognized. Decreasing costs per kilowatt hour due to technological advances, as well as financial support for BCHP (because of the wider recognition of the environmental benefits) are two major drivers making BCHP more widely accessible to building owners.

One important consideration is that the value of a BCHP system in many cases can be gauged by comparing the cost of a BCHP system with that of a conventional boiler. As boilers reach retirement age and require replacement, property owners have the opportunity to consider whether the additional upside of generating power warrants the additional capital cost required to install a BCHP system instead of a conventional boiler. Though a BCHP system will not always supply all of a building's power needs, it will, however provide an extra layer of security that a conventional boiler cannot. In cases where a building has a continual load of heating or cooling a BCHP system may even be sized to meet all local power demands and could send a net amount of power to the grid (providing an attractive financial upside and further accelerating the project's payback).

Fuel

Perhaps the single most important factor hampering BCHP investment is access to an affordable fuel – in most cases natural gas. Gas prices - more specifically the difference between electricity and gas prices, also referred to as "spark spread" - are often cited as the greatest obstacle to BCHP investment. Of course this only applies to those areas that have access to natural gas supplies in the first place. Developing urban gas distribution pipelines in order to make gas more readily available for use in buildings in countries like China and India is the single most important factor which will determine the success of BCHP penetration in those countries.

There is a compelling argument that scarce gas supplies should be used in the most efficient manner possible. Where gas resources have been exploited they should be used not for centralized combined cycle gas turbines (with a maximum efficiency of about 50%); but rather, in applications where waste heat can be put to use thus creating an efficiency of upwards of 75%. The philosophy of wanting to get the most out of scarce gas should drive BCHP investment.

Many BCHP plants are diesel-fired and there is already a well established distribution network for diesel fuel. The rising price of fossil energy provides an ever greater incentive to maximize the efficient use of diesel in CHP applications. Continued research into other fuels, such as biodiesel or biogas, as well as additional investments in their distribution networks will also play a role in shaping the market for BCHP.

Policy

Major barriers facing potential BCHP investors around the globe are outdated policies designed to protect vertically integrated utility monopolies. In many cases such policies still exist because they have been accepted for so long that there is a strong inertia to remove them. Recurring issues include rules preventing BCHP investors from connecting their systems to the grid and inadequate economic mechanisms to remunerate for any excess power fed into the grid (even in cases when the export is not a net export). Other examples of policy-related barriers to BCHP deployment include unfavourable tax structures, lack of training programs to provide the needed skills and awareness, or, in some cases, outright laws prohibiting on-site heat and power generation. There is also a systematic bias in much of today's environmental policy and debate favouring carbon abatements from use of renewables and ignoring the huge potential of mitigation which can be realized by improving efficiencies in fossil fuel-based generation on the supply side. As these policy barriers are addressed BCHP investment will naturally emerge.

Emerging Business Opportunities

Energy Service Companies (ESCOs)- companies that sell energy savings- are already well established around the world. Nevertheless the market is far from saturated and, in emerging economies especially, there is enormous market for energy savings on both the supply-side and the demand-side. An emerging market for BCHP based on the ESCO model is a distinct possibility.

Demand for Reliability

Increasingly all types of building occupants are demanding reliable power. Already in many examples demand for reliability can be one of the main factors attracting occupants to BCHP. Banks, data centres, hotels, supermarkets, even homes are increasingly willing to pay the capital premium and purchase a BCHP system in order to guarantee that no power interruptions will occur which can be embarrassing, costly or even disastrous.

Thermal Demand

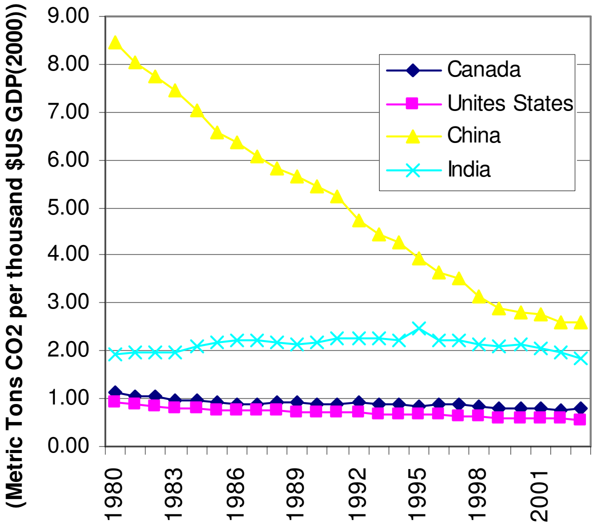
Since thermal demand is the first and most important reason to invest in BCHP systems any increases in heating and/or cooling demand provides a further incentive for owning such integrated on-site generation systems. New build will undoubtedly result in new and increased demand for heating and cooling, but it is likely that the most important driver will be the expected increase in the demand for air conditioning in existing buildings, especially in emerging economies.

Case Study Selection

This analysis has chosen to examine the potential for using BCHP systems in four specific national markets as case studies.

All countries of interest in this study were chosen because they are major energy users. The United States, China, Canada and India were respectively the first, second, sixth and seventh overall users of electricity in 2002[3]. Though Figure 1. shows a general trend of reduced GHG emissions as a ratio of economic output (measured in GDP), the fact remains that all four of the countries of interest produce excessive carbon pollution. The idea of this report was to estimate the technical and economic potential for carbon mitigation via CHP in buildings in four of the world's major energy users. High energy use suggests high potential for energy conservation. This study set out to explore the hypothesis that significant potential for emissions reduction exists by deploying BCHP installation in the abovementioned four countries.

Figure 1.Greenhouse Gas Emission Intensities of Case Study Countries Over Time



Source: 4

Methods

Baseline

In order to project the economic potential for BCHP it is useful to first set some boundaries. This study tries to establish the baseline by conducting an inventory of BCHP in the four countries of interest.

Technical Potential

The next step was to approximate the current theoretical maximum technical potential by examining total floor area of residential and commercial buildings. Floor area is a proxy for the theoretical maximum thermal load, and thus BCHP demand in buildings. The main purpose of installing cogeneration in buildings is to supply heat or cooling. The calculation therefore takes the thermal demand as starting point and considers the electricity generated in the process as a 'by-product'. By then multiplying the total floor area by an average thermal energy demand per unit area we can roughly estimate the overall measure of BCHP potential measured in capacity electrical. Realistically one should also take into consideration net growth (additions minus retirements) in building area, however this additional dimension was omitted from the study for simplification purposes. To further simplify the approximation of the maximum demand for CHP systems, the higher of either the total annual cooling or heating loads was used to estimate maximum BCHP potential.

Economic Potential

The method for estimating baseline and technical potential described above sets a range in between which the actual BCHP capacity growth will lie. To obtain a more realistic approximation of BCHP potential this study uses a number of approaches and make various assumptions that will affect uptake rates of BCHP technology. Some factors that will play a role include:

- Recent trends in BCHP growth or CHP growth more generally;

- Recent trends in growth/ demand for generation capacity;
- Access to fuel (natural gas infrastructure, biomass availability etc.);
- Carbon mitigation targets/government policy related to carbon mitigation; and
- Boiler/Air conditioner retirement rates.

In other words, once the potential for BCHP is gauged, the next step of the exercise is to translate the theoretical BCHP potential into a qualified carbon mitigation potential that is realistic for each country's market and regulatory circumstances.

Although thermal demand usually drives CHP system investment, we chose to base our market projections of BCHP investment over a 15-year time horizon by making assumptions on the potential of BCHP to contribute electrical capacity investment over time. We included projections for 2010 and 2020.

First, using a proprietary computer model, we calculated per unit (MWe) carbon benefit resulting from an additional unit of CHP in each of the four countries. The model calculates carbon savings using a wide range of input data and assumptions but considers all the other factors important for making the comparison: from the thermal efficiency of the BCHP plant and the existing reference plant, to network losses and load factors. More information about the assumptions for each country can be found in the appropriate country-specific sections that follow.

Once we determined the average per unit capacity CO2 displacement factor for each nation, the next step was to translate this displacement factor into actual emissions displacement by looking at BCHP penetration scenarios. We started with the IEA projections[5] for electricity demand (kWh) in both residential and commercial buildings in 2010 and 2020.

Then we made an assumption as to what percentage of electricity demand could be met using BCHP. In other words, we had to come up with a BCHP factor. This was the most challenging part of the exercise because so many variables had to be considered. For each country we came up with separate figures for a "low" scenario, a "medium" and a more optimistic "high scenario". The specific assumptions for each case are summarized in Table 2 below and are also discussed in more detail afterwards.

Table 2. BCHP Growth Scenarios

Country	Sector	BCHP Sector Growth Scenarios		
		Business-as-usual	Medium	High
Canada	Residential	5%	20%	40%
	Commercial	5%	25%	45%
China	Residential	5%	15%	35%
	Commercial	5%	20%	40%
India	Residential	5%	10%	30%
	Commercial	5%	15%	35%
USA	Residential	5%	20%	40%
	Commercial	5%	25%	45%

Source: WADE assumptions

For each year, for both projected residential and commercial demand, we subtracted the total base-year generation from the projected generation to obtain an incremental generation figure. Each of the four resulting figures was then multiplied by each of the three BCHP factors. The result was three different scenarios for each year for the amount of BCHP generation (MWh/year) which we expected to displace other forms of more carbon intensive power generation (i.e. assuming that BCHP was built instead of other technologies to meet demand growth). Finally we multiplied each of the resulting power generation figures by the CO2 displacement figure that was calculated using the model for each country.

Adding the CO2 emissions that are currently being displaced by BCHP every year in each country to the figures for potential reductions from installed BCHP in residential and commercial buildings resulted in the final CO2 emission reduction potential displayed in the figures.

Canada

Context

Table 3. Nation in numbers: Canada

Area (km2)	9,984,670
Population (2005)	32,805,041
Population Density (people/km2)	3
Urban population (%) (2003)	80
Expected Population growth rate (%)(2003-2015)	0.9
Human development index rating (out of 177)	5
Per capita Carbon emissions (MtCe) (2003)	5.19
Per capita GDP in international dollars (2004)	31,500
GDP per unit energy use (2000 PPP US$/ kgoe)	3.60
Electric Power Consumption (Kwh per capita/year)	18,541
Persons without electricity	0
Natural gas consumption billion m3 (2003)	92
Annual per capita natural gas consumption (m3)	2,811
Traditional fuel use (% of total energy demand)	4.6
National mean heating degree days	4,493
National mean cooling degree days	171
Energy Intensity	0.80

Source: various

Infrastructure

Existing Building Stock

There is about 5.9 billion ft^2 of commercial real estate in Canada. An additional 14 billion ft^2 makes up the residential sector. Table 4 shows the approximate breakdown by sub-sector. Most Canadians live in detached or semi-detached homes[6], none of which currently have integrated CHP systems. Even in apartments, where the remaining population live, CHP opportunities for space heating remain limited because demand for heating exists for only eight months of the year. Water heating and space cooling demands can, however, help increase the baseload for CHP applications and improve the economic case for their installation in the residential sector. The most promising immediate markets for BCHP are commercial buildings, such as hotels and supermarkets, which have a more constant need for heating and cooling compared to residential dwellings.

Table 4. Canada Floor Space by Building Type (1994)

Type	(million m2)	%
Single Detached	873	53.0
Single Attached	126	7.6
Apartments	304	18.4
Hotels	24	1.5
Hospitals	38	2.3
Schools	72	4.4
Offices	185	11.2
Other	13	0.8
Recreation	13	0.8
Total	1648	100.0
Subtotal Residential	1303	79.1
Subtotal Commercial	345	20.9

Source: 7

Existing Energy Demand

Buildings in Canada tend to be well insulated and heating and cooling technologies range from forced air ducts to in-floor radiant heating to hot water or electrical radiators. Most buildings in Canada have boilers in the basement for heating needs and take electricity from the grid.

Diverging greatly depending on the type of building average power use in Canada tends to be around 5.92kWh/ ft2 /year. Heating demand exists mostly in the winter months but averages 11.28 kWh/ ft2 /year. Cooling demand is much more modest averaging about 1.15kWh/ ft2 /year. Water heating is also a major fuel user in Canadian buildings. Overall heating, cooling and electrical loads in Canada are summarized in the table below.

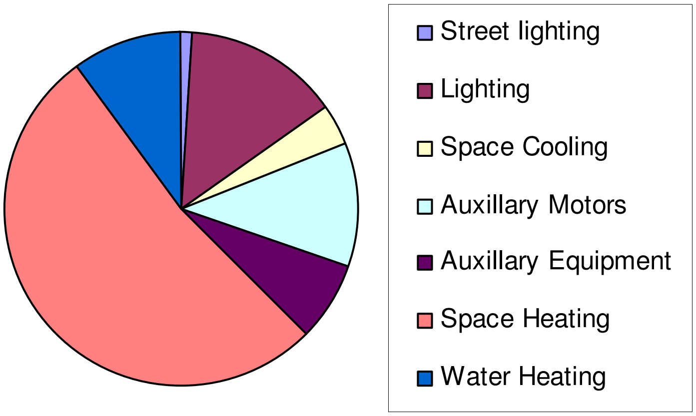
Provinces such as Quebec, which enjoy cheap and abundant supplies of hydroelectric power, use electrical space and water heating in most buildings. Other provinces employ a wider array of fuels to meet heating and cooling needs, with natural gas being the norm in Alberta and much of Ontario and fuel oil in the Maritime Provinces. Heating demand is fuelled largely by natural gas, whereas more modest (but growing) demand for air conditioning is met electrically. Table 5 shows the approximate total energy load of Canadian buildings and Figure 2 shows the source of demand in commercial buildings by end use.

