Greenhouse Gas Emissions in Chicago: Emissions Inventories and Reduction Strategies for Chicago and its Metropolitan Region

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ABSTRACT
A greenhouse gas emissions inventory was conducted for Chicago and its metropolitan region for the years 2000 and 2005. Emissions of carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride totaled 34.7 million metric tons of carbon dioxide equivalents ($MMTCO_2e$) in Chicago in 2000 with 91 percent of emissions attributable to the indirect emissions associated with electricity consumption, the direct emissions of natural gas use, and the direct emissions of the transportation sector. A portfolio of 33 potential emissions reduction strategies was analyzed that, implemented together, could meet Chicago's target of reducing greenhouse gas emissions to 25 percent below 1990 levels by 2020. The largest potential for reduction is found in the areas with the largest emissions—energy use in buildings and transport. Compared to its metropolitan region, Chicago is found to have existing transportation efficiencies on a per household basis that can be an example for other communities.

INDEX WORDS: Climate Change, Chicago, GHG, Inventory, Mitigation

INTRODUCTION

Global climate change presents a challenge of epic proportions for Chicago and the world. To address climate change, its origins must be understood. The primary sources of anthropogenic greenhouse gas (GHG) emissions contributing to global warming have been well documented at a large scale through global studies and national inventory reports. The global standard for such national inventories is the Intergovernmental Panel on Climate Change's (IPCC) "2006 IPCC Guidelines for National Greenhouse Gas Inventories" (IPCC 2006). But, as smaller entities such as cities seek to take action on global warming they must understand their GHG emissions sources at a finer grain of detail.

Creating an emissions inventory at the city level poses unique challenges; for example, many cities are net importers of electricity—meaning that less electricity is generated within the city boundaries than is consumed within the city. If only electricity generation emissions were inventoried, the city would undercount the impact of its electricity use and miss many important opportunities to reduce electricity demand, and perhaps its associated emissions, with energy efficiency and conservation. The IPCC 2006 Guidelines provide no method for calculating GHG emissions based on electricity consumption, because on a national level it is sufficient to calculate the emissions associated with the total fuel consumed for electricity generation. Such issues were addressed in large part for business inventories with the introduction of the World Business Council for Sustainable Development and World Resource Institute's "The Greenhouse Gas Protocol: A Corporate Accounting and Reporting Standard" in 2001. Many cities have used this method to document the GHG emissions associated with their local government operations—their buildings, fleets and other assets—but this standard is not fully applicable to the challenges of emissions inventories for cities as geographic entities, which are too small in geography to accurately follow national inventory methods, yet are more like nations than businesses in that cities do not own or operate all of the facilities in their boundaries. As a result, cities have needed to innovate on these methods to document their contribution to global warming in a complete and accurate way. The challenges of this evolving methodology and limited data have meant that few cities know their total GHG emissions or the sources of those emissions. This situation is changing rapidly as cities seek to address their climate change impact. This article documents the first ever inventory of GHG emissions for Chicago, Illinois.

The primary reason for creating an emissions inventory is to generate an understanding of the sources of emissions and identify where the opportunities for emissions reductions lie. Before taking action, many cities choose to set an emissions reduction target to shape their planning and benchmark their progress. Climate scientists estimate that a 50-85 percent reduction below 2000 global GHG emissions by 2050 is required to achieve an atmospheric concentration of GHGs at 445-490 ppm and stabilize the climate at 2.0-2.4 degrees Celsius above pre-industrial temperatures (Metz et. al. 2007). A thousand cities in the United States have signed on to the U.S. Mayor's Climate Protection Agreement, which encourages cities to reduce emissions to 7 percent below 1990 levels by 2012—the national emissions reductions commitment the U.S. would have made if it had ratified the Kyoto Protocol. Chicago has signed on to this Agreement, but Chicago's Climate Change Task Force used the Chicago emissions inventories for 2000 and 2005 and estimates of future and past emissions to set a more aggressive target of reducing emissions to 25 percent below 1990 levels by 2020, which would put the city on the path to an 80 percent reduction by 2050.

With this target set, a portfolio of emission reduction strategies was developed for Chicago. The emissions reduction potential of each strategy was estimated and quantitative and qualitative analysis was conducted to determine emission reduction potentials, the nature and scale of the programs and policies necessary, similar activities underway in Chicago and the region that could be built upon, examples of successful programs from other areas, and implementation opportunities and barriers. To understand the scale of the reductions needed a business as usual scenario was developed based on historical and national trends for each emissions sector. This projection is discussed further in the research report prepared for the project (McGraw et. al. 2008). This research was done with the goal of providing the Chicago Climate Change Task Force with the information necessary to create a feasible and measurable emissions reduction plan for Chicago.

METHODS

Chicago's GHG emissions inventory was calculated for the years 2000 and 2005 using IPCC and GHG Protocol (IPCC 2006, WBCSD and WRI 2004) methods and local data sources in combination with modeling of national data to local demographics. The emissions inventory for 2000 was prepared because it was the earliest year for which necessary data were readily available. An emissions inventory for 2005 was also created as the most recent year with complete data.

As discussed above, 1990 is one of the standard baseline years for setting emissions reductions targets and it was the year the City of Chicago wanted to use as a reference point to make comparisons with other communities and programs; however relevant activity data for Chicago in 1990 were unavailable from local energy utilities and others. Therefore an estimated emissions value based on historic Chicago area and national growth trends was used as a reference point for 1990. This point is just an estimate and should be viewed as such; its primary use is to enable a reduction target to be set. Reaching that target is the focus of the Chicago Climate Action Plan.

Emissions in the years 2000 and 2005 were calculated for all direct sources within the geographical boundaries of the city of Chicago—natural gas use, transportation, non-energy industrial processes, and the use of GHGs in products. Indirect emissions from the consumption of electricity and disposal of waste to waste treatment facilities outside of city boundaries were also calculated. Finally, emission sequestration associated with Chicago's trees was estimated. Emissions were calculated for the six major categories of GHGs regulated under the Kyoto Protocol: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF6). Emissions were converted into carbon dioxide equivalents (CO_2e) by multiplying emissions in mass by global warming potentials (GWPs) from the IPCC Third Annual Assessment Report (Houghton et. al. 2001) and summing the resulting weighted emissions (Table 1).

TABLE 1. *Summary of Chicago GHG emissions inventories including primary activity data type by emissions source.*

Emissions Source	**Primary Activity Data Sources for Chicago Inventory**	**2000 Chicago GHG Emissions MMTCO2e**	**2005 Chicago GHG Emissions MMTCO2e**	**Percent of 2005 Total Chicago Emissions**
Energy: Electricity Use	Electricity use from utility billing data	12.9	16.0	44%
Energy; Natural Gas Use	Natural gas use from utility billing data	11.5	9.9	27%
Transportation: On-Road	Vehicle travel statistics for city from state department of transportation	6.6	6.5	18%
Transportation: Off-Road	National transit database commuter rail fuel use, Amtrak passenger rail energy use, regional air quality monitoring agency cargo rail fuel use, utility electric use data for transit system	0.7	0.7	2%
Aviation	City aviation fuel use from tax data	8.7	7.5	Not included in total
Industrial Processes	National emissions inventory, U.S. Census	0.4	0.0	0%
Product Use	National emissions inventory, U.S. Census	1.2	1.5	4%
Waste	City annual solid waste disposal data	1.1	1.2	3%
Wastewater	Emissions report from regional wastewater treatment agency	0.4	0.3	1%
Total		**34.7**	**36.2**	**100%**
Total Including Aviation		**43.5**	**43.7**	**121%**
Agriculture, Forestry, and Other Land Use	Tree crown cover calculated using GIS analysis	-0.1	-0.1	0%

Energy

Energy emissions in this study include emissions associated with electricity and natural gas consumption. Other non-transport energy sources (for example, kerosene and propane) were investigated and data for Chicago were unavailable. However, electricity and natural gas are 96 percent of the energy use in the area (Energy Information Administration 2004).

