CHAPTER THREE

Carbon Storage and Sequestration by Boulder's Urban Forest

> "Every gallon of gasoline burned sends about 20 pounds of carbon dioxide, containing 5 pounds of carbon, into the atmosphere. . . It's like tossing a five-pound bag of charcoal briquettes out the window every 20 miles or so."
> -James Ryan, research director of Northwest Environmental Watch, Seattle"

Carbon Storage and Sequestration by Boulder's Urban Forest

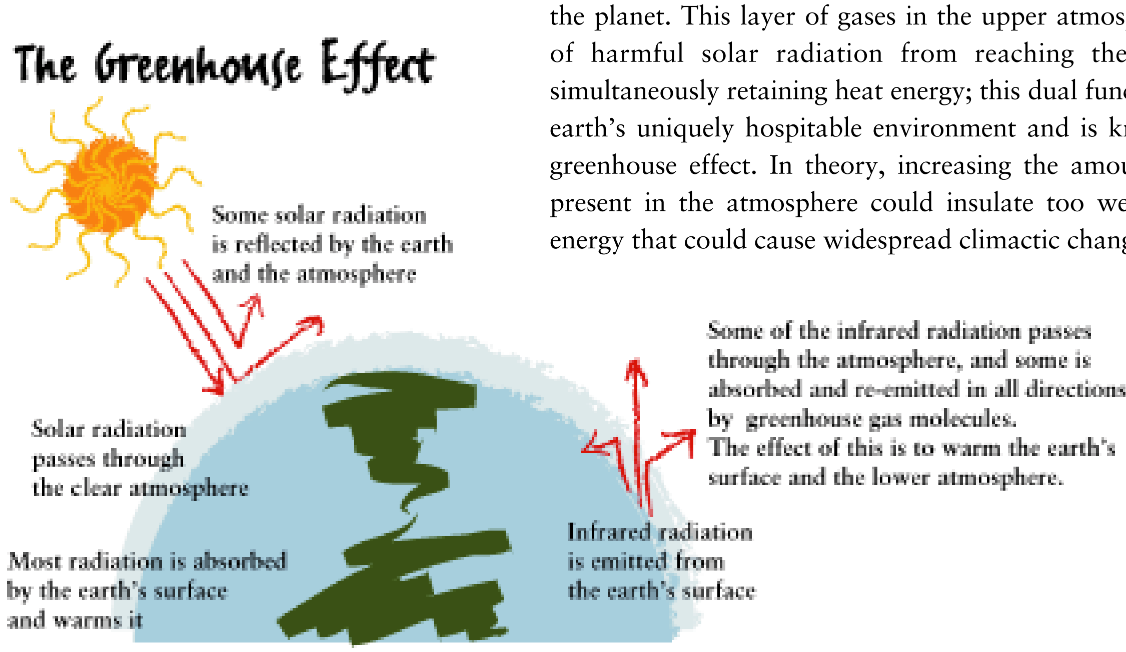
Introduction

Prior to the industrial revolution, scientists believe the earth's production and consumption of carbon were in balance. Studies show a correlation between the rise of industry and the rise of carbon-containing atmospheric gases, specifically carbon dioxide (CO_2). Over the last century we have been releasing greenhouse gases to the atmosphere faster than natural processes can remove them. It is now generally agreed that global CO_2 concentrations have reached previously undocumented levels, although the jury is still out regarding what, if anything, should be done. Urban trees provide a natural method by which we can mitigate the increase of atmospheric carbon attributed to global growth. Because trees store carbon in their structure and sequester additional carbon in the process of growth, they act as a sink for the tremendous amount of CO_2 produced by our industrialized societies.

This chapter details both the beneficial and detrimental effects of carbon dioxide on the environment and outlines some of the reasons urban and community planners should consider cultivating urban forests as one of the foremost ways to combat the continued proliferation of greenhouse gases.