Table 5 Canadian Energy demand in Buildings by End Use (2003)

End Use	GWh/year
Electrical load	105,000
Cooling load	20,000
Heat load	200,000

Source: 8

Figure 2. 2000 Canadian Energy Demand in Commercial Buildings by End Use



Source: 9

Existing Generation

Power generation varies to a large extent by region with areas such as Quebec and Manitoba obtaining close to 100% of their power from hydro electricity while other regions, such as Alberta, generate their electricity mostly from coal. Aggregated power generation sources are reflected in Table 6 below:

Table 6. Power Generation Capacity in Canada by source (2002)

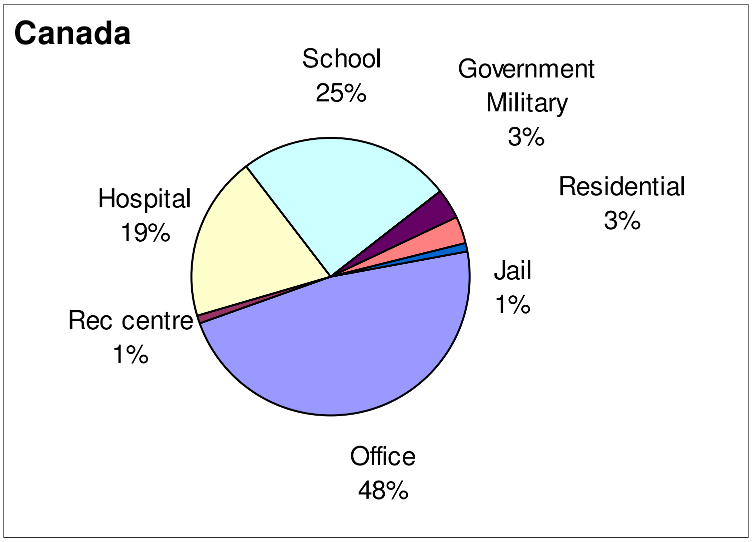
Generation Source	installed capacity (MW)	%
Total fossil fuels, of which:	32,585	29.36
Coal	23,940	21.57
Oil	3,325	3.00
Natural Gas	5,320	4.79
Nuclear	14,430	13.00
Hydro	63,270	57.00
Other	2,220	2.00
Total installed (MW)	**111,000**	**100.00**
Total produced (GWh)	**548,900**	

Source:3, 10 and 11

Existing CHP

Canada has vast experience with CHP but so far almost all of the CHP capacity exists in the industrial sector only. Of the almost 7 GWe[12] of total CHP capacity currently installed in Canada only about 205 MW[13], or 3%, is in non-industrial applications. A breakdown of CHP installations in the commercial and residential sectors in 2005 is illustrated in Figure 3 below. Of the total millions of commercial and residential buildings in Canada only 51 sites have BCHP systems installed, meaning a massive potential remains.

Figure 3. Stock of BCHP in Canada by Sub Sector (Number of installations n=51)



Source: WADE compilation based on 13

Climate Change

Existing emissions by sector

The buildings sector is responsible for a significant proportion of Canada's total greenhouse gas emissions (more than half of the nation's total GHG including emissions from the power sector for power used in buildings) according to the third greenhouse gas inventory report submitted to the UNFCCC. The biggest source of GHG emissions in the buildings sector in Canada can be attributed to space heating, followed by water heating and then electricity[8] (94% of space cooling in Canada is electric so GHG emissions from cooling is included in the electricity portion). Table 7 below shows a break down of emissions by source.

Carbon mitigation via BCHP in Canada

Canada is the only country of the four case study countries examined considered herein that has ratified the Kyoto Protocol and has established concrete emissions reduction targets. Canada's target under the Kyoto Protocol is to reduce its annual GHG emissions by 6% below 1990 levels by 2012.

Table 7 Approximate Total CO_2 Emissions by Sector in Canada

Sector	Mt CO_2 (2003)
Residential	45
Commercial	39
Industrial	116
Transportation	169
Agriculture	13
Total (excluding electricity)	381

Source: 14

Because the Canadian power sector is relatively less carbon-intensive compared to other countries examined in this report the carbon mitigation potential in Canada from widespread BCHP adoption, though significant, will not be as striking as elsewhere.

Though it is generally accepted that CHP has significant environmental benefits some specific research has been carried out in Canada to quantify the actual observed benefits. Canadian research suggests that existing CHP capacity (including industrial applications) across the country reduces total GHG emissions by up to 29.5 Mt compared to the reference scenario of separate production of heat power[6]. CHP also results in fewer criteria air contaminant (CAC) emissions than stand-alone alternatives. The same research suggests that CHP in Canada reduces particulate matter by 95, VOCs by 156, NOx by 68 and SOx by 81 thousand tons every year[6].

Projections

Baseline

There is currently about 205 MW of BCHP installed in Canada.

Technical Potential

WADE estimates that there is a potential of 36GWe BCHP capacity in Canada. Over 92 million tons of CO2 could be displaced annually if this potential was realized.

Economic Potential

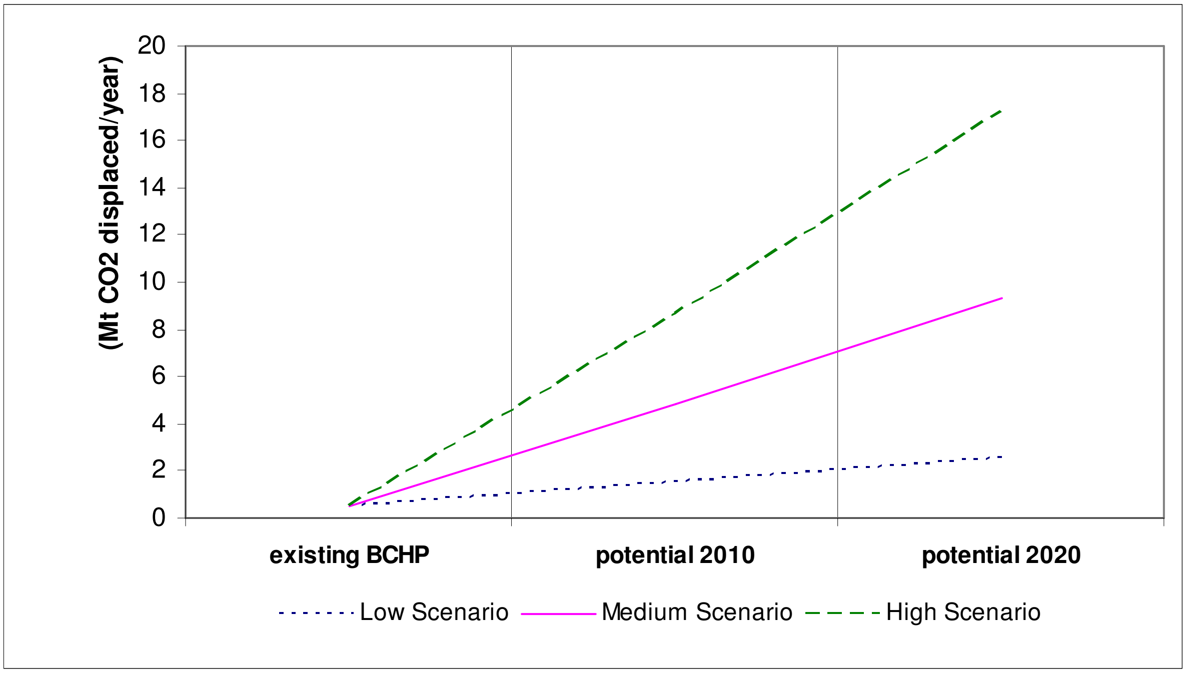
In the case of Canada we assumed that realistic uptake of BCHP to meet incremental demand for power in residential buildings was 5%, 20% and 40% for the low, medium and high scenarios respectively; and 5%, 25% and 45% respectively for the commercial buildings.

These assumptions are based on the fact that gas supplies are already well established in Canada and are likely to expand to other areas soon. It was further assumed that the power generated by new BCHP plants would displace the output from new gas plants. This is thought to be realistic for several reasons.

Gas fired generation is the fastest growing technology even in areas traditionally rich in hydroelectric power, and Most BCHP investment will occur in areas that rely on fossil fuels for heating purposes as opposed to electric heating. Such areas use fossil fuels (most often coal) for baseload power generation also, and thus the assumption that BCHP will displace gas is likely conservative in terms of carbon benefit it could provide.

The lower scenario illustrated in Figure 4 below represents the status quo. This is a possible scenario and would result if the economics for BCHP did not improve and no significant policies incentives were introduced. Given that total emissions from stationary sources in 2003 were 357Mt* (meaning a shortfall of 92 Mt using the 6% below the 1990 emissions for stationary sources) even in the low BCHP scenario Canada is on track to omit about 2% of Canada's total goal in that sub-sector by 2010.

Figure 4. CO_2 Mitigation Potential from BCHP in the Canadian Building Sector



Source: WADE projections

With the high uptake scenario BCHP could meet up to 10% of the goal by the end of the first Kyoto commitment period (2012). The IEA projects that the total North American carbon emissions will increase by 41.7% from a 1990 baseline by 2020. Assuming this projection holds true in Canada the high-growth scenario could easily displace 16% of the total projected increase in emissions (including all sectors).

In order to realize the maximum carbon mitigation potential from the use of BCHP, Canadians have to eliminate existing barriers and promote policies conducive to DE. At the moment the main barriers in Canada mirror the barriers experienced by the rest of the world, namely burdensome interconnection procedures and the absence of fair contracts for the small amount of power not used on site.

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* i.e rows under section a. "stationary sources" transportation, agriculture etc omitted. 15

Potential cost savings

An increasing body of evidence suggests that BCHP can be a cost-effective method of supplying a building's heat and power; even without the added reliability benefits. There is compelling evidence that BCHP can have cost benefits from improved reliability and that increased use of BCHP will reduce capital costs of the power sector as well put strong downward pressure on retail electricity prices all else being equal.

From a whole building perspective research concludes that new "green buildings" cost the same or only marginally more than new conventional buildings[16]. This because marginal capital expenditures in green technologies can often eliminate other capital costs and certainly decreases operation and maintenance costs over the building's life time.

Research by the Canadian Mortgage and Housing Corporation has shown that CHP is practical and economic even at the scale of detached single-family dwellings[17]. Research by the same organization showed that, as early as 1993, BCHP was already economic for systems over 100 kW and in buildings that did not require significant retrofits in order to install the system[18]. In the same reference year (1993), the BCHP installation costs ranged between $1,440 and $2,250 per kW depending on the size of the application. Even though installing BCHP in new buildings was cheaper than in existing buildings, both applications could prove economical depending on the case[18]. Since 1993, energy prices have risen dramatically thereby increasing the economic attractiveness of pursuing energy efficiency measures by installing BCHP systems in Canadian buildings.

The joint US- Canada Power System Outage Task Force concluded in its August 2003 blackout report that the power outage resulted in a cumulative loss of between US$4.5 and US$8.2 billion[19]. Another independent study calculated the loss at 18.9 million work-hours in Canada alone, and a 0.7% drop in GDP for the month of August[20]. A study surveying CHP systems within the area affected by the blackout concluded that nine of 12 systems were unaffected by the outage and remained fully operational during the incident[6]. BCHP units have the potential to significantly mitigate costs related to similar incidents in the future.

Computer modeling undertaken by WADE has consistently demonstrated the economic benefits of increased uptake of decentralized energy (including BCHP) at the level of an electricity system. Results show that significant reductions in both overall the capital costs of the power system, and the retail price of electricity, can result from increased use of DE such as BCHP[21].

Drivers for BCHP in Canada

The environmental benefits of BCHP will increasingly appeal to the Canadian public. The technology's attractiveness will likely increase in the eyes of politicians as pressure mounts to find realistic solutions to hot political issues such as accessible and affordable fuel supplies, air quality, grid reliability and climate change.

Given that less than 1% of the current Canadian building stock has any form of on-site power generation system, the future potential for developing such installations is enormous. Every year, thousands of residential and commercial boilers in Canada need to be replaced. This provides a guaranteed market for BCHP and also has the potential to reduce transaction costs of a BCHP system investment. Furthermore investors in BCHP plants need only consider the marginal cost between a replacement boiler and a new integrated BCHP plant.

Gas infrastructure in Canada, especially in the western part of the country, is well developed and buildings have been using piped gas for heating purposes for many years. Gas infrastructure is expected to further grow and new gas distribution networks will render gas an accessible new fuel option to an increasing number of commercial and residential building owners. A robust gas infrastructure is arguably the most important driver for BCHP due to the emergence of natural gas as the fuel of choice for the majority of BCHP applications. As discussed above there is a strong argument that now that gas transmission infrastructure investment has been made that the gas should be burned as efficiently as possible to optimise the value of the infrastructure. In other words Canadians would be wise to give preferential access, or even prices, to gas for BCHP applications where efficiency is typically in the range of 25% better than a CCGT plant where waste heat is not used.

Many BCHP units also run on diesel which is readily available across Canada. Alternative fuels for BCHP systems in Canada, such as biodiesel or biogas are also future possibilities but supplies and distribution networks remain limited.

Much BCHP installation is likely to occur in new build in Canada. Projections suggest that new build will increase steadily in the coming decades and the older end of the building stock will also require significant refurbishment. In 1994 the total Canadian residential floor space equaled approximately 14.2 billion ft2, of which more than half was built over 25 years ago[8]. Both total floor area and number of buildings are expected to grow. Particularly fast growth is expected in the office sector and single-family residential sub-sectors as Canada continues to expand its tertiary industry and grapples to slow urban sprawl. Other drivers for BCHP such as increasing electricity prices, cost reductions in BCHP, demand for secure power and environmental concerns may also come into play and provide further incentive for investment in BCHP in Canadian markets.