Electricity emissions were calculated by gathering electricity consumption data from the local utility, Commonwealth Edison, and applying CO_2 emissions factors associated with the local North American Electric Reliability Council region from the U.S. Environmental Protection Agency (U.S. EPA) Emissions & Generation Resource Integrated Database (eGRID) (U.S. EPA. 2006) and CH_4 and N_2O emissions factors from the California Climate Action Registry General Reporting Protocol (California Climate Action Registry 2006). The regional power pool emissions factors were used rather than emissions factors associated with specific generation plants because electricity is traded across a grid and at any given point electricity could be supplied by any of the grid-connected plants in operation. Hence, a regional average of GHG emissions per kilowatt hour (kWh) is the best representative of the GHG impacts of electricity consumption. Electricity consumption, in terms of kWh, was measured based on user account data, and transmission and distribution losses were not included.

Natural gas emissions were calculated by gathering natural gas consumption data from People's Energy and from the Illinois Commerce Commission for the Nicor Gas service territory (Illinois Commerce Commission 2002 and 2006), and applying natural gas emissions factors from the U.S. EPA's Inventory of U.S. Greenhouse Gas Emissions and Sinks (U.S. EPA 2007a) and the IPCC 2006 Guidelines for National Greenhouse Gas Inventories (IPCC 2006). For energy consumption the calculation of emissions is a simple equation of energy consumed * GHG emissions per unit of energy = GHG emissions.

Transportation

Transportation emissions were developed using vehicle miles traveled (VMT) data from the Illinois Department of Transportation (Illinois Department of Transportation 2001 and 2006) for on-road vehicles combined with fleet mix data from the Lake Michigan Air Directors Consortium (Lake Michigan Air Directors Consortium 2007) and vehicle efficiency data from the Federal Highway Administration (Federal Highway Administration 2001 and 2006) to create a profile of fuel consumption and VMT in Chicago by vehicle type. Fuel use and VMT data from Amtrak, Lake Michigan Air Directors Consortium, Energy Information Administration (Energy Information Administration 2007b) and National Transit Database (Federal Transit Administration 2001 and 2006) were used to calculate passenger rail, cargo rail, and commuter rail emissions. In addition, the emissions associated with electricity used for Chicago's transit system was categorized as part of transportation emissions.

Fuel sales from the City of Chicago Department of Aviation were used to calculate emissions associated with flights originating at Chicago's two airports. A recent publication from the Airport Cooperative Research Program (ACRP) recommends the use of modeled fuel use data by flight to calculate emissions from air travel, but those modeled data are not yet publicly available by airport from the Federal Aviation Administration. The ACRP report recommends aviation fuel sales data as an alternative method (Kim et. al. 2009.).

Emissions from flights originating in Chicago, though calculated, are not included in Chicago's total inventory, as there is not yet a standard for allocating responsibility for air travel emissions to specific cities. The Kyoto protocol excludes international shipping and aviation from national GHG reduction commitments (United Nations 1997). The transnational nature of these modes of transport complicates the accounting of, and designation of responsibility for, their resulting GHG emissions. Similar accounting questions arise for domestic and international aviation when examining GHG emissions on the city scale, as airports generally serve an entire region rather than a city, and at major aviation hubs like O'Hare many passengers are simply transferring and are not originating nor terminating their trip in Chicago.

There are other off-road transportation emissions sources that were not captured in this inventory because data were unavailable. These sources include fuel consumed by marine transportation, construction equipment, business equipment (i.e. forklifts), recreational equipment (i.e. golf carts), and lawn and gardening equipment. None of these is likely to be significant for Chicago; marine transportation uses 5 percent of transportation energy nationally, and other off-road sources not addressed here, including agricultural equipment, use 8 percent of the national total (U.S. EPA 2007a). Moreover, one would expect these off road uses of petroleum to be included in fuel sales data, which was cross checked with VMT for on-road transportation and fond to be within the same range. Future research should investigate the off-road uses of fossil fuels in Chicago in further detail through fuel sales, activity surveys, and vehicle sales.

Emissions factors for transportation are from the U.S. EPA Inventory of U.S. Greenhouse Gas Emissions and Sinks (U.S. EPA 2007a) and the U.S. EPA State Inventory Tool (U.S. EPA 2007b). Fuel consumption data in the transport sector was multiplied by the fuel emission factor to calculate emissions. For on-road transport, CH_4 and N_2O emissions factors are expressed as emissions per mile, because the value is dependent on emissions control technology, as opposed to the straight fuel combustion-based calculation for CO_2 (IPCC 2006). The emissions from on-road transportation in Chicago were cross checked with fuel sale data from the City of Chicago Department of Revenue.

Industrial Processes and Product Use

Industrial processes and the use of GHGs in products contributed 5 percent of U.S. GHG emissions in 2007 (U.S. EPA 2009). Data on emissions from non-energy industrial processes and the use of GHGs in products are very difficult to find at the city level, so the emissions are estimated as a proportion of national emissions as reported in U.S. EPA 2007a. Inventories of local industrial emitters and data on the sales and use of products that result in GHG emissions would be preferable, and further research in this area is encouraged. If Chicago was a smaller city, or home to a major industrial emitter, such a as a large cement producer, industrial process emissions might be a significant share of the community's emissions, but industries using GHG emitting processes are no longer major employers in Chicago, and given the share of the city's emissions from industrial processes and product use, this rough estimation method was deemed to introduce an acceptably small level of error into the study. Understanding the scale of likely emissions from these sources for Chicago and discussing the emission reduction potential presented in this sector make it worthwhile to include these sources in the community's emissions profile.

The industrial processes sector includes non-energy related GHG emissions, such as those generated in the process of cement manufacturing. The US Census Bureau's Economic Census and Annual Survey of Manufacturers (U.S. Census Bureau 2001a and 2005) was used to determine the proportion of U.S. GHG producing industrial activity in Chicago. First, GHG producing industries located in Chicago were identified by North American Industry Classification System (NAICS) code. The relevant industries in Chicago were found to be Iron and Steel Production and Integrated Circuit or Semiconductor manufacturing. The employment in these sectors in Chicago was then calculated as a percentage of national employment by sector and used to prorate the national GHG emissions in that sector. The potential for error in this method is substantial, but until better data are available for industrial processes at the city scale, it is a fair approximation.

In addition to these industrial activities, there are a number of products used in Chicago that contain GHGs. These include the sulfur hexafluoride (SF6) used as an insulator in electrical equipment and the nitrous oxide (N_2O) used as an anesthetic by dentists. Again, local data on these emissions were unavailable, so a similar method as the industrial process emissions was employed—national emissions were prorated by Chicago's share of the national population using the U.S. EPA National Inventory and U.S. Census data (U.S. EPA 2007a and U.S. Census Bureau 2001b).