Carbon:
Essential To Life on Earth

Greenhouse gases (GHGs) serve the dual purpose of filter and insulator for the planet. This layer of gases in the upper atmosphere stops many forms of harmful solar radiation from reaching the earth's surface while simultaneously retaining heat energy; this dual functionality helps maintain earth's uniquely hospitable environment and is known collectively as the greenhouse effect. In theory, increasing the amount of greenhouse gases present in the atmosphere could insulate too well, trapping excess heat energy that could cause widespread climactic changes.



Carbon Out of Balance

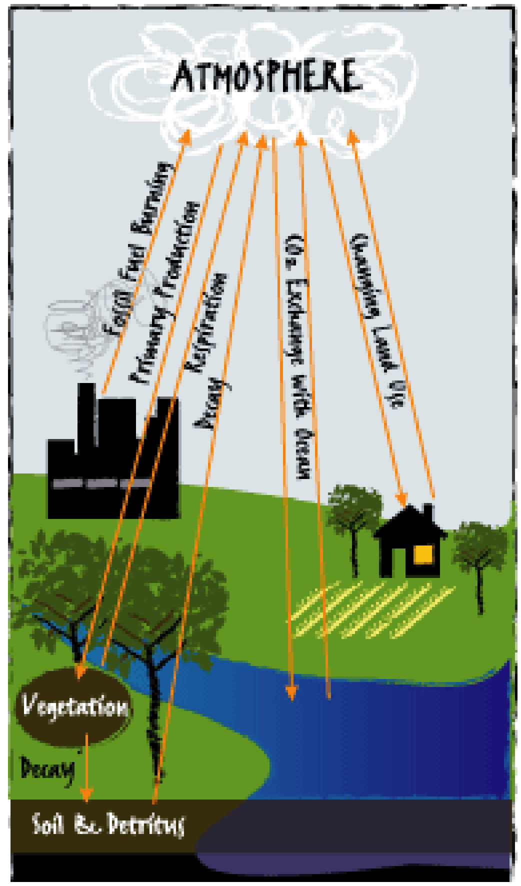
Before industrialization, there was a natural balance between sources and sinks of carbon; but recent anthropogenic sources of carbon have come to greatly outweigh the planet's ability to store carbon. The U.S. is responsible for contributing more GHGs to the atmosphere than any other country. In 1999 total U.S. carbon dioxide emissions amounted to 6.2 billion tons (5.6 billion metric tons), or over 1.8 million tons carbon equivalent. On average, each person in the U.S. emits 15 thousand pounds annually. The primary reasons for such high levels of emissions are the burning of fossil fuels and byproducts, and automobile exhaust. In fact, in 1999, 98% of carbon emissions resulted from the combustion of fossil fuels as reported by the Energy Information Administration.[44]

Over half the electricity generated in the U.S. comes from coal-fired plants. Coal is affordable and keeps energy prices reasonable, yet combustion of coal releases a tremendous amount of CO_2 into the atmosphere, about twice as much as other fuels such as natural gas.[46] In 1996, coal accounted for 83% of energy production by Public Service of Colorado, now XCEL Energy.[47]

The U.S. recognizes the need to reduce atmospheric CO_2, and research is being conducted to determine how best to achieve this. The Department of Energy has outlined three approaches to dealing with the carbon issue:[49]

- Increase efficiency of primary energy conversion and end use (fewer units fossil fuel required to produce same energy service)
- Substitute lower-carbon or carbon-free energy sources. Example: natural gas for coal, renewable energy supplies
- Carbon sequestration: capture and storage. Keeps emissions from reaching the atmosphere, removes additional carbon from the atmosphere [49]

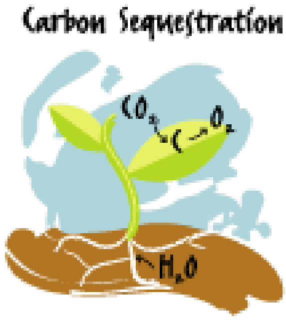
Of all the above methods of mitigation, the most feasible for municipal governments desiring to improve their environment may be sequestration. Urban and community forests are responsible for storing and sequestering large amounts of carbon, while simultaneously providing other environmental benefits covered within the scope of this study, such as stormwater runoff mitigation, water quality improvement, energy saving through shading and air pollution abatement.