New build will increase the overall demand for heating and cooling but the effect will be somewhat counterbalanced with retrofits in existing buildings such to improve the building envelope performance reducing wastage of heat and cooling of space and water. The demand for heating may also be reduced slightly because the Canadian climate is expected to warm slightly.

Law and policy could become major drivers for further BCHP development in Canada and greatly accelerate its uptake. Types of policies which could play an important role include the establishment or development of programs like the CBIP program discussed above, or introducing feed-in tariffs for BCHP installations as is currently under discussion in the Canadian province of Ontario. Another factor which could prove important in moving markets forward is organization. The United States is partly ahead because proponents of BCHP are well organized as is evidenced by the existence of the United States Combined Heat and Power Association (USCHPA) and its many working groups at the state level. A similar organization in Canada, provided that it is adequately funded, in Canada could go a long way to making quick progress in realizing the many benefits offered by BCHP.

United States

Context

Table 8.Nation in numbers: USA

Area (km2)	9,631,418
Population (2005)	295,734,134
Population density (people/km2)	31
Urban population (%) (2003)	80
Expected population growth rate (%)(2003-2015)	0.9
Human development index rating (out of 177)	10
Per capita carbon emissions (MtCe) (2003)	5.44
Per capita GDP in international dollars (2004)	40,100
GDP per unit energy use (2000 PPP US$/ kgoe)	4.40
Electric power consumption (kWh per capita/year)	13,456
Persons without electricity	0
Natural gas consumption billion m3 (2003)	645
Annual per capita natural gas consumption (m3)	2,182
Traditional fuel use (% of total energy demand)	3.6
National mean heating degree days	2,159
National mean cooling degree days	882
Energy intensity	0.56

Source: various

Infrastructure

Existing Building Stock

Information on the American building stock is quite well developed. In 2003 there were about 4.9 million commercial buildings in the United States that occupied 71.6 billion ft^2 of area[22] and consumed approximately 1.3 million GWh of electricity[23]. The breakdown by building type is reflected in Table 9. There were approximately 107 million residential buildings in the USA in 2001 making up about 201.3 billion ft^2[24] . Total building area is thus about 272.9 billion ft^2.

About half of Americans live in detached or semi-detached homes[25] none of which currently have CHP systems. The other 50% of Americans live in apartment buildings[25]. More than 90% of the existing U.S. stock of residential buildings was built prior to 1990 and about 18% was built before 1940[26]. Although the vast majority of such buildings have shared boilers only a tiny percentage currently have CHP systems installed. Periods of the year where no heat is required remain an economic barrier to CHP systems in apartments however water heating and space cooling demands can help increase base load for CHP applications and improve the economic case for their installation.

The low hanging fruit in for BCHP opportunity in the Unites States remains in the commercial sector with more constant demand for heating and cooling. Installing BCHP in such systems can offer attractive pay back.

Table 9. Number of Buildings and Floorspace by Principal Building Activity, 2003

	Number of Buildings	Total Floorspace	Mean Square Feet per Building
	(thousand)	(million ft^2)	(thousand)
All Buildings	4,859	71,658	14.7
Principal Building Activity			
Education	386	9,874	25.6
Food Sales	226	1,255	5.6
Food Service	297	1,654	5.6
Health Care	129	3,163	24.6
Lodging	142	5,096	35.8
Mercantile	657	11,192	17
Office	824	12,208	14.8
Public Assembly	277	3,939	14.2
Public Order and Safety	71	1,090	15.5
Religious Worship	370	3,754	10.1
Service	622	4,050	6.5
Warehouse and Storage	597	10,078	16.9
Other	79	1,738	21.9
Vacant	182	2,567	14.1

Source: 27

Gas infrastructure is well developed in the United States and it has been a common fuel for heating buildings for many years. About 20% of the gas used in the United States must be imported though significant domestic reserves still exist.

Existing Energy Demand

Over 85% of all commercial buildings are heated in the Unites States, and more than 75% are cooled[25]. Due to high demand for air conditioning electrical peak demand is in the summer. Newer buildings are well insulated, but, along with the older stock and largely outdated building standards there remains much room for improvement. A diversity of fuels and technologies are employed for heating in the United States but typically a boiler is installed in the basement and is either fired by fuel-oil fired or natural gas. Technologies include forced air ducts, in-floor radiant heating and fluid radiators. In the residential sector 99% of space is centrally heated and 72% is cooled[25]. Close to 100% of buildings employ grid-based power. In some states electric heating is common because of the cheap electricity in most states where gas or oil is the main fuel.

Total heating demand is approximately 3.37kWh/ ft^2 /year in the United States, based on 2002 data. Total cooling demand is 2.17 kWh/ ft^2 /year and demand for air conditioning is expected to outstrip new building construction as older buildings are retrofitted. These figures will of course vary widely depending on the location of the building (i.e. Anchorage vs. Atlanta) and building type (air-conditioned supermarket vs. unheated warehouse). The figure is expected to grow in step with construction of new buildings. Tables 10 and 11 show, respectively, the total American energy load and electricity use in buildings by end use.

Table 10. American Energy demand in Buildings by End Use (2003)

End Use	GWh/year
Electrical load	1,256,000
Cooling load	592,000
Heat load	920,000

Source: 23

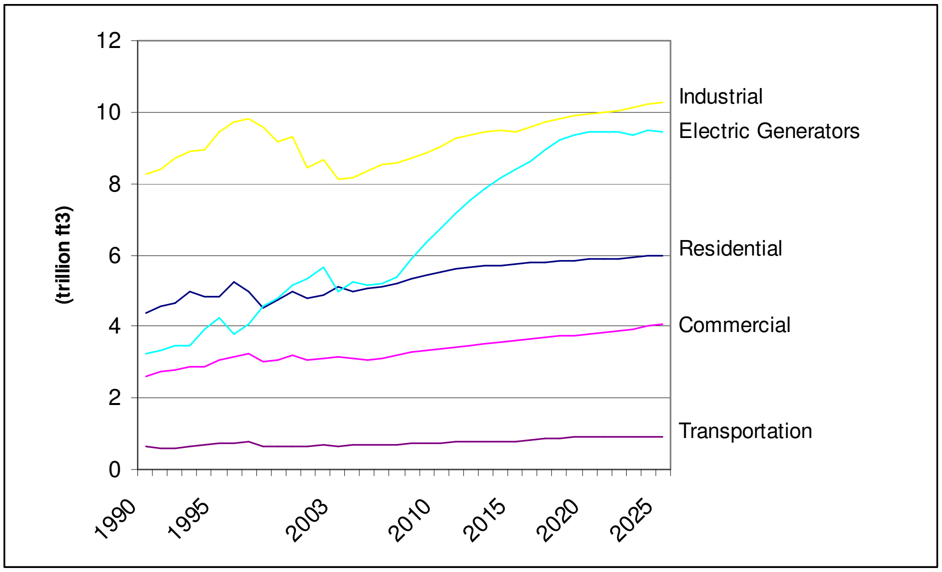
Table 11. Percent of Electricity Consumption by End Use in the United States

End Use	Survey Year				
	1987	1990	1993	1997	2001
Air-Conditioning	15.8	15.9	13.9	11.8	16
Space Heating	10.3	10	12.4	11.4	10.1
Water Heating	11.4	11.2	10.3	11	9.1
Total Appliances	62.5	63	63.4	65.9	64.7

Source: 28

Figure 5. shows total projected natural gas demand by sector. Demand for gas in both residential and commercial buildings is expected to grow steadily.

Figure 5. Projected Natural Gas Consumption by Sector (trillion ft^3)



Source: 29

Existing Generation

Some states, such as Ohio or North Dakota employ almost 100% coal for power generation, whereas hydroelectric power is the most common source of electricity generation in a small number of states. The overall power generating mix in the United States in summarized in Table 12.

Table 12. Power Generation in the United States by Source (2002)

Generation Source	installed capacity (GWh)	%
Coal	1,971,000	51
Oil	119,000	3
Natural Gas	632,000	16
Nuclear	764,000	20
Other	359,000	9
Total	3,850,000	100

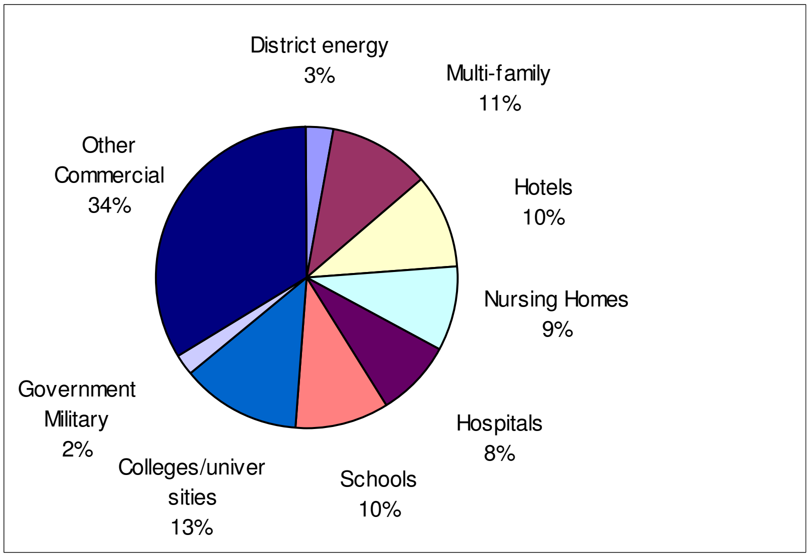
Source: 30

Existing CHP

The US Combined Heat and Power Association (USCHPA) estimates that about 9% of the generating capacity in the United States is generated in CHP applications, the majority of which are installed in industrial applications. Of the 82 GWe of installed CHP capacity in the United States about 4.3% or 3.5 GWe is presently installed in buildings (including district heating)[31].

BCHP therefore currently represents about 0.4% of the US total power generating capacity. A recent EIA study estimated that approximately 0.7% of all commercial buildings generate power on-site not including those that have the ability to generate back-up power in the case of emergencies[32]. Therefore despite the existing achievements there remains an enormous potential for BCHP in the US. Figure 6 below illustrates the breakdown of building types in which BCHP systems were installed between 2000 and 2005. There were far more CHP systems installed in buildings in the United States in those years than in industrial applications yet the overall capacity of the industrial systems installed dwarfed the capacity of BCHP.

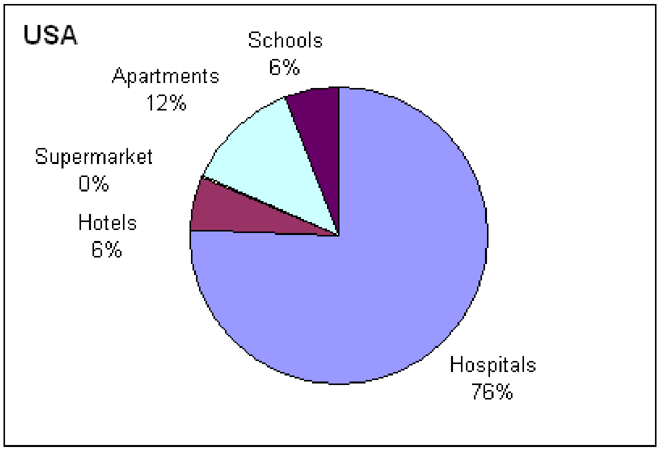
Figure 6. BCHP Additions USA 2000-2005 (n=248)



Source 29

Figure 7 shows the approximate breakdown of total BCHP systems installed in the US at the moment.

Figure 7 Stock of BCHP in US by Sector (n=577)



Source: 33

The great majority of the systems added in recent years are reciprocating engines 1 MW or less generating capacity[29]. If the trend continues, and it is likely to, this bodes well for smaller scale BCHP systems. Other technologies are also likely to increase in popularity such as fuel cells and microturbines.

Climate Change

Existing emissions by sector

Emissions from the US building sector play an important role in the overall national emissions. Together the US commercial and residential buildings are responsible for more emissions than any other sector (as illustrated in Table 13.). On-site combustion of fossil fuels for heating space and water are the biggest source of emissions in American buildings followed by electricity generated off-site.

Table 13 Approximate Total CO_2 Emissions by Sector in the United States

Sector	Mt CO_2 (2003)
Residential	1,098
Commercial	916
Industrial	1,897
Transportation	1,820
Other	56
Total	5,788

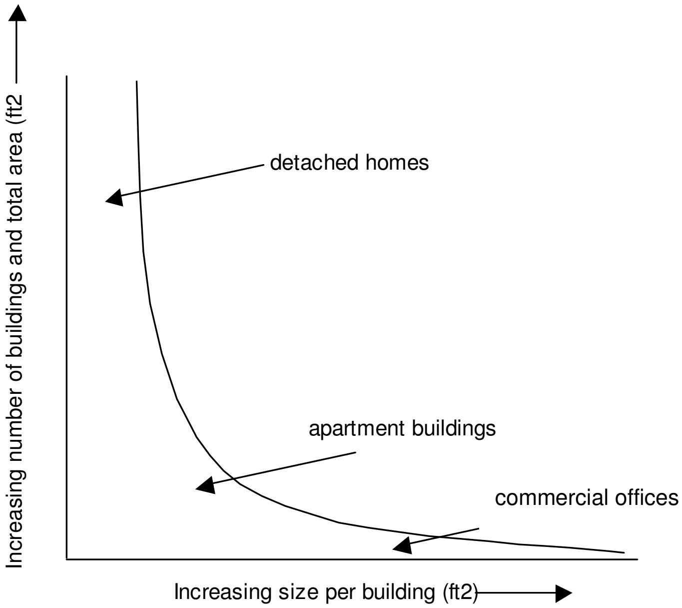
Source: WADE approximation based on 23 and 25

Carbon mitigation via BCHP in the USA

Despite the opposition of the United States federal government to adopting emissions reductions targets, low carbon leadership starts to emerge at city, state and company level. The USA is a Kyoto protocol signatory[34] but is not expected to ratify the accord. Of the four case study countries examined in this report, the US offers the best source of BCHP-related information and has better developed its strategy and implemented policies and programs to promote BCHP. As the vast majority of the US electricity generation is fossil-fuel based (about 70%) a large potential exists for carbon mitigation via BCHP.