Waste and Wastewater

Annual waste disposal and waste composition data provided by the City of Chicago were used with degradable organic content values by waste type from IPCC 2006 to enable the calculation of the total degradable organic content (DOC) of landfilled waste at 16 percent. This was used to calculate methane generation by using the following IPCC 2006 default values: a methane correction factor (MCF) of 1, 10 percent oxidation (OX) of CH_4, 50 percent CH_4 content in landfill gas (F), and a conversion of carbon to CH_4 of 16/12. The U.S. EPA National Inventory value of 77 percent of degradable organic content decomposed (DOCf) was used along with the City of Chicago's data on 75 percent methane recovery (R). The equation to calculate emissions from waste disposal was: Mass of Waste Disposed (net of recycling and other diversion) * DOC * MCF * DOCf * F * OX * 16/12 * R = CH_4 from landfilled waste.

Only CH_4 associated with waste decomposition was calculated. Solid waste also produces CO_2 as it decomposes, but as the carbon stored in decomposing food, paper, and paper products is biogenic in origin—it was absorbed from the atmosphere by plants in recent history—its release does not contribute to global warming, and therefore is not counted in this inventory. All of the landfills used by Chicago in 2000 and 2005 were located outside of the city (Illinois Environmental Protection Agency 2006), so the emissions associated with waste disposal are considered indirect emissions. Chicago has a number of closed landfills within its city boundaries. Solid waste takes decades to decompose, so closed landfills can continue to generate CH_4 emissions for 50 years or more. IPCC 2006 uses a first order decay method to account for current year emissions from historic waste disposal, but data were unavailable at the time of this study to estimate these emissions for Chicago.

Emissions associated with wastewater treatment were based on an estimate conducted by the Metropolitan Water Reclamation District (MWRD) using the methodology detailed in IPCC 2006. It was assumed that all sewer discharge was delivered to the MWRD plants via a covered sewer collection system. The MWRD estimate of the fugitive methane emissions for the entire district (which is larger than Chicago) was then scaled to represent the water treatment associated only with the Chicago population. IPCC 2006 methods calculate wastewater emissions as a function of wastewater treatment technology and total organic waste (TOW). TOW is calculated based on population and biological oxygen demand (BOD) per capita, so prorating emissions by population is a reasonable estimation method for this sector., although further study in this area would be useful, because Chicago is both an economic center and a tourist destination, so its share of regional wastewater generation may be higher than its proportion of the regional population. Chicago accounted for 57 percent of the MWRD population in 2000 and 54 percent of the MWRD population in 2005. As with solid waste, the CO_2 emissions associated with wastewater are considered biogenic and were not included in the inventory.

Water reclamation plants recover methane during the water treatment process. This recovered methane is used on site for heating and/or electricity generation. There are no data available on the amount of methane that is recovered by MWRD annually. This is an area for further research.

Agriculture, Forestry, and Other Land Use

IPCC 2006 provides an estimated annual carbon accumulation value per hectare of tree crown cover in settled areas of 2.9 tons carbon per hectare (10.6 tons CO_2). This value was multiplied by the total crown cover in Chicago to estimate the CO_2 sequestered by Chicago's urban forest annually. Chicago's tree canopy was calculated using GIS analysis from aerial photos and shapefiles provided by the Chicago Department of Environment. Chicago may have benefited from additional carbon uptake from the growth of other plants such as shrubbery and grasses, but this would be negligible at the city scale and was not measured.

Agriculture in the U.S. emitted 547.4 MMTCO_2e in 2000 through livestock, crop, and soil activities. Some of these agricultural emissions are associated with the food and goods Chicagoans consume, however, from a direct emissions accounting perspective there is little agricultural activity within Chicago's borders, so no agricultural emissions are included in Chicago's emissions inventory. The lifecycle and indirect emissions associated with goods and services is an issue of importance to long term climate stability and should be further studied.

Regional GHG Emissions

Inventories of GHG emissions in 2000 and 2005 for the six-county Chicago Metropolitan Region were also conducted in order to examine the role of Chicago in the region, and the emissions reduction potential of regional strategies such as transit and transit-oriented development. While most of this article discusses the emissions inventory and mitigation strategies developed for Chicago, the regional inventory is also discussed as a point of comparison.

The methods described above for the Chicago city inventory were also used for most sections of the regional inventory. Data were obtained for activities in the six-county Chicago region from the sources described above for energy, transportation, and industrial processes and product use, and the same methods were used to estimate these emissions at the regional scale. Regional solid waste disposal data (IL EPA 2006) were combined with the solid waste emissions estimation methods used for Chicago. The wastewater emissions from MWRD were prorated based on regional population, as the six-county area extends beyond the MWRD service area, but wastewater data for those other areas were not available. Unlike Chicago, the region contains both agriculture and livestock that contribute to the area's GHG emissions. These emissions were estimated as a share of national emissions based on agricultural land area and livestock counts by type (U.S. EPA 2007a and U.S. Department of Agriculture 2004). A more specific inventory of regional agricultural emissions using IPCC 2006 methods would be informative.

Mitigation Strategies

A broad survey of projects and programs that can reduce GHG emissions was conducted including solicitation of input from stakeholders and research into best practices in communities around the world to identify feasible solutions that suit Chicago. After review of all mitigation ideas, 33 were selected for in-depth research based on their feasibility, potential for GHG reductions, and capacity for rapid implementation at the city and regional level. Many programs with smaller emission reduction potentials were combined into larger strategies that met the scale of the reductions needed. It should be noted that nearly all of these strategies utilize currently available technology, and therefore, from a technical standpoint, could begin to be implemented immediately. Two of the strategies, Cap and Trade and Carbon Tax, were researched as umbrella strategies that could enable all of the others, thus their emissions savings are equal to the size of the whole.

Estimating the emissions reduction potential of each strategy required assuming a specific scale of adoption and a potential emission reduction per unit of activity. The scale of adoption for these illustrative purposes was set at an achievable, but aggressive, level. For strategies that expand programs that already exist, the current level of activity was assumed to be part of business as usual, because it is represented in Chicago's emissions inventory, and savings were calculated only for program expansion.

In many cases the potential emissions reductions per unit of activity were developed based on data in the 2000 emissions inventory, such as annual emissions per household associated with electricity and natural gas consumption. For example, consider the residential energy retrofit strategy which assumes a program that targets 400,000 homes by 2020 and saves an estimated 30 percent of energy use per building on average. Using the 2000 inventory, residential energy use emitted 11.4 MMTCO_2e and there were 1.06 million occupied housing units (U.S. Census 2001b), so each unit's energy use contributed 10.7 metric tons of CO_2e on average. A 30 percent savings would therefore result in an annual 3.2 metric ton CO_2e reduction per unit, or 1.3 MMTCO_2e per year for 400,000 homes. This is just an estimate of the scale of such a program. As an emissions reduction program is planned the assumptions inherent in such a calculation should be vetted and actual savings should be tracked over time. The methodologies for the United Nations Framework Convention on Climate Change Clean Development Mechanism are a good resource for information on how to measure emissions savings from particular projects as they are planned and implemented.

For other strategies, such as the adoption of car sharing, the activity savings or associated emissions reduction were developed based on literature. In the case of car sharing programs, Cervero et. al. 2007 shows that the average car share user saves 0.28 gallons (1.06 L) of fuel per day as compared to a non-user. Over the course of a year, that results in 102 gallons (386 L) of fuel and 0.88 metric tons CO_2e saved per car share user based on emissions rates from the 2000 Chicago inventory. The addition of 183,000 car share users therefore results in a total annual savings of 0.16 MMTCO_2e.