If every American family planted just one tree, the amount of CO_2 in the atmoshere would be reduced by 1 billion pounds annually. (American Forests)

"Simulations in three cities (Sacramento, Phoenix, and Lake Charles) found that three mature trees around energy-efficient homes cut annual air conditioning demand by 25 to 43 percent and peak cooling demand by 12 to 23 percent".[48]

Planting trees can reduce one pound of atmospheric CO_2 for about 1 cent, whereas, increasing vehicle fuel efficiency to remove the same amount of CO_2 costs approximately 10 cents per pound.[58]



Living plant material takes in CO_2 during the process of respiration and gives off oxygen.

Trees and Vegetation:
Their Role in Mitigating the Carbon Issue

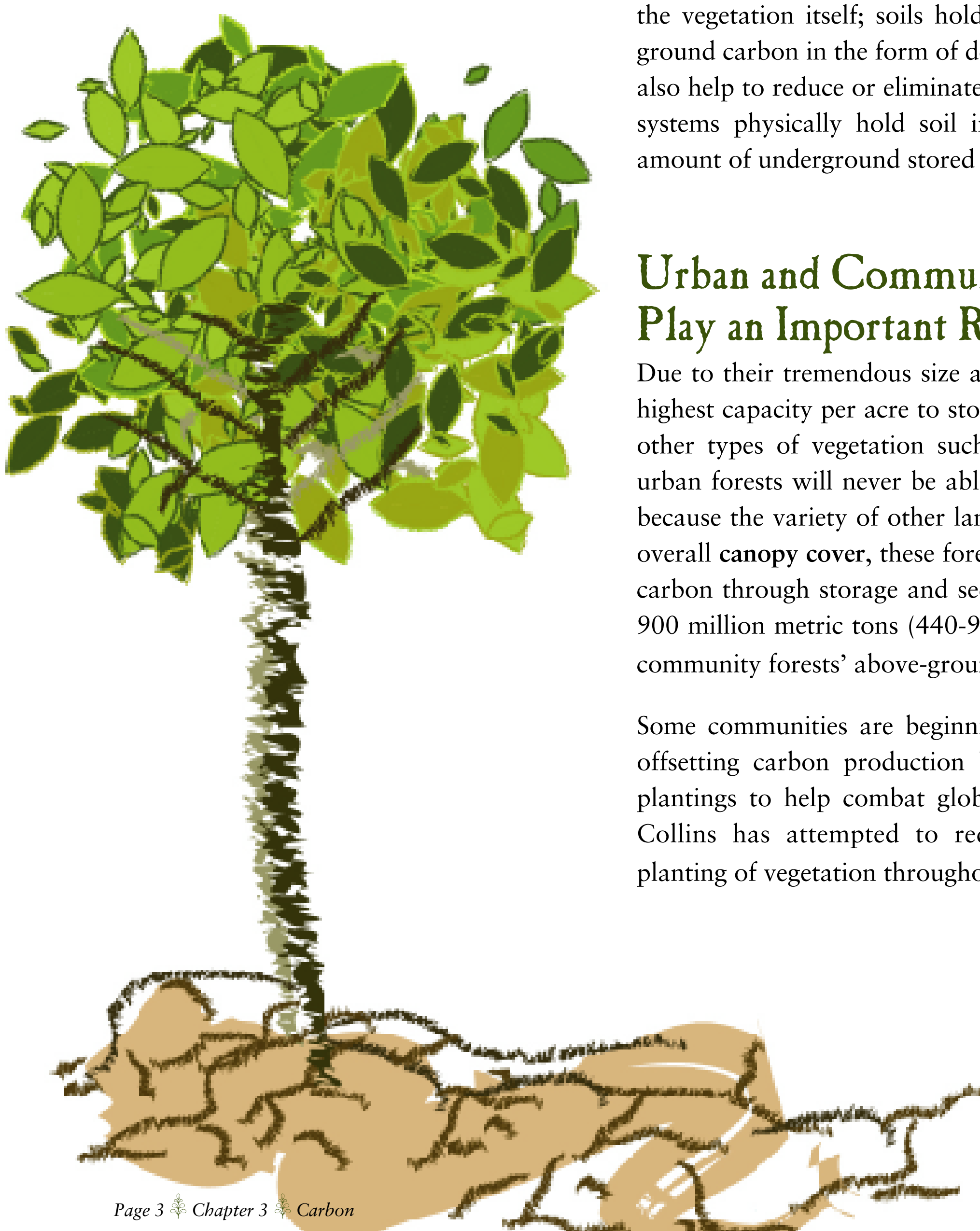
Carbon is the major component of all cellular life forms; trees utilize carbon as a building material with which to form trunks, roots, stems, branches, and leaves. Trees remove (sequester) carbon from the atmosphere through photosynthesis, extracting carbon dioxide from the air, separating the carbon atom from the oxygen atoms, and returning oxygen to the atmosphere. In doing so, trees store a tremendous amount of carbon in their structures, and annual growth increases the carbon stored within the structure. Generally, trees are comprised of 45% carbon, 50% water, and 5% minerals, but vary with species.