The market sub-sectors which can deliver the most reductions in the short term are commercial buildings which have large thermal baseloads, i.e. hotels and supermarkets. However in the longer term the residential sector represents the largest potential because it is the building sub-sector with the largest floor area and thus the largest absolute demand for thermal energy. One way of looking at this is represented in Figure 8 below. Even though the total building footprint per building is very small in the residential sector the cumulative potential far outweighs the low hanging fruit for CHP potential represented in the commercial sector. High transaction costs are the main obstacle to widespread BCHP in individual homes.

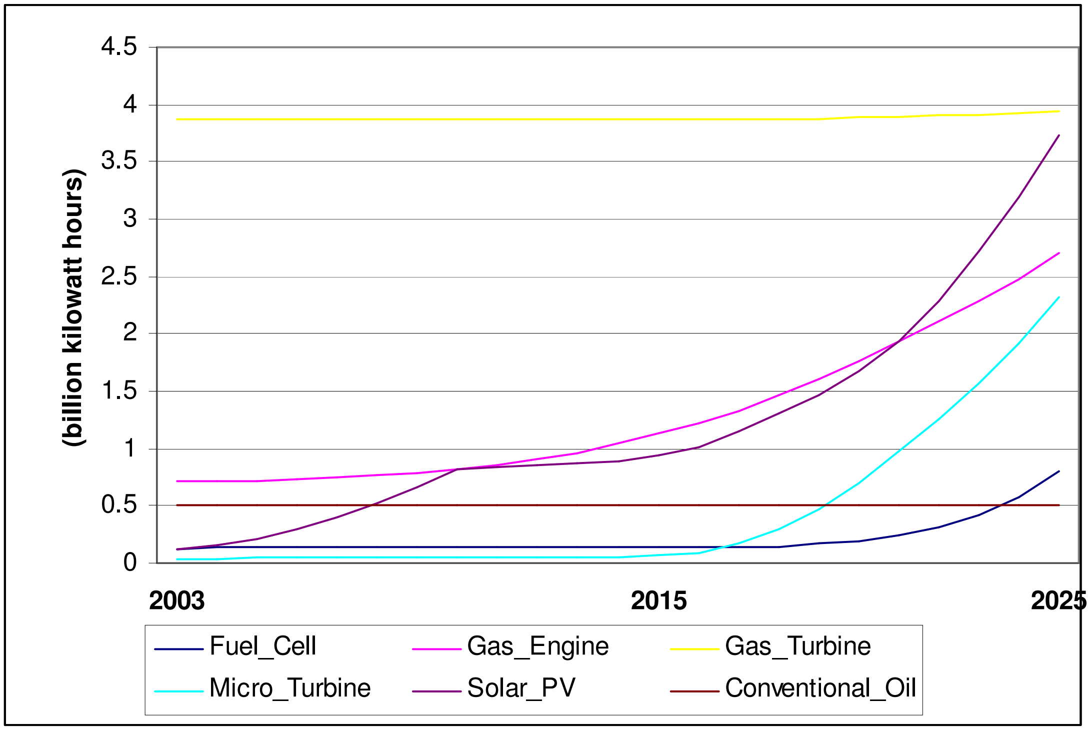
Figure 8. Theoretical BCHP potential by building sector



Source: WADE

In the 2005 Energy Outlook reference scenario the EIA estimates that even with an 80% increase in BCHP systems by 2025 such systems would still only account for less than 1% of total demand for electricity in buildings in the United States[32]. A projection (see Figure 9 below) by the EIA for market penetrations of decentralized energy demonstrates nevertheless that billions of kilowatt hours of power could be generated by BCHP and other DE technologies, which would mean massive carbon savings.

Figure 9 Projected buildings sector electricity generation by technology (2003-2025)



Source: 32

Projections

Baseline

There is currently about 3.5GW of BCHP installed in the United States.

Technical Potential

An approximate theoretical upper limit for BCHP in the United States was calculated to be around 163 GWe. Translating this into CO_2 displacement means that about 415 million tons of CO_2 could be displaced in the United States every year with maximum BCHP uptake.

Economic Potential

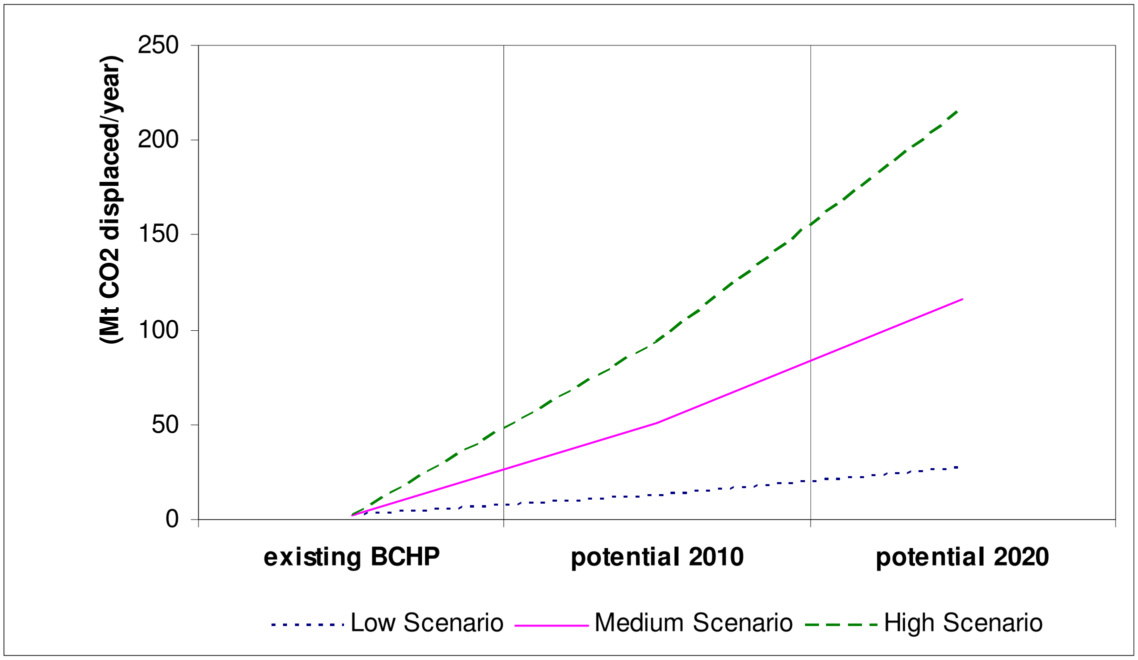
The existing CHP capacity (including industrial applications) in the Unites States in 2005 is thought to eliminate over 400 Mt of CO_2 emissions every year[35]. WADE has calculated that the BCHP portion is responsible for about 2 Mt reduction per year. As in the case for Canada, our projections are based on the assumption that new BCHP capacity would displace the carbon emissions of new gas plants.

In the United States we assumed a modest 5% for the low BCHP market penetration scenario, 20% for the medium scenario and 40% for the high scenario. Likewise, for the commercial subsector assumptions were 5%, 25% and 45% respectively.

The scenarios (Figure 10.) show that in the case of low BCHP penetration CO_2 abatement resulting from BCHP will likely increase six fold from the 2005 baseline. In the high scenario abatement from BCHP installations could increase 44 fold by 2010 and more than 100 fold by

2020. Taking the IEA projection that North American emissions will be 29.7% higher in 2010 and 41.7% higher in 2020 than a 1990 baseline, we can get an idea of the scale for carbon mitigation from BCHP in the United States. Even in the low BCHP uptake scenario the technology has the potential to displace close to 3% of projected growth of total emissions. The high scenario suggests about 20% of total emission growth (all sectors) could be displaced.

Figure 10 CO_2 Mitigation Potential from BCHP in the US Building Sector



Source: WADE projections

The prospects for increased BCHP investment in the United States are especially good because of gaining momentum and better organization of the BCHP promoters compared to the other three nations examined in this report. Because of this a medium or high scenario may be more realistic. More BCHP installations exist in the US than any other country and the experience gained in developing these projects could give Americans a competitive advantage in further developing projects.

Figures 6 and 7 show that there may be a shift in the CHP industry from industrial projects to commercial projects and American research suggests that the most common CHP developments in recent times are under 1MW in capacity[29]. Certainly in order to achieve the emission reductions illustrated in the medium or high scenarios much more work is required and support needed.

Potential cost savings

Table 14 below summarizes projected costs of BCHP technologies in the Unites States for 2010 and 2020. Costs are expected to decease significantly in every case which will broaden the market for BCHP.

Table 14. Projected installed costs (2003 dollars per kilowatt) and electrical conversion efficiencies (percent) for distributed generation technologies by year and technology

Technology	2004		2010		2020	
	Cost	Efficiency	Cost	Efficiency	Cost	Efficiency
Residential photovoltaic	8,600	14	6,200	18	3,814	22
Commercial photovoltaic	6,250	14	4,750	18	3,178	22
Commercial fuel cell	5,200	36	2,500	49	1,800	51
Natural gas turbine	1,860	22	1,679	24	1,567	27
Natural gas engine	1,130	32	1,030	33	930	34
Natural gas microturbine	1,773	28	1,415	36	870	38

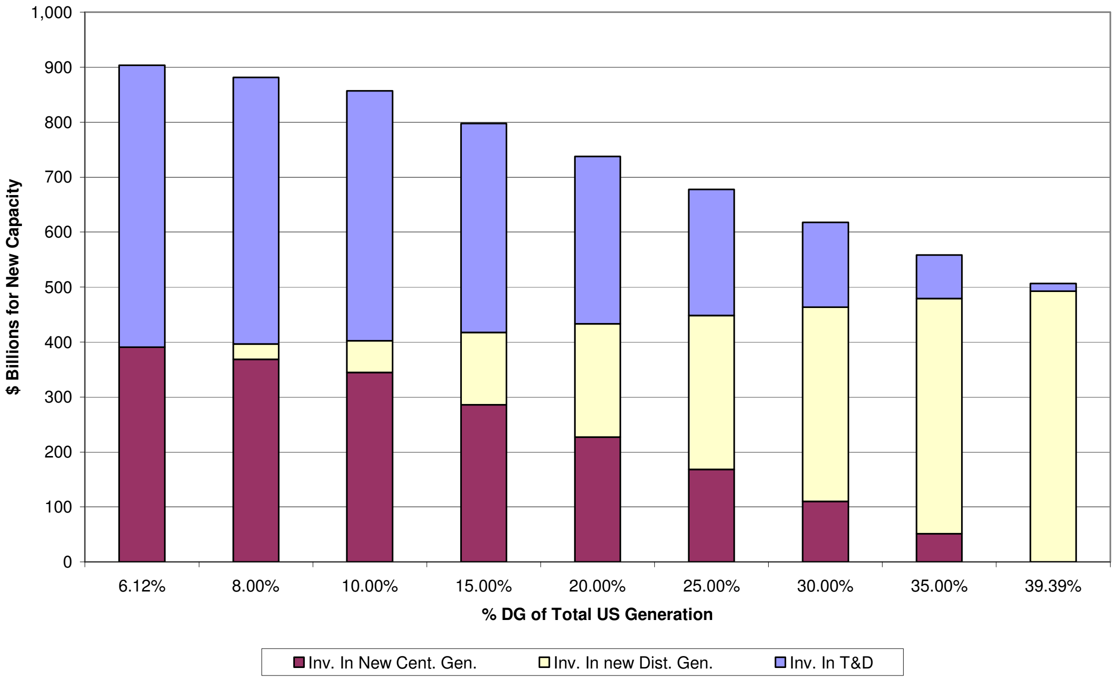
Source: 32

A joint US-Canada Power System Outage Task Force concluded in its report written to explore the economic benefits that CHP systems afforded their owners during the August 2003 blackout concluded that significant benefits were accrued in almost every case[20]. Survey respondents reported that they were satisfied in all cases with the performance of their systems and in many cases facilities with BCHP systems on-site were able to carry on business as usual even as their neighbours were paralysed by the blackout.

Economic modelling work by WADE has consistently shown that investing in decentralized power generation reduces not only overall CO_2 emissions but also both the capital cost of generation capacity of the electric system and retail electricity prices for end users.