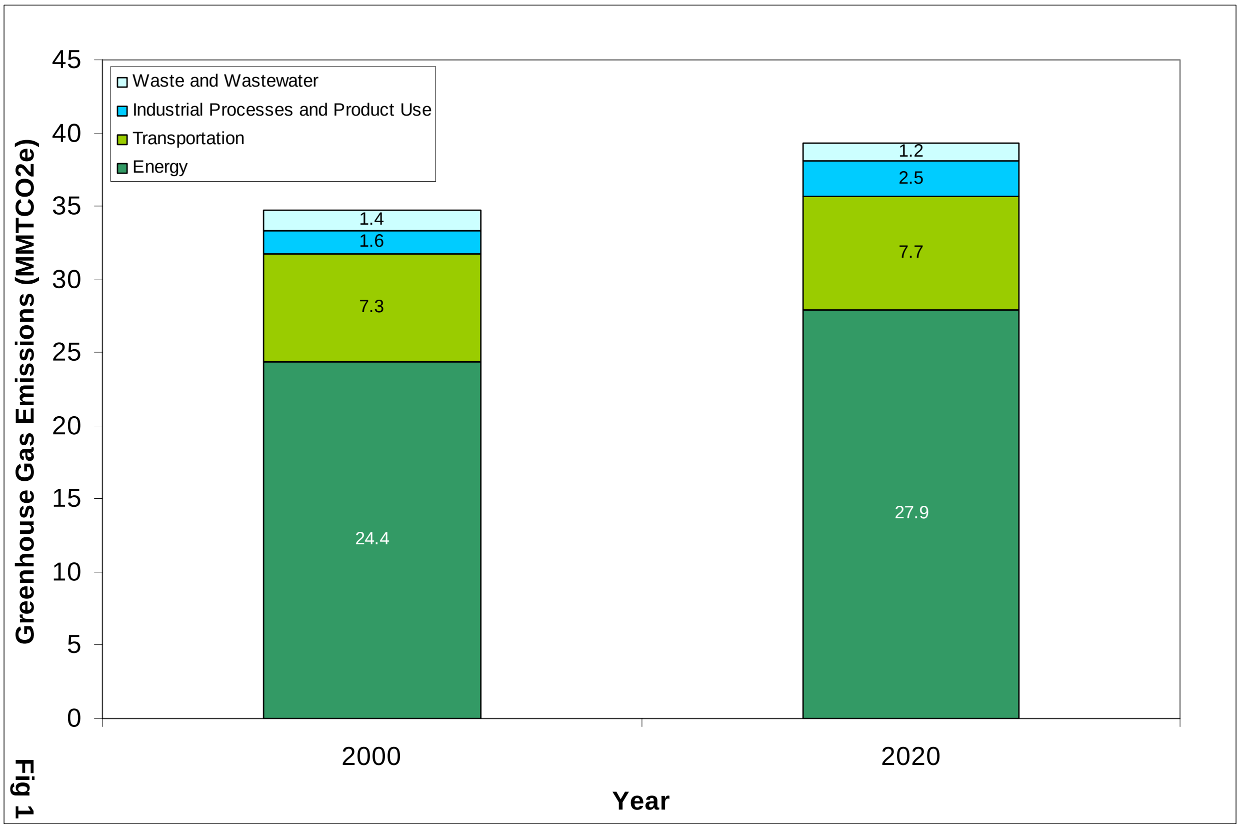
The actual emission reduction impacts of a given policy or program will depend on dozens of implementation details, so the emission reduction potentials of each strategy the City of Chicago puts into place will need to continue to be refined and actual savings achieved should be studied, but the research discussed here is meant to give a sense of the scale of the reduction potential of each strategy for planning purposes. Additionally, the GHG impacts of some strategies, such as high speed rail, are more aptly measured at a regional scale. A discussion of regional savings and more details on the methods for each strategy can be found in McGraw et. al. 2008.

Many of the emission reduction strategies overlap in their impacts. An energy efficiency strategy that reduces electricity use has a different emissions reduction potential when combined with a renewable power strategy that decarbonizes the electricity supply. As a result, after the emissions reduction potential of each strategy was documented separately the strategies were analyzed together as a whole with their interactions accounted for. This ensured that the potential savings of the portfolio of strategies would meet Chicago's emissions reduction target, because even though the sum total of the individual savings of each emissions strategy is much greater than the reduction target, taken together they offset each other in many places. This often overlooked issue added a level of complexity to the mitigation analysis, but was essential to ensure enough reduction options were developed to meet Chicago's goals.

RESULTS

In the year 2000, Chicago emitted 34.7 million metric tons of carbon dioxide equivalents (MMTCO_2e) of GHGs—12 tons for each of Chicago's 2.9 million residents, or 32 tons per household (U.S. Census Bureau 2001b). The majority—91 percent—of these emissions came from the consumption of electricity, natural gas, and transportation. Chicago's GHG emissions grew in 2005 to 36.2 $MMTCO_2e$, 4.2 percent higher than 2000 emissions levels. Comparatively, U.S. national emissions grew 1.6 percent 2000 to 2005 from 7,146.1 to 7,260.4 $MMTCO_2e$ (U.S. EPA 2007a) (Fig 1).

FIG. 1. *Chicago's greenhouse gas emissions in the year 2000 were 34.7 $MMTCO_2e$ and rose to 36.3 $MMTCO_2e$ in 2005.*



Energy

Chicago's non-transportation energy use emitted 24.4 $MMTCO_2e$ in 2000, which was 71 percent of the total citywide emissions. By 2005, energy emissions grew by 6 percent to 25.9 $MMTCO_2e$. Chicago's GHG emissions from energy use were nearly evenly split between electricity and natural gas in 2000, but in 2005 electricity emissions grew while natural gas emissions shrank.

The 25 percent growth in electricity emissions from 2000 to 2005 was due in part to a 14 percent growth in electricity consumption from 21 billion kWh to 24 billion kWh. The growth in emissions was also attributable to an increase in electricity emissions per kWh. The emissions from electricity consumption are calculated based on the average emissions from all power plants in the North American Electric Reliability Council region, or regional power pool. In addition to any real changes within the electric supply, the boundaries of the power pool that includes Chicago changed between 2000 and 2005. The resulting emissions factor for electricity grew nine percent from 2000 to 2005; in 2000, it was 0.609 kg per kWh and in 2005, it was 0.664 kg per kWh (U.S. EPA 2002 and 2006).

Electricity emissions in Chicago's residential sector grew 34 percent and electricity consumption grew from 5.5 to 6.8 billion kWh from 2000 to 2005. Non-residential electricity consumption emissions grew 21 percent as electricity use increased from 15 to 17 billion kWh from 2000 to 2005.

While this study measured electricity emissions based on consumption, there are two large coal-fired electricity generation facilities in Chicago. These two plants create approximately 1 percent of the electricity generated in the regional power pool (U.S. EPA 2002 and 2006), so their emissions impact is already included in this research. Taken together, these two plants produced the equivalent of 21 percent of the electricity consumed in Chicago, but their emissions were equivalent to 35 percent of the CO_2 emissions from Chicago's electricity consumption (U.S. EPA 2002 and 2006).