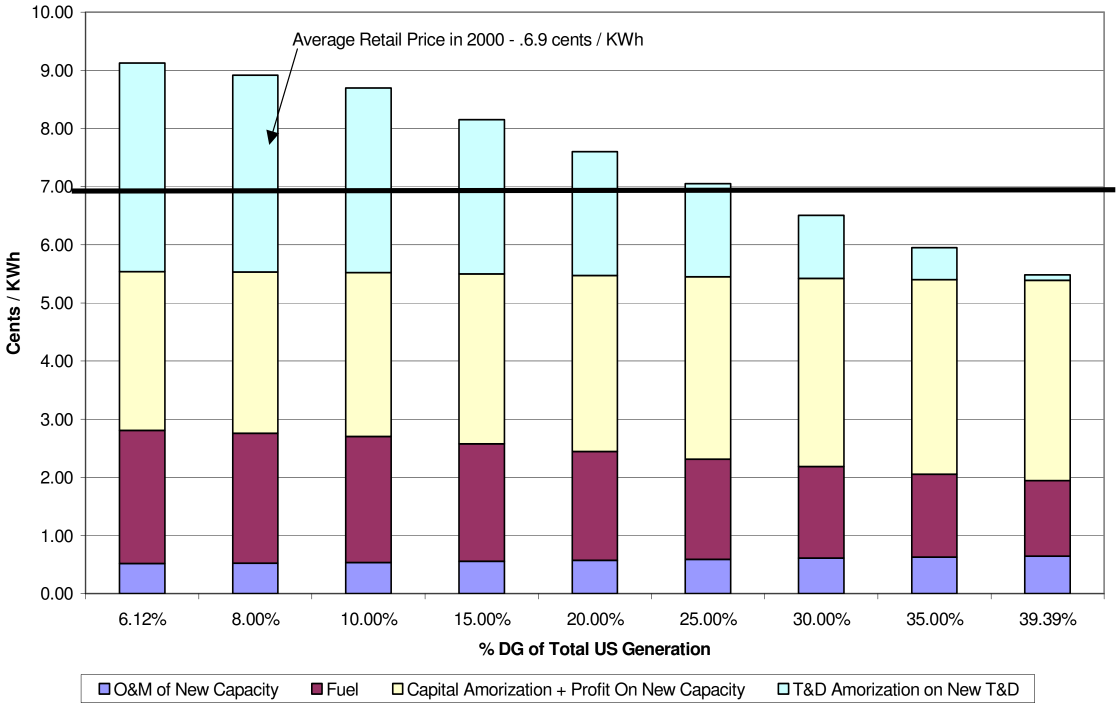
Figures 11 and 12 below illustrate the potential scale of cost savings using various mixes of centralized and decentralized electricity investment. Note that significant investment in BCHP could, according to the modelling, result in significant savings in retail electricity prices. Indeed if 100% of new demand for power in the United States was met with BCHP the country could expect to see a reduction of almost 3.5 cents /kWh on average retail rates. Similarly almost $400billion in capital expenditures would be saved, mostly by displaced need for T&D.

Figure 11
US – Projected Capital Cost for New Capacity to 2020 With Various Proportions of DE



Source: WADE

Figure 12
US Projected Retail Costs for New Capacity to 2020 With Various Proportions of DE



Source: WADE

Drivers for BCHP in the USA

Demand for reliable power and the public demand to do something about climate change and air pollution may be the two most potent drivers for BCHP investment in the United States. There is scope for strong policy leadership to improve the prospect of BCHP investment at both a state and federal level. Many examples of successful practices to promote DE already exist in the United Sates but there remains scope for improvement.

Policies will continue to move markets for BCHP forward in the United States. If a strong policy were introduced at the federal level the BCHP could witness a very significant and rapid expansion. Examples of US efforts which are already proving successful in increasing the use of BCHP include certain clauses in the US Energy Policy Act, the establishment of Regional CHP initiatives, and air quality regulations which recognize the positive benefits of BCHP. The California Self Generation Incentive Program and the Federal Energy Regulatory Commission Small Generator Interconnection agreement are two other examples that are likely to continue benefiting BCHP. Other policy victories at the state level include renewable portfolio standards that can be met in part via BCHP projects, and agreements that establish a hierarchy of priority for meeting demand for power with BCHP given priority over central plants. There is also an effort underway to have the environmental benefits of BCHP recognized in the US green building certification standard. For detailed explanations of these and many other efforts being undertaken consult the 2005 CHP Action Agenda[29]. The USCHPA has played an important role in many of these initiatives.

There is scope for the USA to benefit from experience elsewhere such as a unique policy approach being employed in Japan to provide incentive for building owners to consider replacing old boilers with new BCHP units rather than new boilers. The scheme subsidizes half the marginal cost between a boiler and a BCHP system and educates potential buyers of the massive potential of reduced operational costs of the BCHP system in relation to a replacement boiler[36].

The EIA's in depth analysis of the BCHP market cites local emissions regulations as well as general regulatory barriers and interconnection difficulties as obstacles to optimum DE development in the United States[32]. The same study cites the fact that energy provision is not the core business for potential BCHP investors as a key issue.

Like elsewhere fuel access is a vital consideration in projecting CHP investment growth in the USA. Though networks are already well established penetration of natural gas is residential and commercial markets is expected to increase as more distribution networks are constructed. The challenge will be to ensure that projects that use gas efficiently, such as BCHP installations, get priority over less efficient uses of gas such as large central CCGT plants. Distribution networks for diesel fuel are already well established and so it is likely that diesel will remain a popular choice for BCHP systems well into the future. Emerging fuels such as biodiesel may also eventually play a role as resources are allocated to increase supplies.

Gas Markets are expected to continue to be the main deciding factor in BCHP economics for some time to come. The influence on project economics will be particularly acute in areas that do not rely heavily on natural gas for centralized power generation because power prices in those regions are less directly tied to gas prices and thus spark spread is more volatile. In regions with high power prices BCHP will still be economic even as gas prices climb. BCHP will also provide an element of buffer against power price volatility.

Population growth in the United States is estimated to be 0.9% between now and 2015[37]. Growth is expected in single detached housing markets and also commercial buildings so in absolute terms energy demand is set to expand greatly. The demand would be even greater if it were not for the ongoing retrofits to increase energy efficiency in existing buildings. Retrofits of aging buildings will also be a major potential market for BCHP especially as boilers are replaced and older areas gain access to piped gas.

China

Context

Table 15.Nation in numbers: China

Area (km2)	9,596,960
Population (2005)	1,306,313,812
Population Density (people/km2)	136
Urban population (%) (2003)	39
Expected Population growth rate (%)(2003-2015)	0.6
Human development index rating (out of 177)	85
Per capita Carbon emissions (MtCe) (2003)	0.74
Per capita GDP in international dollars (2004)	5,600
GDP per unit energy use (2000 PPP US$/ kgoe)	4.60
Electric Power Consumption (Kwh per capita/year)	1,484
Persons without electricity	23,000,000
Natural gas consumption billion m3 (2003)	33
Annual per capita natural gas consumption (m3)	25
Traditional fuel use (% of total energy demand)	5.3
National mean heating degree days	2,158
National mean cooling degree days	1,046
Energy Intensity	1.86

Source: various

Infrastructure

Existing Building Stock

In 2003 about 39% of the Chinese population was considered to live in urban environments. Many of the rural population live in multifamily homes, many in traditional style. In the majority of rural dwellings installing gas-fired CHP might not be immediately practical though there is still much potential in rural areas in commercial BCHP applications. Rural Chinese may build upon their own experience employing residential scale biogas-fired CHP for cooking/generating very small amounts of electricity (the experience of other nations such as India and Nepal may also prove useful). The majority of urban Chinese live in apartment blocks with central boilers in the basement and grid power.

Many of the buildings in China are old and approaching retirement age. In addition to the retrofits that will be required as existing boilers age, new build has experienced significant linear growth in most sectors. Table 16 below shows the building area in China by sub-sector over time.

Table 16. The Area of New Added Building in China (1000 m^2)

Year	Total Area	Residential buildings	Apartment buildings	Office buildings	Commercial buildings	Other Buildings
1997	140269.8	105269.2	4697.2	8724.4	14624.5	6954.4
1998	203879.0	159989.0	6386.0	8715.0	19386.5	9402.5
1999	225794.1	182038.7	5940.6	6902.9	21985.6	8926.2
2000	295826.4	232320.6	11690.9	8988.1	30347.7	12479.1
2001	373941.8	290760.3	14566.9	10729.8	41054.0	16830.8
2002	428005.2	324411.8	22781.7	12542.4	49264.8	19004.5
2003	547075.3	415046.0	23492.9	14668.9	67068.0	26799.6
2004	604138.6	412915.1	24000.0	17041.9	77908.1	29698.5

Source: 38

Existing Energy Demand

Demand for energy in China is currently outstretching supply which is causing upward pressure on prices and increased demand for imports. Many major power plants are working at capacity leaving almost no extra capacity in order to schedule maintenance or to be available in the case of contingency[39]. In the summer of 2004 the shortage of installed power generating capacity was estimated to equal about 40 GWe. Since 2003 there has been very high growth for electricity in the residential sector as a result of major investments in urban and rural power networks. It is estimated that during the summer months more than 15% peak electrical demand is a direct result of air-conditioning use in China[39]. Much potential remains for demand-side efficiency improvements in Chinese buildings. Many homes and apartment buildings in China remain poorly insulated so retrofits are likely to be as much a driver for BCHP as new build.

Varying greatly depending on location and season the average heat demand for buildings in China is 2.1 kWh/ ft^2. Average cooling load, because of China's warm climate, is slightly larger at 5.2 kWh/ ft^2. Table 17 shows the approximate total energy load in Chinese buildings. Table 18 shows typical heating demand for selected Chinese cities and price per floor area.

Table 17. Chinese Energy Demand in Buildings by End Use (2004)

End use	GWh/year
Electrical load	1,694,000
Cooling load	779,000
Heat load	314,000

Source: WADE calculations based on 40

Table 18. Heating Degree Days and Space Heating Price in selected Chinese Cities

Region	Heating days	Heating Degree days	Space heating price	
Unit	Day	C.day	US$/m2 floor area	RMB/m2 floor area
Xi-an	100-130	1500	1.8	15
Beijing, Tianjin	120-150	2000	2.4	20
Harbin, Da-Qing	180-200	4500	5.4	45
Average	130-160	2700	3.3	27

Source: 40

Existing Generation

Power generation in China is almost exclusively fossil fuel-based though power generating sources do vary by province. Table 19. below shows the total capacity by source and generation. Fuel mix is expected to be dominated in the foreseeable future by coal generation but there is currently an aggressive effort underway by the Chinese government to diversify largely as a result of high coal prices. Major efforts are currently underway to increase gas in the fuel mix as well as increase the use of renewables. The key challenge in optimising natural gas use will be to prioritise CHP applications ahead of CCGT applications.

Table 19. Power Generation capacity in China by source (2002)

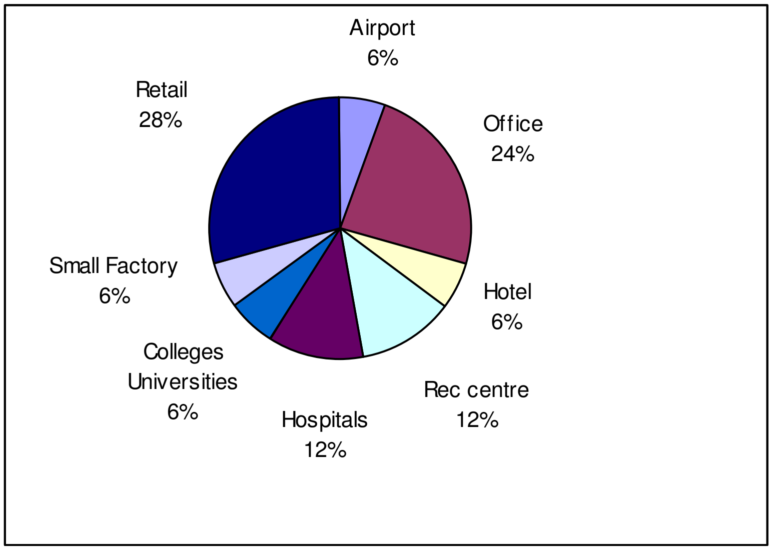
Generation Source	MW installed
Total fossil	272000
Coal	247000
Oil	17000
Natural Gas	8000
Nuclear	4000
Hydro	82000
Other	2000
Total MW installed	360000
Total MWh produced	1675000000

Source: 5

Existing CHP

The Chinese have much experience using CHP installations, but to date these systems have mostly been integrated in coal-fired steam turbines for industrial applications. Currently there is between 32[42] and 50 GW[39] of installed capacity in the country. China has recently also developed some gas-fired CHP plants, some of which are in buildings. A recent study has concluded that approximately 60% of central heating in urban China is CHP based and that combined cooling heat and power applications in both the buildings and industrial applications are also becoming increasingly popular[42]. There are currently less than 20 BCHP applications in the country with a total capacity of about 21MW so the potential remains enormous. Figure 13 below shows the break down of the BCHP applications by sector. Despite the small number of applications a wide base of building owners are seeing the value and versatile application of this technology, from retail outlets and offices to hotels and recreation centers.

Figure 13. Stock of BCHP in China by Sub Sector (Number of installations n=17)



Source: WADE compilation based on 40

Climate Change

Existing emissions by sector

In China industrial emissions still account for the lion share of the nation's total carbon pollution, however, the building sector's contribution is substantial (this is illustrated in Table 20). Fuel burned for heating still accounts for most of the CO_2 emissions in the building sector but with the quickly growing demand for electric air conditioning, and a power sector heavily based on fossil fuels, cooling buildings will likely soon become the main source of Chinese emissions.

Table 20. Approximate Total CO_2 Emissions by Sector in China

Sector	Mt CO_2 (2002)
Residential	232
Commercial	429
Industrial	1,230
Transportation	243
Agriculture	99
Other	194
Total	3,307

Source: WADE approximation based on 5 and 43

Between 1991 and 2001, the total area in need of heating rose by five times, to 1.2 billion m^2, an additional requirement of about 200 million m^2 which require about 12.9 million TJ of heat per year[42].