Natural gas use in Chicago fell 14 percent from 2000 to 2005 with the largest drop—34 percent—in the industrial sector from 300 million to 200 million Therms. The residential sector fell 13 percent from 1.5 to 1.3 billion Therms, while the commercial sector stayed level at 350 million Therms. The emissions factors used for natural gas were the same in 2000 and 2005 at 5.31 kg CO_2, 0.527 g CH_4, and 0.0105 g N_2O per Therm (U.S. EPA 2007a).

Transportation

Transportation is the second largest source of GHG emissions in Chicago. Excluding the airports, transportation emitted 7.3 $MMTCO_2e$ in 2000 and 7.1 $MMTCO_2e$ in 2005. In 2000, transportation was 21 percent of Chicago's GHG emissions.

On-road vehicles, including cars, trucks, and motorcycles, generated the majority of transportation GHGs in Chicago in 2000 and 2005—91 percent. The 3 percent decrease in total GHGs in this sector from 7.12 $MMTCO_2e$ in 2000 to 6.85 $MMTCO_2e$ in 2005 was largely due to an increase in the weighted average fuel economy for the vehicles on the road in Chicago from 16.5 miles per gallon (mpg) to 18.7 mpg (7.01 to 7.95 km/L) as vehicle efficiency in the U.S. increased from 2000 and 2005 for passenger cars and heavy-duty trucks (Federal Highway Administration 2001 and 2006).

Emissions associated with off-road transportation accounted for nine percent of Chicago's transportation emissions in 2000 and 2005—0.687 $MMTCO_2e$ and 0.657 $MMTCO_2e$ respectively. Metra, the Chicago regional commuter rail system, consumed 90.5 million L of diesel fuel in 2000, generating 0.244 $MMTCO_2e$. In 2005, Metra's fuel consumption increased to 91.2 million L and its emissions increased slightly to 0.247 $MMTCO_2e$. At 1.6 billion reported passenger miles (2.6 billion km), Metra's GHG emissions were 0.15 kg CO_2e per passenger mile(0.093 kg/km) in 2000 (Federal Transit Administration 2001 and 2006).

Electricity consumed by transportation in Chicago was 331 million kWh in 2000, generating 0.202 $MMTCO_2e$. Most of this can be attributed to the Chicago Transit

Authority (CTA), operators of Chicago's "L", elevated electric train system. In 2005, electricity use associated with transportation increased 23 percent to 406 million kWh and the associated emissions increased to 0.271 $MMTCO_2e$. At a reported 1 billion passenger miles per year (1.6 billion km), the CTA's GHG emissions were approximately 0.20 kg CO_2e per passenger mile (0.12 kg/km) in 2000 (Federal Transit Administration 2001 and 2006).

Emissions for Amtrak regional and long-distance rail emissions in Chicago were estimated at 0.01 $MMTCO_2e$ in 2000 and 2005 based on VMT and vehicle efficiency data in Chicago provided by Amtrak. Chicago was one of the nation's busiest Amtrak locations with 2.5 million passengers riding Amtrak to or from Chicago in 2005 (Amtrak 2005). As with air travel and cargo, the total emissions associated with Chicago Amtrak passengers is much greater than what is emitted within Chicago boundaries, and for most purposes regional and long distance rail emissions should be examined at a geographic scale larger than a city.

Chicago is a major shipping hub, and cargo rail emissions in the city were 0.23 $MMTCO_2e$ in 2000 based on 83 million L of diesel fuel consumed as reported by the Lake Michigan Air Directors Consortium. Cargo rail emissions fell to 0.13 $MMTCO_2e$ in 2005, as reported fuel consumption fell to 49 million L. It is not clear that this decrease is a trend however, as multimodal shipping using rail is gaining popularity in the U.S. (Davis and Diegel 2007).

With 77 million passengers traveling through O'Hare airport and 18 million passengers using Midway airport in 2005, Chicago is one of the busiest aviation hubs in the world (City of Chicago 2006). In the year 2000, air travel GHG emissions in Chicago were 8.74 $MMTCO_2e$ based on domestic aviation fuel sale data provided by the Chicago Department of Revenue and international aviation fuel information from the Chicago Department of Aviation. Aviation emissions in Chicago were lower in 2005 at 7.53 $MMTCO_2e$, though passengers and aircraft traffic increased between 2000 and 2005. This may be due to efficiency improvements, changes in refueling practices, or inconsistencies in the way the taxed fuel data were recorded. More detailed study of aviation GHG emissions in Chicago may help answer this uncertainty.

Industrial Processes and Product Use

Industrial processes and product use generated 1.6 $MMTCO_2e$ in 2000, or 5 percent of the city total GHG emissions, and 1.5 $MMTCO_2e$ in 2005, or 4 percent of the total. The activity data in this sector are very difficult to find on at the city level, so the emissions of this sector are estimated as a proportion of national emissions as reported in U.S. EPA 2007a. Many of the emissions in this sector are compounds with high GWPs, so relatively small emissions in this area can have large comparative climate change impact. Industrial processes were found to emit 0.433 $MMTCO_2e$ in 2000 and 0.0443 $MMMTCO_2e$ in 2005. Emissions from industrial processes decreased because of lower employment levels in GHG emitting industries due to the continuing deindustrialization of Chicago. The use of GHGs in products generated emissions of 1.19 $MMTCO_2e$ in 2000 and 1.53 $MMTCO_2e$ in 2005 in Chicago. The growth in this area is largely due to increasing use of high GWP compounds as substitutes for ozone depleting substances, such as refrigerants.

Waste and Wastewater

Chicago's waste and wastewater treatment emitted 1.37 MMTCO$_2$e in 2000 growing 15 percent to 1.58 MMTCO$_2$e in 2005. Emissions in this sector were 4 percent of Chicago's total GHG inventory.

Chicagoans generated 4.3 million metric tons of solid waste in 2000—1.5 metric tons per person according to data provided by the Chicago Department of the Environment. Waste generation grew by 16 percent to 5.0 million tons in 2005—1.77 metric tons per person. According to the City of Chicago, 56 percent of the waste generated was sent to landfills in 2000 and 2005. The result was emissions of 1.06 MMTCO$_2$e in 2000 and 1.23 MMTCO$_2$e in 2005. Solid waste made up 77 percent of the emissions in this sector in 2000.

Fugitive methane emissions from water reclamation plants were estimated to be 0.352 MMTCO$_2$e in 2000 and 0.346 MMTCO$_2$e in 2005 according to calculations performed by MWRD using IPCC 2006 methods.