Carbon Mitigation Potential via BCHP in China

China is an original Kyoto signatory and approved the accord in 2002[34]. Because China is an Annex 2 country no CO_2 reduction target has yet been set.

Compared with separate production of power and heat, a recent study has shown that CHP has saved about 65 Mt CO_2 than would otherwise have been generated in China between 1991 and 2000[42]. Work by Aki et al. has concluded based on empirical data on buildings in China that BCHP had carbon mitigation and energy conservation potential far exceeding that of conventional energy systems[40].

The fast growing energy demand and the heavy coal-intensity of the Chinese power sector provides an unparalleled opportunity for effective and efficient carbon mitigation compared to other nations where central power is less carbon intensive. This is because the chances are good in China that new gas-fired BCHP capacity will displace coal fired remote generation.

Projections

Baseline

There is currently about 21 MW of BCHP installed in China.

Technical Potential

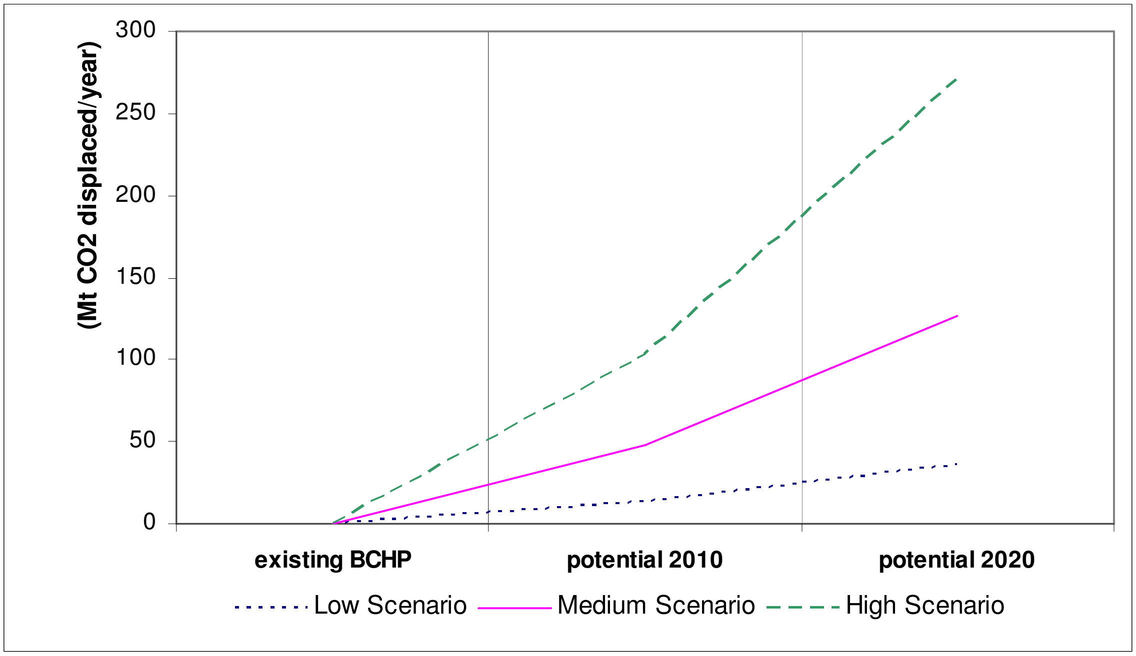
WADE has approximated that about 141GWe of BCHP would be theoretically possible based on existing building stock estimates. Realizing this potential could displace about 683Mt CO_2/year.

Economic Potential

In the case of China WADE's assumptions for realistic BCHP uptake potential were slightly more conservative than in Canada and the Unites States where gas supplies are better established and capital less constrained. As a result for the residential sector we assumed a 5% uptake in the low scenario, 15% for the medium scenario and 35% in the high scenario. In the commercial sector we assumed 5%, 20% and 40% respectively.

Especially in areas where urban populations are dense and gas supplies are available there is potential for fast growth in Chinese BCHP markets. A clear government mandate in support of optimising scarce gas could also be an important driver for BCHP. Figure 14 below shows the possible carbon emission displacement scenarios as envisioned by WADE.

Figure 14. CO_2 Mitigation Potential from BCHP in the Chinese Building Sector



Source: WADE projections

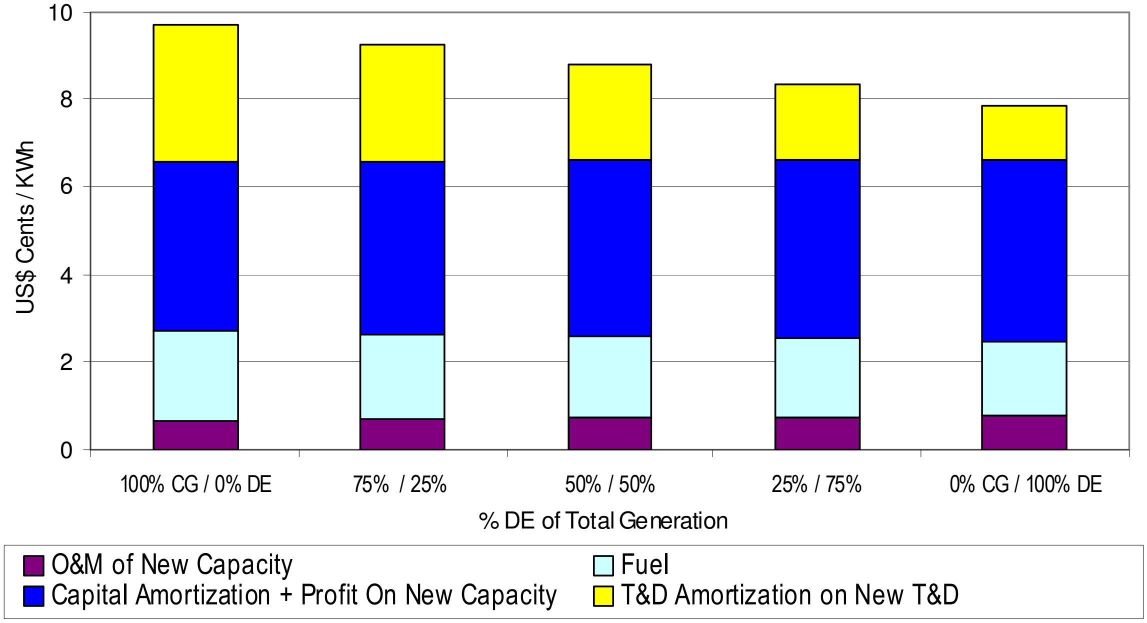
The projections show that, in the case of low BCHP uptake, the potential for CO_2 displacement is around 13.6 Mt per year by 2010. This equals to about 1.3% of total projected growth in emissions from all sectors. The high scenario shows potential to displace upwards of 11% of total projected Chinese emissions in all sectors. From a global perspective the absolute potential for displacement is enormous.

In all the WADE scenarios it is assumed that no subsidies are required for BCHP investment to be economic. The main factor that will decide whether a low or high scenario is realized is largely whether government policies simplify the paperwork required for BCHP development or if the approval procedure remains burdensome, often differing from case to case and city to city.

Potential cost savings

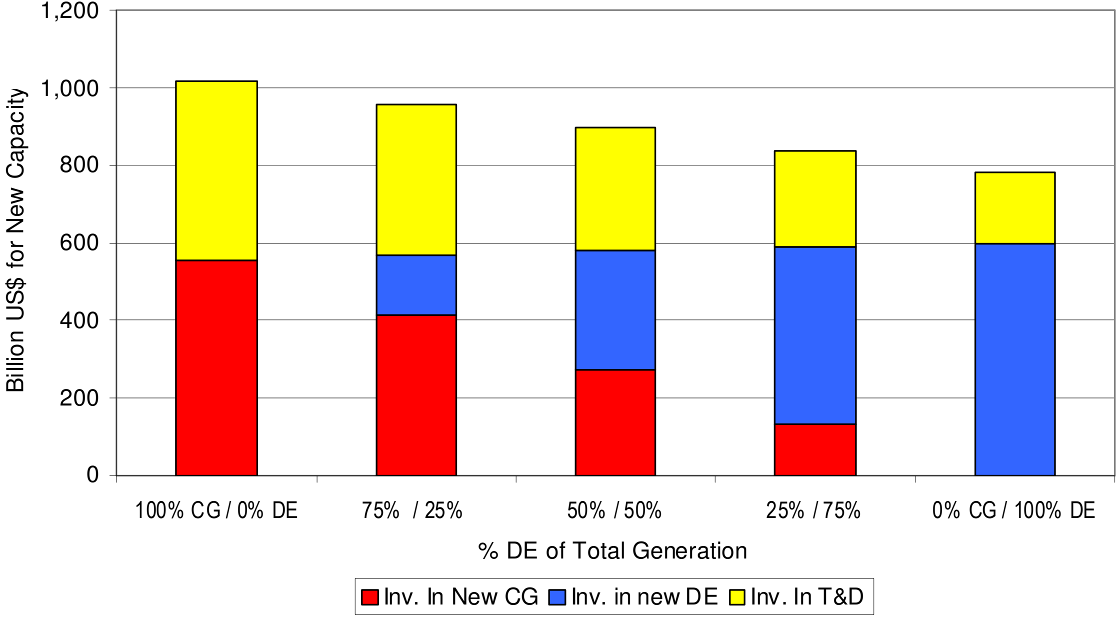
From the level of the electrical system as a whole WADE modelling has demonstrated that significant savings can be realized by investing in decentralized energy in China. Realizing maximum BCHP investment, for example, could reduce the average retail price for a kilowatt of electricity by about 2cents while reducing overall capital expenditures by a fifth, at the same time increasing overall system reliability and security. Figures 15 and 16 below illustrate the economic benefits from maximum investment in decentralized energy systems such as BCHP.

Figure 15. Chinese Retail Electricity Costs per kWh for Incremental Load in 2021



Source: 21

Figure 16 China – Capital Cost to Supply Incremental Electricity Load to 2021



Source: 21

Drivers for BCHP in China

The Chinese government has shown with its recent act of renewable energy that it is capable of moving quickly under the correct circumstances. The great social and environmental benefits of BCHP to society may convince the Chinese government to once again move swiftly and promote BCHP widescale market development. Fuel scarcity and environmental pressures are likely to influence the adoption of favourable government policies for BCHP.

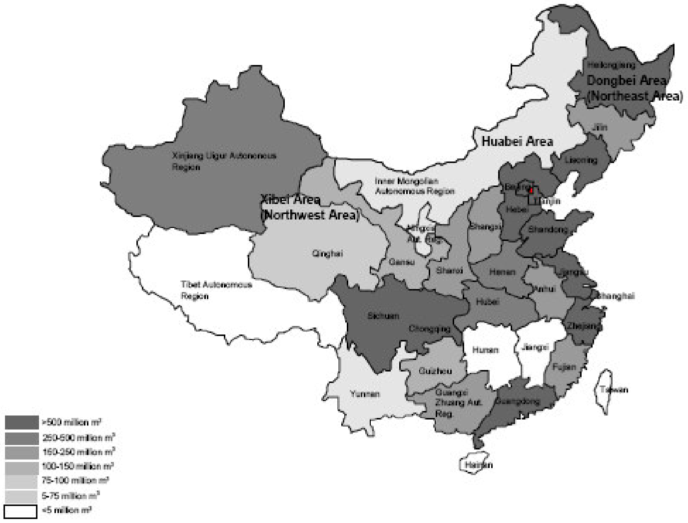
Policies that could be considered include mandatory BCHP installations in all new buildings meeting certain criteria or obligations for building owners to consider BCHP systems when replacing old boilers. Preferential financing and tax schemes can be another effective instrument for BCHP promotion. Some of the tools already in use elsewhere could provide the basis for effective government policy supporting BCHP development in China.

Certainly one important driver for BCHP in China will be fuel access. Gas infrastructure in China is underdeveloped yet ambitious expansion plans are currently on the table so there is a good chance that access to gas in cities will improve in the short term. With coal supply bottlenecks and increasing pressure to find lower carbon fuels demand for gas will certainly continue to increase. Figure 17 below illustrates projected gas demand in 2010 by province. Residential natural gas demand is expected to reach 22 billion m^3/year in China by 2010 and 50 billion m^3/year by 2020[43].

The fact that gas reserves are located in western China and the biggest demand for gas use in buildings is in the eastern part of the country means that bringing gas to market requires large-scale capital investment. To get the most value from infrastructure investment the Chinese will want to ensure it is burned in a manner which minimizes waste. BCHP is perhaps the best application for optimising the value of the incoming gas supplies.

Boiler replacements and new air conditioning installations will also be two important economic drivers for BCHP development in China.

Figure 17. Projected 2010 Natural Gas Demand by Province in China



Source: 43

India

Context

Table 21. Nation in numbers: India

Area (km2)	3,287,590
Population (2005)	1,080,264,388
Population Density (people/km2)	329
Urban population (%) (2003)	28
Expected Population growth rate (%)(2003-2015)	1.4
Human development index rating (out of 177)	127
Per capita Carbon emissions (MtCe) (2003)	0.26
Per capita GDP in international dollars (2004)	3,100
GDP per unit energy use (2000 PPP US$/ kgoe)	5.00
Electric Power Consumption (Kwh per capita/year)	569
Persons without electricity	440,000,000
Natural gas consumption billion m3 (2003)	30
Annual per capita natural gas consumption (m3)	28
Traditional fuel use (% of total energy demand)	20.0
National mean heating degree days	80
National mean cooling degree days	3,120
Energy Intensity	2.58

Source: various

Infrastructure

Existing Building Stock

Available data suggests that there are approximately 77.9 billion ft^2 of residential and commercial buildings in India though this is likely an underestimation. In rural areas detached homes are the norm and in cities most Indians live in densely populated apartment buildings. Table 22 below gives an indication of the geographic distribution of commercial office space in Indian cities. High-rise buildings such as these are likely good candidates for BCHP though to date none have BCHP installations. Omitted from the table are the thousands of academic institutions, hospitals, hotels, supermarkets, shopping centres and others. that would also be ideal BCHP applications due to their high and constant demand for cooling.