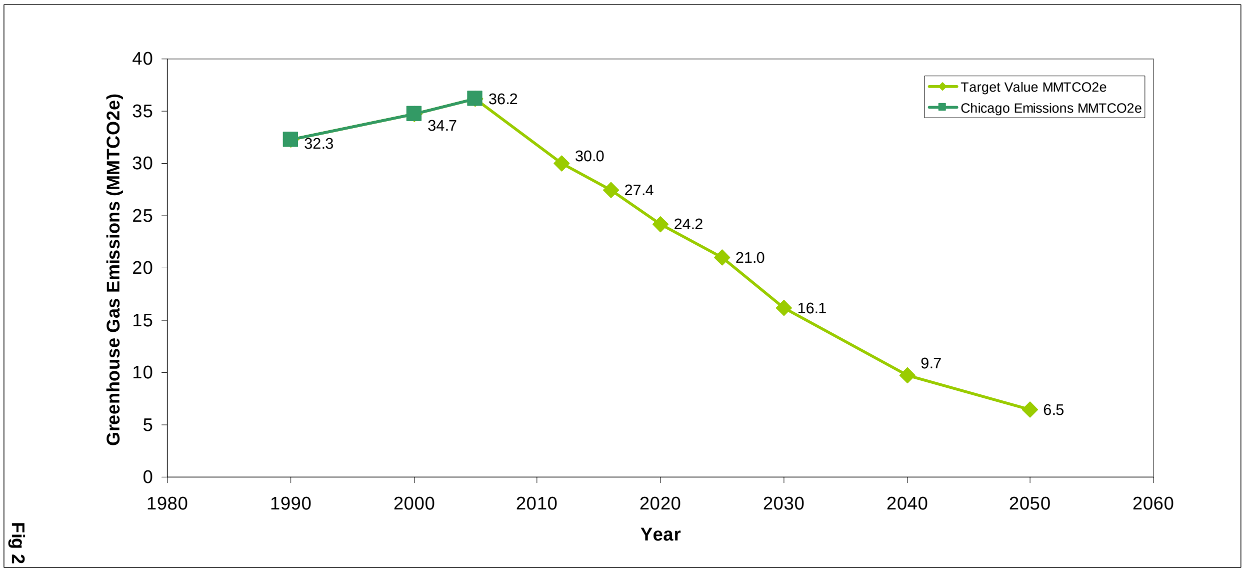
Agriculture, Forestry, and Other Land Use

Chicago's trees had a crown cover of 8,350 hectares in 2000. Thus, trees covered 14.2 percent of Chicago's land area—greater tree cover than the average desert (10 percent), but less than the average grassland (20 percent) (IPCC 2006). The result is that Chicago's trees absorbed 0.0888 MMTCO$_2$e in 2000. This was 0.3 percent of the total citywide emissions.

Reduction Target

A reduction target of 25 percent below 1990 levels by 2020 was set. Based on an estimate of 1990 emissions this target would be equivalent to 24.2 MMTCO$_2$e in 2020, which is 30% below 2000 emissions levels and 33% below 2005 emissions levels. Several other interim and longer-term targets were also set in relation to the 1990 reference point to guide short and long-term climate action planning (Fig 2).

FIG. 2. *The Chicago Climate Action Plan calls for a reduction to 25 percent below 1990 emissions levels by 2020 and sets interim and future targets as well. The 1990 value is an estimate because activity data required for an emissions inventory were not available for 1990.*



Regional GHG Emissions

The six-county Chicago metro area—Cook, Will, DuPage, Kane, McHenry and Lake counties—had a population of 8.1 million in 2000 (U.S. Census Bureau 2001b). Chicago's 2.9 million residents made up 36 percent of the region (U.S. Census Bureau 2001b). The Chicago region emitted 105 MMTCO_2e in 2000, or 12.9 tons per capita. As in Chicago, energy and transportation accounted for 91 percent of the regional emissions. However, transportation was a larger share of emissions in the region—31 percent—than in Chicago—20 percent. Emissions in all sectors grew at a faster rate in the region than in Chicago, resulting in ten percent growth between 2000 and 2005 to 116 MMTCO_2e, or 13.8 tons per capita (U.S. Census Bureau. 2006). The two main sources of this growth in GHG emissions were electricity use and solid waste generation.

Mitigation Strategies

The emission reduction potentials of 33 strategies were analyzed for Chicago to use in developing its Climate Action Plan. The estimated annual emissions savings of each strategy at full deployment were modeled for 2020—the year of Chicago's emission reduction target—and range from 0.01 to 3.0 MMTCO_2e. Due to the impacts of the mitigation strategies on each other they are not simply additive, but when modeled together to account for overlapping savings the total emission reductions can meet the goal of reducing Chicago's emissions to 24.2 MMTCO_2e by 2020 if implemented aggressively.

The quantitative and qualitative analysis of each mitigation measure is discussed in further detail in McGraw et. al. 2008. Not all strategies analyzed were adopted by Chicago in its final plan, and some were altered in scale or scope for adoption (City of

Chicago 2008). Moreover, these strategies were analyzed to understand the scale of their potential mitigation impact for planning purposes, and as Chicago works to implement its Climate Action Plan the emission reduction strategies will evolve and actual program results should be tracked.

The strategies developed for Chicago's emission reduction portfolio fall into nine categories:

Framing/Leadership: Climate action in Chicago should be framed by ongoing City and civic leadership; early action; measurement and evaluation mechanisms; and education and promotion of behavior change. These framing strategies influence the implementation of all other strategies. While they may not be individually measurable, deploying them effectively is essential for the success of the overall portfolio.

Energy Demand: Reducing the amount of energy used in buildings, both existing and new, is one of the largest potential sources of emissions savings for Chicago. Savings can begin to be achieved quickly in this area and provide additional benefits that include lower utility bills.

Energy Supply: Decarbonizing Chicago's energy sources by expanding the supply of renewable energy and reducing the GHG emissions of conventional energy sources will lower the emissions of the remaining energy Chicago needs after demand reductions.

Transportation Demand: Reducing the miles traveled by vehicles in Chicago through promotion of transit-oriented development; alternative means of transportation, including walking, bicycling, car sharing, and public transportation; and efficient freight movement will reduce the emissions from transportation fuel use and can lower costs for households and organizations.

Transportation Petroleum Use: Transportation demand reductions will not eliminate on-road vehicle travel in Chicago altogether, so lowering petroleum use by increasing the number of fuel-efficient vehicles and utilizing alternative fuels will further cut Chicago's transportation emissions.

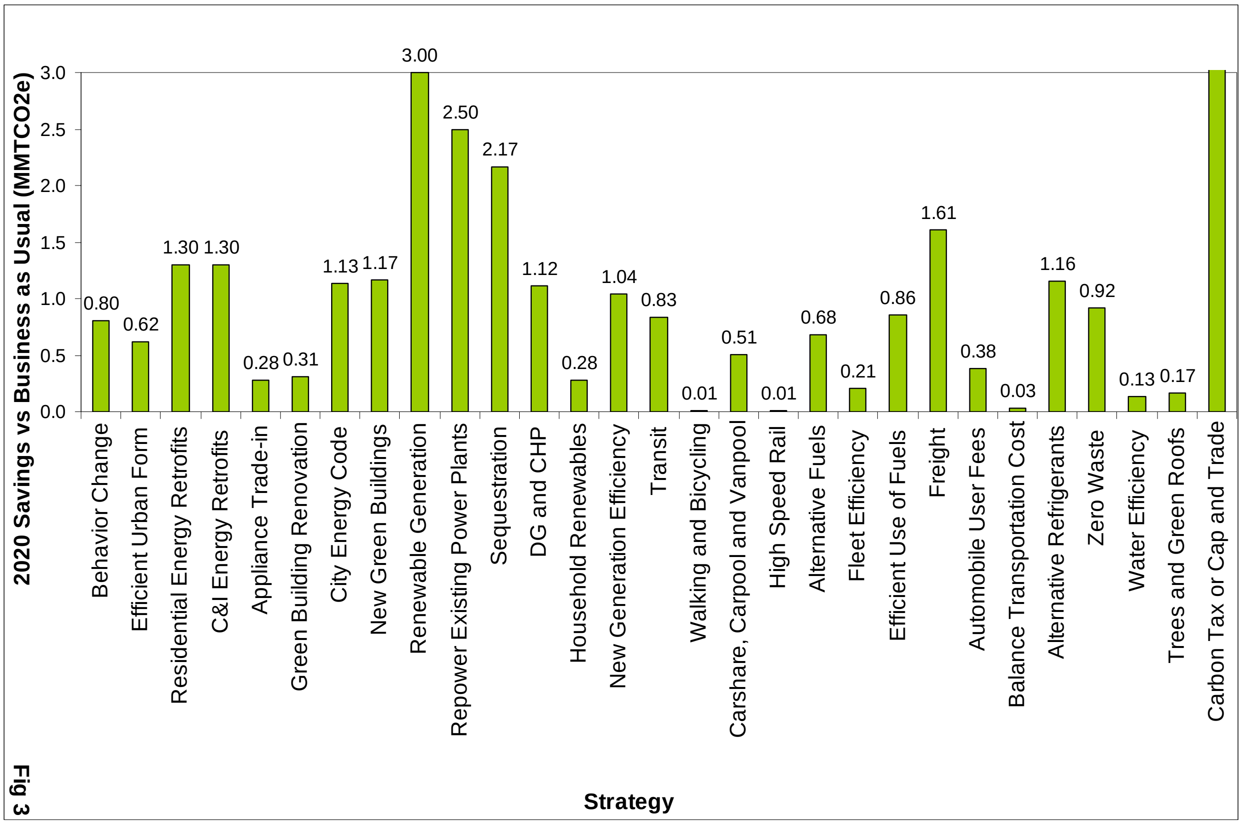
Waste and Water: Improving water efficiency, reducing waste generation, and increasing reuse and recycling can reduce waste methane emissions as well as associated energy emissions from transport and treatment.