Table 22. Number of Highrise Buildings by Indian City (2005)

City	Population	Number of high-rise buildings
Mumbai	11,914,398	547
Kolkata	4,580,544	103
Gurgaon	173,542	85
New Delhi	301,000	74
Navi Mumbai	703,947	58
Pune	2,540,069	53
Bangalore	4,292,223	48
Cochin	564,589	32
Chennai	4,216,268	23
Thane	1,261,517	22
Ghaziabad	968,521	19
Lucknow	2,207,340	12
Thiruvanathapuram	2,938,538	10
Mangalore	490,000	7
Bidhan Nagar	167,848	6
Hyderabad	3,449,878	4
Trichur	2,737,331-	3
Surat	2,433,787	3
Aluva	24,108	2
Ahmadabad	3,515,361	2
	Total	**1113**

Source: 44

Existing Energy Demand

Information on Indian energy demand is often out-of–date and difficult to find. Average demand for heating by area in Indian buildings can be approximated at a very modest 0.05kWh/ ft^2 /year mostly as a result of its hot climate. Average cooling demand on the other hand is 0.24kWh/ ft^2 /year and growing quickly as air conditioning becomes ever more popular and accessible. Both of these averages are of course far below actual kWh/ ft^2 demand of air-conditioned buildings because the majority of the buildings included in the area figure (itself an underestimation) have limited climate systems and bring the average down. Table 23 shows average annual thermal and electrical demand.

Table 23. Indian Energy demand in Buildings by End Use (2004)

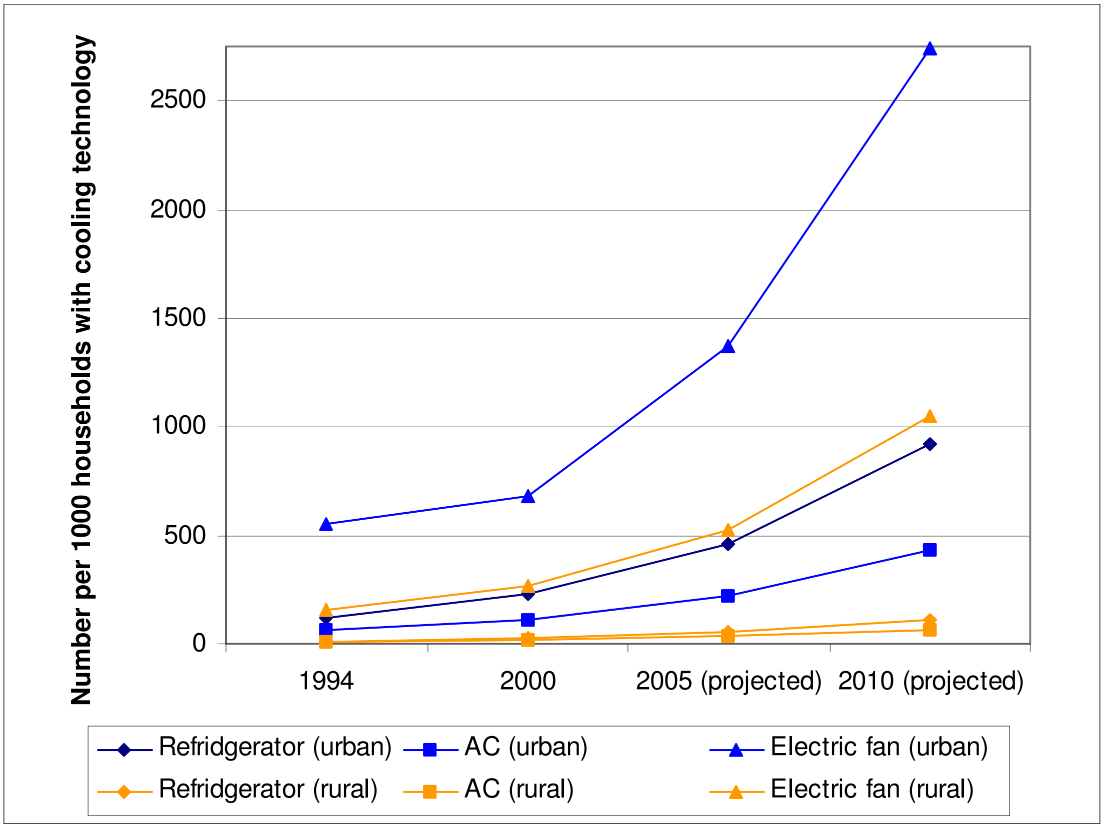
End Use	GWh/year
Electrical load	57,600
Cooling load	18,432
Heat load	3,888

Source: WADE estimates based on 45

In Indian buildings without any climate control system lighting usually accounts for the majority of energy needs. In a building with air conditioning, on the other hand, the air conditioner usually accounts for 40% - 50% of the building's total energy requirement followed by 20% dedicated for light and assorted pumps, with fans and other such appliances contributing to the balance of the building's energy need[46]. According to the All India Air Conditioning and Refrigeration Association, India produces over 1 million air conditioners for buildings, about 4 million domestic refrigerators, 100,000 water coolers and over $US 218 million worth of cooling systems for industrial and commercial applications each year. The total turnover of the industry is about $US 872 million[47].

By all accounts the cooling industry is set to grow as the number of new buildings increase and existing buildings are retrofitted with air conditioners. Figure 18 below, showing projected increases in demand for selected cooling technologies based on historical data, illustrates that there is certainly room for further growth. The potential for greatest growth is in the urban areas.

Figure 18. Projected Demand for Cooling Technologies in India per 1000 Households by 2010



Source: WADE projection based on data from 48

Existing Generation

Table 24 shows that India has a diverse mix of sources in its centralized power generation sector but almost 60% of the capacity is based on coal. Extensive domestic coal supplies means that any gas-fired BCHP plants will have increased carbon displacement potential because there in an increased chance they will displace coal instead of gas.

Table 24. Power Generation capacity in India by source (2002)

Generation Source	MW installed
Total fossil	87,000
Coal	69,000
Oil	5,000
Natural Gas	13,000
Nuclear	3,000
Hydro	25,000
Other	2,000
Total	117,000
Total production (GWh) 2002	598,000,000

Source: 5

Existing CHP

In India there is currently about 18.7 GW[49] of CHP applications in place, but the vast majority of that capacity is in industrial applications. A mere 30 MW of BCHP has been identified in India[*].

Figure 19 below shows the breakdown of BCHP plants identified in India. No examples of BCHP in buildings other than hotels or offices were identified so there remain many segments of both the residential and commercial building sectors that have yet to discover the potential benefits of onsite power generation using BCHP. Indeed the potential in all buildings in India remains enormous.

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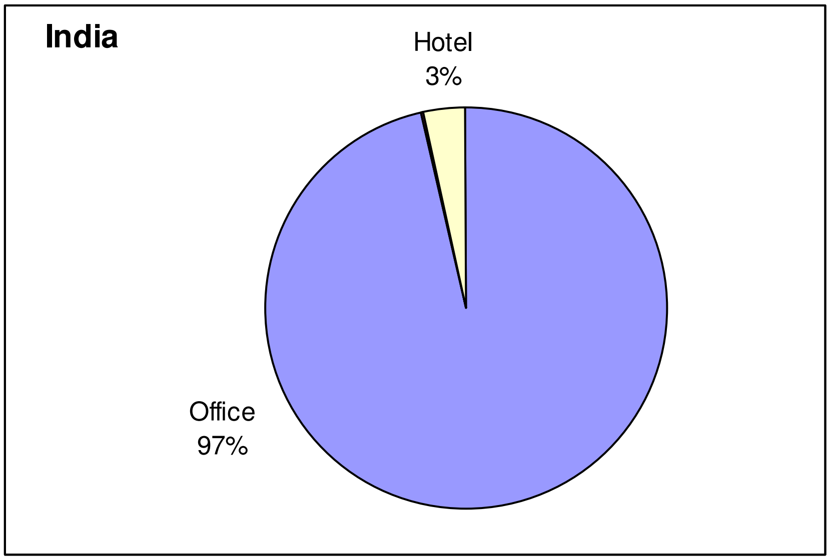
[*] WADE compilation

Figure 19. Stock of BCHP in India by Sub Sector (Number of installations n=15)



Source: WADE compilation

Climate Change

Existing emissions by sector

Though the building sector in India is responsible for a smaller proportion of total emissions than the other four nations examined in the report, in absolute terms there is much potential that should not be ignored. This is especially true because there is much "low-hanging fruit" in the building sector via BCHP - opportunities that are economic and that could be easily taken advantage of with small legislative and policy changes. Table 25 illustrates approximate emissions by sector.

Table 25. Approximate Total CO_2 Emissions by Sector in India

Sector	Mt CO_2 (2002)
Residential	60
Commercial	28
Industrial	206
Transportation	110
Agriculture	471
Other	44
Total	1,016

Source: WADE approximation based on 5 and 48

Carbon Mitigation Potential via BCHP in India

Projections

Baseline

The current installed capacity of BCHP systems in India is about 30 MW.

Technical Potential

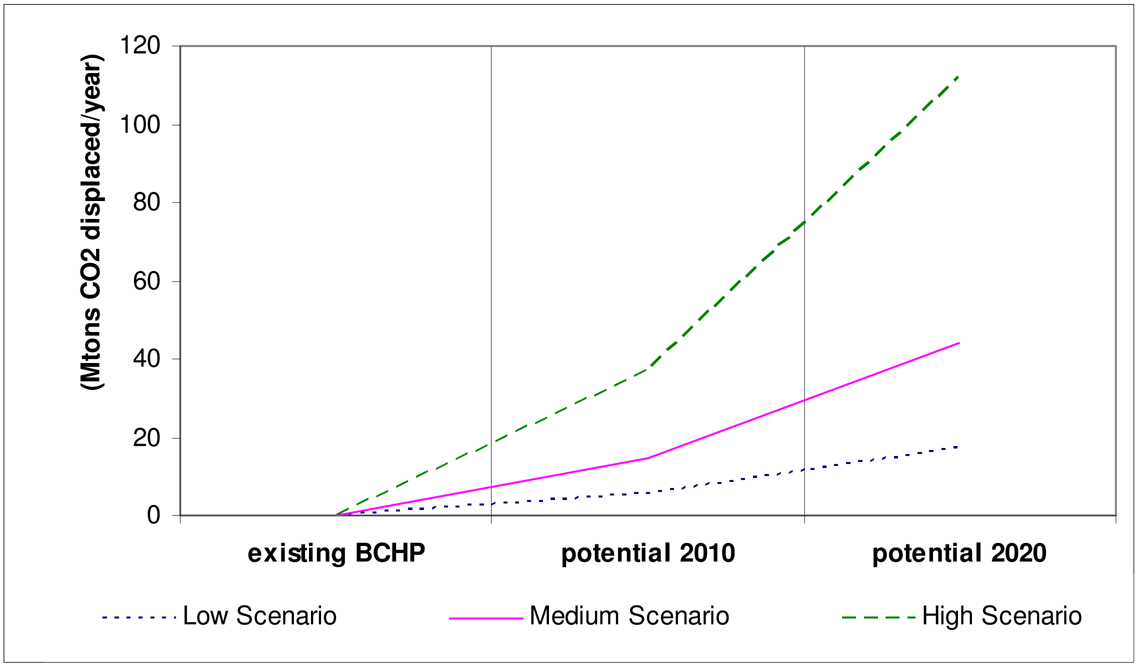
A conservative estimate of total BCHP potential based on existing building stock data is about 3.4 GWe of capacity. If all the potential were realized, then about 18 Mt CO_2/year could be displaced in India from BCHP.

Economic Potential

Because Indian commercial and residential building owners have limited access to piped natural gas we took a more conservative approach when making our assumptions of what amount of BCHP uptake was realistic. We assumed only 5% of new residential electricity demand could be met by BCHP in a low scenario, 10% in a medium scenario and 30 % in the high. For commercial demand the assumptions were 5%, 15% and 35% respectively. Lack of capital for BCHP investments could further hamper the growth of BCHP markets in India compared to those in other nations.

Figure 20. below shows the various WADE projections of what amount of BCHP uptake in India is immediately economic under the three scenarios. In the low uptake scenario some 5.7 Mt CO_2 could be displaced in India via economic BCHP installations requiring no subsidy. This represents 2.3% of the projected CO_2 emissions growth of all sectors based on a 2002 baseline. In the high BCHP uptake scenario more than 111 Mt CO_2 could be displaced every year, approximately 16% of total projected CO_2 emissions for the year 2020.

Figure 20 CO_2 Mitigation Potential from BCHP in the Indian Building Sector



Source: WADE projections

Potential cost savings

As for the other cases examined in this report significant economic benefits can be derived from investing in BCHP in India. Analysis from the Indian Centre for Fuel Studies and Research has concluded that the unit cost DE sources such as BCHP over a 20 year lifespan can be about half as much as a centralized option (see Table 26. below).

Modelling work by WADE has demonstrated that increased use of BCHP on a system level can reduce capital costs, retails costs, fossil fuel consumption and carbon emissions.

Table 26. Comparison of the costs for centralized mega power plants and distributed generation ($US)

	Centralised Generation CCP 2500 MW	Distributed Generation CCHP 2100 MW	Distributed Generation with CCP 2100 MW
Delivered Power	2000 MW	2000 MW	2000 MW
Capital Cost			
Generation	2.22 billion	2.34 billion	2.34 billion
Incremental T&D	2.22 billion	0.23 billion	0.23 billion
Total Capital Cost	4.45 billion	2.57 billion	2.57 billion
Fuel Cost for 20 Years	13.08 billion	5.49 billion	10.99 billion
Total Life Time Cost for 20 Years Operation	17.53 billion	8.06 billion	13.59 billion
Unit Cost of Generation	96.53/MWh	49.31/MWh	66.49/MWh

Assumptions:

Capital Cost

Centralised Generation	$US 890,000/MW
Distributed Generation	$US 1,112,000/MW

T&D Losses

Centralised Generation	20%
Distributed Generation	5%

Fuel Consumption

Centralised Generation-CCP	210 NM^3/ MWh
Distributed Generation-CCP	210 NM^3/ MWh
Distributed Generation-CCHP	105 NM^3/ MWh

Source: 50

Drivers for BCHP in India

The power reliability benefits will likely be the biggest demand-side driver for BCHP development in India. Data centres are one example of a booming business in India with over 160,000[51] people employed in the sector and growing quickly. BCHP systems are becoming increasingly appealing for the management of data centre buildings providing a constant and reliable source of power supplies in an industry that cannot afford sudden power outages resulting in loss of data that may occur when relying on centralized grid power supplies. As mentioned above, the increased demand for cooling in both new build and existing buildings will create an important opportunity for BCHP investors. Ironically, demand for cooling will also increase as a result of the warmer temperatures that are expected from a changing climate. The mean average temperature on the Indian subcontinent is estimated to have increased by 0.8 degrees in the last

200 years[48]. A continuation of this trend would mean an increased need for cooling and refrigeration. According to one estimate, an additional 1.5% of electric power generation capacity will be required in order to operate the electric air conditioners required as a result of the rise in temperature[48].

Fuel access will also be an important driver for BCHP development in India. Natural gas access in some urban areas is expected to become available or improve, as the case may be, in the near future as both domestic supplies and imports increase. Such a development could provide the foundation for a booming BCHP industry in the cities that gain access to natural gas distribution systems. In rural areas India already has extensive experience with biomass and biogas to meet basic cooking and electricity needs. In the long term this experience could provide a solid base for developing a biogas-based BCHP infrastructure throughout rural India. Research in this area could create affordable BCHP technologies for meeting both and cooling needs. India's robust agricultural industry could also provide the platform for the development of a bio-diesel industry to fuel BCHP systems.

Policies that allow BCHP installations to connect to the Indian power grid will be essential in order for the country to overcome what is considered as one of the greatest challenges in the way of BCHP's development. Effective tax and financing schemes which favour efficient fuel use will also play a very important part in making BCHP installations more affordable and widespread across India.

Box 1.
Shanghai Tindian Hotel

Location:	Shanghai, China
Type:	Hotel
Year:	2004
Technology:	Gas engine (MDE) Power capacity: 357kW Thermal capacity: 529kW
Fuel:	natural gas
More Info:	http://www.cn-greenlights.gov.cn

Box 2.
TERI RETREAT

Location:	Delhi, India
Type:	Educational facility and residence
Year:	2000
Technology:	Biomass gasifier and ecofriendly absorption chillers Power capacity: 50kW Thermal capacity:
Fuel:	biomass waste, diesel and LPG
Savings:	40%-50% of energy costs over conventionally designed buildings
CO_2 savings:	~570 tons/year (total building)
More Info:	http://www.teriin.org/case/retreat.htm

Box 3.
St. Catharine’s General Hospital

Location:	St Catharine’s, Canada
Type:	Hospital
Year:	1999
Technology:	Gas Engines with Heat Recovery Boilers Power capacity: 2.5MW Thermal capacity: 5.12 million btu/hr.
Fuel:	Natural Gas
More Info:	http://www.cumminspower.com/library/casehistories/

Box 4.
Waldbaum's Supermarket

Location:	New York, USA
Type:	Supermarket
Year:	2005
Technology:	Gas Turbine and absorption chiller Power capacity: 75kW Thermal capacity: 40tons cooling
Fuel:	Natural gas
Savings:	Annual energy savings of over $50,000
More Info:	http://www.capstoneturbine.com/onsites/pdf/OpenHouseFlyerWaldbaums.pdf

General conclusions

From the case studies in the previous section it is clear that incorporating CHP systems into existing buildings as boilers/furnaces are replaced, as well as new buildings, offers enormous potential for cost effective carbon displacement. In all four nations the few BCHP installations that already exist are proving that carbon mitigation via BCHP is affordable and effective today. There remain some significant barriers to widespread BCHP adoption but none of the problems are insurmountable.

Access to fuel is the most important. Fuel must be both accessible where it is needed, i.e. in the case of gas it must be piped to the building where the BCHP unit is to be installed and it must be affordable- the ratio between electricity and gas prices is the single biggest factor.

Policy barriers are next in importance. There are already some good examples of policies that are today proving that BCHP markets can be improved. Much work remains in all countries to remove BCHP obstacles such as unnecessary interconnection barriers and unfair financing schemes and pricing mechanisms.

Although detailed prescriptions for realizing the massive potential for building integrated CHP is outside the scope of this study some general guidelines can be concluded. The US, although it still has a long way to go, has shown that strategic and concerted efforts to promote CHP via policy implementation and organized interest groups can go a long way in realizing objectives. Other nations outside the scope of this study, such as Denmark, where CHP now accounts for more than 50% of total electricity production, have achieved through political will even more striking success.

Common factors which have proven useful for successfully promoting BCHP include:

- Guaranteed access to the grid for property owners who decide to invest in BCHP
- Technical support throughout the grid connect process;
- Mandatory energy-efficiency standards for buildings;
- Quota systems requiring all new build to install a certain percentage of onsite power;
- Increased research and development of demonstration programs for the various BCHP technologies.

Allocating scarce fuel to the most efficient use and adopting other policies favourable to BCHP could help nations go a long way in realizing the significant carbon mitigation potential, and other benefits of BCHP in the short and long term.

References

1 Mitigation. Intergovernmental Panel on Climate Change 2001.
2 WADE, Guide to DE Technologies, September 2003.
online: http://www.localpower.org/documents_pub/report_de_technologies.pdf
3 CIA World Fact Book
online: http://www.cia.gov/cia/publications/factbook/docs/rankorderguide.html
4 International Energy Annual 2003, Energy Information Administration.
5 IEA World Energy Outlook 2005, International Energy Agency, 2005
6 Strategic Options for Combined Heat and Power in Canada. Final Report MK Jaccard and Westminster, BC. Alison Laurin, Dr. John Nyboer, Catherine Strickland, Nic Rivers. August 2004
7 The State of Energy Efficiency in Canada, Office of Energy Efficiency Report 2005
online: http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/data_e/see05/buildings.cfm?attr=0
8 Comprehensive Energy Use Database, Natural Resources Canada, Canadian Office of Energy Efficiency
9 Canada's Energy Future Scenarios for Supply and Demand to 2025
online: http://www.nrcan.gc.ca/es/etb/cetc/combustion/cctrm/pdfs/canadas_energy_future%20.pdf
10 Canada's Third National Report on Climate Change. Actions to Meet Commitments Under the United Nations Framework Convention on Climate Change. Canada 2001. En21-125/2001E
11 Energy Information Administration Country Analysis briefs
online: http://www.eia.doe.gov/emeu/cabs/contents.html
12 A Review of Existing Cogeneration Facilities in Canada Prepared by Catherine Strickland John Nyboer of the Canadian Industrial Energy End-Use Data and Analysis Center Simon Fraser University March 2005
13 Canadian Industrial Energy End-Use Data and Analysis Center, Cogeneration Database
http://www.cieedac.sfu.ca/CIEEDACweb/mod.php?mod=cogeneration&menu=1604
14 Canada's GHG Emissions by Sector, End-Use and Sub-Sector– Excluding Electricity-Related Emissions
online: http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/tableshandbook2/
15 Summary Canada's 2003 Greenhouse gas inventory Region CANADA Year 2003 Table Sectoral Greenhouse Gas Emission Summary
online: http://www.ec.gc.ca/pdb/ghg/2005summary/2005summary_e.cfm
16 A Business Case for Green Buildings in Canada, 2005, Mark Lucuik, March 2005, Morrison Hershfield
17 Development of Micro-CHP Technology Assessment Capability at CCHT, Canadian Mortgage and Housing Corporation, June 2005 Technical Series 05-102
18 Cogeneration Systems in Multi-Unit Residential Structures, Canadian Mortgage and Housing Corporation 1993 Technical Series 93-216
online: http://www.cmhc-schl.gc.ca/publications/en/rh-pr/tech/93216.htm
19 Electricity Consumers Resource Council, The Economic Impacts of the August 2003 Blackout, February 2004.
20 Assessing the Benefits of On-Site Combined Heat and Power during the August 14, 2003 Blackout, Carlson, A., Hedman, B., Oak Ridge National Laboratories, June 2004.
21 The WADE Economic Model: China. A WADE Analysis, January 2005,
online: http://www.localpower.org/documents_pub/report_model_china_english.pdf

22 The Market and Technical Potential for Combined Heat and Power in the Commercial/Institutional Sector. EIA, 2003
online: http://www.eia.doe.gov/emeu/cbecs/cbecs2003/detailed_tables_2003/pdf2003/a6.xls

23 Reference Case Forecast, Energy Information Administration
online: http://www.eia.doe.gov/oiaf/aeo/pdf/appa.pdf#page=13

24 Energy Information Administration Home Energy Use and Costs Residential Energy Consumption Survey
online: http://www.eia.doe.gov/emeu/recs/

25 U.S. Climate Action Report – 2002 Third National Communication of the United States of America Under the United Nations Framework Convention on Climate Change

26 Overview of the US Building Stock, Richard C. Diamond LBNL-43640 January 2001 Lawrence Berkeley National Laboratory
online: http://eetd.lbl.gov/ied/pdf/LBNL-43640.pdf

27 Energy Information Administration, 2003 Commercial Buildings Energy Consumption Survey.

28 End-Use Consumption of Electricity 2001, Energy Information Administration.
online: www.eia.doe.gov/emeu/recs/recs2001/enduse2001/enduse2001.html

29 2005 CHP Action Agenda : Innovating, Advocating, Raising Awareness, and Delivering Solutions. October 2005

30 Energy Information Administration Figure 69. Electricity generation by fuel, 2003 and 2025
online: http://www.eia.doe.gov/oiaf/aeo/excel/figure67_data.xls

31 Energy Annual 2003 Energy Information Administration International .
online: http://www.eia.doe.gov/pub/international/iealf/tableh1c.xls

32 EIA Annual Energy Outlook, 2005 with Projections to 2025
http://www.eia.doe.gov/oiaf/aeo/pdf/0383(2005).pdf

33 Personal communication with Anne Hampson Energy and Environmental Analysis Inc.

34 Kyoto Protocol Status of Ratification.
online:http://unfccc.int/files/essential_background/kyoto_protocol/application/pdf/kpstats.pdf

35 Where Are We on the Road to 92 GigaWatts, Bruce Hedman, Energy and Environmental Analysis. October 2005

36 Marketing Strategy of “ECOWILL” a Residential Cogeneration System Seiichi Higuchi Osaka Gas Co., Ltd. November 12, 2003

37 Human Development Report 2005
online: http://hdr.undp.org/statistics/data/indicators.cfm?alpha=yes

38 China Statistics Yearbook 2005, Compiled by National Bureau of Statistics of China, China Statistics Press, 2005.

39 WADE Market Analysis 2005: China

40 A Fundamental Study on Introduction of Natural Gas Cogeneration in Urban Commerical Building in China, 2004. http://staff.aist.go.jp/h-aki/papers/aki_jser_conf04-2.pdf

41 The Opportunity and Risk of Geothermal Heating Investment in China, Wanda Wang
Tianjin Geothermal Research and Training Center, Tianjin University, PRC, Proceedings of the World Geothermal Congress 2000, Kyushu Japan, May 28 - June 10 2000

42 Report of Assessmetn on Barriers of CHP/Trigeneration Promotion and Potnetial Countermeasure in China, 2004 European Commission (Directorate-General for Energy and Transport) Contract no. NNE5/2002/52: OPET CHP/DH Cluster

43 Natural Gas in China, Institute fro Energy Economics Japan: August 2003 Kaoru YAMAGUCHI, Keii CHO,

44 Emporis Skyscrapers in Cities database, Emporis November 2005
online: http://www.emporis.com

45 Special address at the International Conference at Energy Conservation October 2004,
online: http://presidentofindia.nic.in/scripts/sllatest1.jsp?id=399

46 Energy efficiency in green buildings- An integrated approach to building design
online: http://www.teriin.org/division/eetdiv/crsbs/docs/ft01.pdf

47 All India Air conditioning and Refrigeration Association
online: http://www.aiacra.com/growth.htm

48 India's Initial National Communication to the United Nations Framework Convention on Climate Change, Government of India 2004

49 Indian Central Electricity Authority General Review 2005
online: http://www.cea.nic.in/ge_re/2004-05/contents.pdf

50 The Case for DG in India. Subcontinent Needs High-efficiency local power. Ajit Kapadia, Kirit Naik, COSPP, July-August 2005

51 Call Centers in India - Challenges for HR Professionals
online: http://www.bpoindia.org/research/call-centers-challenges-for-hr.shtml