Industrial Processes and Product Use: Reducing the use of high GWP GHGs in products, such as refrigerants, may be the best source of emissions reduction potential for Chicago in this sector, but additional research and development is needed on these technologies.

Land Cover and Forestry: Additional trees, green spaces, and green roofs can improve the carbon sequestration potential of Chicago's urban forest as well as lower heating and cooling emissions in buildings.

Cross-cutting Strategies: Two overarching strategies were analyzed: creation of a carbon tax, and creation of a cap and trade system. In both cases, the role of the City could be to advocate for implementation of the strategy at a national level and then to use the strategy as a tool to help implement the other reduction measures. Because of the nature of these strategies as mechanisms to enable the implementation of other mitigation strategies, they were not included in the Chicago GHG reduction totals.

FIG. 3. *Chicago GHG mitigation strategies and estimated projected annual GHG reduction potential in Chicago by 2020. Taken together the strategies can meet the goal of reducing Chicago's emissions to 24.2 MMTCO₂e in 2020.*



DISCUSSION

Electricity consumption, natural gas use, and transportation are the main sources of Chicago's global warming impact—91 percent of Chicago's emissions come from these three sectors, therefore most emission reductions opportunities come from these areas as well. There is no one single cure for Chicago's climate impact, but many actions that must be taken together. A portfolio of 33 climate change mitigation strategies was developed that will allow Chicago to contribute its share to climate stabilization. With early, continuous, and aggressive action, these strategies will reduce Chicago's GHG emissions and bring additional environmental and economic benefits to Chicago.

While they range widely in scale and scope, each of the strategies analyzed can make a significant contribution to Chicago's GHG reduction effort. In some cases, such as building retrofits, the potential reductions are large and the value of implementation is clear. Some smaller strategies, however, such as the planting of trees or promotion of walking, are valuable components of a broader sustainability strategy, because they bring significant additional benefits, add to public awareness of the issues, or can be relatively easily deployed.

Chicago's emission reduction goal of 25 percent below 1990 GHG levels by 2020 is ambitious in terms of the action required, but essential from a global climate standpoint. All the strategies framed here, taken together and deployed at scale, could reach Chicago's overall reduction goal. Getting there is attainable, but will require significant action by every sector of Chicago. It will also require Chicago to work regionally, nationally, and in concert with other cites. Climate analysis and planning at the city-scale is important, because many of the actual changes that must occur to reduce global GHG emissions will be implemented at the local level, but some reduction strategies that benefit Chicago, such as high speed rail or fuel economy standards, will only be feasible at larger geographies of implementation.

Not all emissions reductions are identical. Some programs are more cost effective than others, some programs deliver significant benefits in addition to GHG savings, and programs can vary widely in their financial, political, and technical feasibility. Moreover, in the race to curb global warming emissions reductions achieved now may be of more value than those implemented at a later time. All of these elements should be considered before choosing to implement one mitigation strategy over another. Due to space constraints, such quantitative and qualitative discussion for each strategy is not presented here but can be found in McGraw et. al. 2008.

Some of the strategies with the biggest reductions are also those that will bring the biggest economic benefits to Chicago residents and businesses. For example, energy and transportation efficiencies could save Chicago households hundreds, if not thousands, of dollars a year, and will bring substantial savings to Chicago businesses as well.

Energy Strategies

Demand side strategies are as critical as supply side strategies for GHG reductions at the city and regional level. The energy saved in buildings and the miles not driven can together account for nearly half of the targeted reductions. They can take advantage of the inherent efficiency of urban areas and the extraordinary resources represented by the public transportation network. Having implemented efficiency measures wherever possible, renewable sources of energy can ensure that the energy we do use is as clean as possible.

Improving the energy efficiency of buildings is the biggest single opportunity for GHG reduction in Chicago. With 70 percent of Chicago's GHG emissions generated by electricity and natural gas use, energy efficiency is a critical strategy. Because 80 percent of buildings that will exist in 2020 are already built, these strategies must focus on both existing and new buildings. Taken together, strategies to reduce energy use in buildings accounts for approximately 30 percent of GHG reductions analyzed.

Since such a large portion of electricity and natural gas use in Chicago heats and cools our buildings, the use is very dependent on the weather. This trend is seen in the residential sector: the number of cooling degree days—a measure of how hot weather is and how much air conditioning might be used—was 52 percent higher in 2005 than in 2000 (Illinois State Water Survey 2007), and the residential electricity usage was 23 percent higher. Similarly, the number of heating degree days—a measure of how cold weather is and building heating needs—was 3 percent lower in 2005 (Illinois State Water Survey 2007) and residential natural gas use was 13 percent lower. Year-to-year variations in weather will always be a factor in Chicago's energy use and GHG emissions inventories, and global warming may change those patterns over time by requiring more cooling in summer and less heating in winter. However, with better weatherization of buildings and cleaner energy sources Chicago can keep its buildings a comfortable temperature while reducing its emissions.

Transportation Strategies

Expanding the opportunities for reduced auto travel will make a major contribution to GHG reduction as well as quality of life. Many of the 33 strategies will reduce energy used in transportation, both by residents and businesses. Together, transportation efficiency accounts for approximately 20 percent of GHG reductions analyzed.

Chicago's transportation emissions are lower on a per-household basis than in the region. The 56 million vehicle miles (90 million km) traveled in the region in 2000 was 6,894 miles (11,095 km) per capita, 64 percent higher than the 4,214 miles (6,782 km) per capita in Chicago. Chicago's efficient urban form, transit service and bicycling and walking amenities provide residents with lower-GHG transportation alternatives. The reduction strategies identified support and build on this existing base of efficiency.

Strategies in Other Areas

Strategies were developed to address the other 9 percent of emissions in the industrial processes, product use, waste, and forestry sectors, but these areas play a smaller role in reductions because they are a smaller share of overall city emissions. Industrial process emissions are on the decline in Chicago due to the declining employment in Chicago as a share of national employment in these industries, and therefore, no reduction strategies were developed to address these industries. Promoting cleaner industries and enabling manufacturer innovation will allow Chicago's economy to continue to grow with less global warming impact. A shift to alternative, non-GHG refrigerants as they are available and the support of further development of such alternatives is also recommended for Chicago.

In Chicago, the relative impact of sequestration by the urban tree canopy is small, but together with their shade, cooling, and many other benefits, trees are an important part of a sustainable city. Ensuring long-term emissions benefits from trees in Chicago will require maintaining and replacing trees as well as enlarging the urban canopy. Expanding Chicago's green infrastructure, green roofs and water efficiency will produce additional emissions reductions through reduced energy use for heating, cooling, water treatment and transport.

Chicago's Role Regionally and Globally

Chicago is part of the climate change solution regionally and globally. Emissions are growing at a faster rate in the six-county metropolitan region than in Chicago. Chicago's efficient land use and transit assets can allow a household to own fewer autos and drive fewer miles than in other areas—encouraging development in location efficient areas and expanding transportation alternatives can reduce the impacts of growth on the region. Moreover, as Chicago takes action it will serve as a model for communities around the world.

The primary sources of anthropogenic GHG emissions are increasingly clear globally, and many of the technologies needed to begin to reduce emissions exist and can be cost effective. But every action to reduce emissions must occur in a real place with individual circumstances. Cities such as Chicago have clear advantages with lower transportation emissions per household and many opportunities for efficiencies of scale in emission reduction strategies as compared to less dense communities. Documenting these place-based efficiencies can help decision makers understand the benefits of action. So, while Chicago works to implement emission reduction strategies further research should be done on impacts and benefits of mitigation efforts so other communities can learn from Chicago's experiences and the rate of adoption of emission reductions can be significantly increased.

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REFERENCES

Amtrak. 2005. *Amtrak Fact Sheet, Fiscal Year 2005, State of Illinois.* Amtrak, Washington, DC.

California Climate Action Registry. 2006. *California Climate Action Registry General Reporting Protocol. Version 2.1.* California Climate Action Registry. Los Angeles, CA.

Cervero, R., Golub, A., and Nee, B. 2007. City CarShare: Longer-Term Travel Demand and Car Ownership Impacts. *Transportation Research Record.* Vol. 1992.

City of Chicago. 2006. *Airport Activity Statistics*. City of Chicago. Chicago, IL.

City of Chicago. 2008. *Chicago Climate Action Plan.* City of Chicago. Chicago, IL.

Davis, S. and Diegel, S. 2007. *Transportation Energy Data Book, Edition 26*. U.S. Department of Energy, Oak Ridge National Laboratory. Oak Ridge, TN.

Energy Information Administration. 2004. *Residential Energy Consumption Survey 2001.* U.S. Department of Energy, Energy Information Administration. Washington, DC.

Energy Information Administration. 2007b. *State Energy Consumption, Price, and Expenditure Estimates*. U.S. Department of Energy, Energy Information Administration. Washington, DC.

Federal Highway Administration. 2001. *Highway Statistics 2000.* U.S. Department of Transportation, Federal Highway Administration. Washington, DC.

Federal Highway Administration. 2006. *Highway Statistics 2005.* U.S. Department of Transportation, Federal Highway Administration. Washington, DC.

Federal Transit Administration. 2001. *National Transit Database: Report Year 2000*. U.S. Department of Transportation, Federal Transit Administration. Merrifield, VA.

Federal Transit Administration. 2006. *National Transit Database: Report Year 2005*. U.S. Department of Transportation, Federal Transit Administration. Merrifield, VA.

Houghton, J. T. et. al. eds. 2001. *Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report.* Intergovernmental Panel on Climate Change. Geneva, Switzerland.

Illinois Commerce Commission. 2002. *A Comparison of Gas Sales Statistics for Calendar Years 2001 and 2000.* Illinois Commerce Commission. Springfield, IL.

Illinois Commerce Commission. 2006. *A Comparison of Gas Sales Statistics for Calendar Years 2005 and 2004.* Illinois Commerce Commission. Springfield, IL.

Illinois Department of Transportation. 2001. *Illinois Travel Statistics 2000.* Illinois Department of Transportation. Springfield, IL.

Illinois Department of Transportation. 2006. *Illinois Travel Statistics 2005.* Illinois Department of Transportation. Springfield, IL

Illinois Environmental Protection Agency. 2006. *Nonhazardous Solid Waste Management and Landfill Capacity in Illinois: 2005.* Illinois Environmental Protection Agency. Springfield, IL.

Illinois State Water Survey. 2007. *Illinois State Climatologist Data. Monthly Data for Station 111549 (Chicago O'Hare).* Illinois State Water Survey. Champaign, IL.

Intergovernmental Panel on Climate Change. 2006. *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. Intergovernmental Panel on Climate Change. Geneva, Switzerland.

Lake Michigan Air Directors Consortium. 2007. *Vehicle Mix Analysis: CATS 7.15.05.* Lake Michigan Air Directors Consortium. Rosemont, IL.

McGraw, J., Haas, P., Young, L., and Evens, A. et. al. 2008. *Chicago Greenhouse Gas Emissions: An Inventory, Forecast and Mitigation Analysis for Chicago and the Metropolitan Region.* Center for Neighborhood Technology. Chicago, IL.

Metz, B. et. al. eds. 2007. *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Intergovernmental Panel on Climate Change. Geneva, Switzerland.

Kim, B., Waitz, I., Vigilante, M., and Bassarab, R. 2009. *ACRP Report 11: Guidebook on Preparing Airport Greenhouse Gas Emissions Inventories.* Transportation Research Board, Airport Cooperative Research Program. Washington, DC.

U.S. Census Bureau. 2001a. *1997 Economic Census.* U.S. Census Bureau. Washington, DC.

U.S. Census Bureau. 2001b. *U.S. Decennial Census 2000*. U.S. Census Bureau. Washington, DC.

U.S. Census Bureau. 2005. *2002 Economic Census.* U.S. Census Bureau. Washington, DC.

U.S. Census Bureau. 2006. *Population Estimates.* U.S. Census Bureau. Washington, DC.

U.S. Department of Agriculture, National Agricultural Statistics Service. 2004. *United States 2002 Census of Agriculture.* U.S. Department of Agriculture. Washington, DC.

U.S. Environmental Protection Agency. 2002. *Emissions & Generation Resource Integrated Database (eGRID)*. U.S. Environmental Protection Agency. Washington, DC.

U.S. Environmental Protection Agency. 2006. *Emissions & Generation Resource Integrated Database (eGRID)*. U.S. Environmental Protection Agency. Washington, DC.

U.S. Environmental Protection Agency. 2007a. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2005.* U.S. Environmental Protection Agency. Washington, DC.

U.S. Environmental Protection Agency. 2007b. *State Inventory Tool.* U.S. Environmental Protection Agency. Washington, DC.

U.S. Environmental Protection Agency. 2009. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2007.* U.S. Environmental Protection Agency. Washington, DC.

United Nations. 1997. *Kyoto Protocol to the United Nations Framework Convention on Climate Change.* United Nations. New York, NY.

World Business Council for Sustainable Development (WBCSD) and World Resources Institute (WRI). 2004. *The Greenhouse Gas Protocol: A Corporate Accounting and Reporting Standard, Revised Edition.* World Business Council for Sustainable Development and World Resources Institute. Washington, DC.