Soils are often overlooked as a crucial component of carbon sequestration. The soils beneath vegetation have a higher capacity to store carbon than the vegetation itself; soils hold two to three times the volume of above-ground carbon in the form of dead organic matter, or humus.[49] Urban trees also help to reduce or eliminate soil erosion because their far-reaching root systems physically hold soil in place, therefore retaining a tremendous amount of underground stored carbon.

Urban and Community Forests
Play an Important Role in Carbon Equation

Due to their tremendous size and volume, natural forested areas have the highest capacity per acre to store carbon above ground when compared to other types of vegetation such as grasslands. Although community and urban forests will never be able to reach this high level of carbon storage because the variety of other land uses within urban areas leads to a lower overall **canopy cover**, these forests still play a part in reducing atmospheric carbon through storage and sequestration. Currently, approximately 400-900 million metric tons (440-990 million tons) of carbon is stored in U.S. community forests' above-ground biomass.[50]

Some communities are beginning to recognize the role they can play in offsetting carbon production by using urban forestry maintenance and plantings to help combat global change. For example, the City of Fort Collins has attempted to reduce GHG concentrations by increasing planting of vegetation throughout the city.[51]



The extensive root system beneath trees enables the storage of carbon in the soil. In order to support healthy root functioning, the soil beneath must be extremely porous; in effect the tree's roots need to breath. The soil, roots and detritus store more carbon than the above-ground portion of the tree, as long as this vegetation remains stable.

Urban Trees Can Help Prevent More Carbon Emissions Than They Sequester

Not only does increasing urban tree canopy cover directly help to reduce carbon emissions, but providing shade indirectly reduces the need for air conditioning and power generation. Since power generation is a major source of carbon emissions, these urban trees are actually responsible for preventing more carbon from being released into the atmosphere than they remove through sequestration, on the order of several times.[53] This is referred to as the avoided carbon savings, and is recognized as yet another benefit of community trees.

Many entities reporting the reduction of GHG emissions through the Energy Information Administration's Voluntary Reporting of Greenhouse Gases Program show the amount of carbon emissions avoided by urban forestry projects to be much greater than the carbon sequestered by the same project.[52] The same phenomenon exists in Boulder, where residential urban trees have been estimated by this study to avoid annual carbon emissions at a rate of more than four times that of the overall annual carbon sequestered by Boulder's entire urban forest.

It has also been estimated nationwide that annual CO_2 reduction through shade tree programs could offset up to 2% of annual emissions.[54] In order to realize the shading and cooling benefits of trees, care and thought must be put into the proper species selection and placement, because the trees must be tall enough and close enough to buildings to actually provide shade.

Modeling Boulder's Carbon Storage and Sequestration with CITYgreen

CITYgreen's carbon storage and sequestration model was created with help from U.S. Forest Service scientists Dr. Greg McPherson and Dr. David Nowak, and is an adaptation of the Urban Forest Effects Carbon Storage and Sequestration Module (UFORE-C). It quantifies the role of urban forests in removing atmospheric carbon dioxide and calculates the volume of carbon stored by the urban forest using a combination of tree canopy area measurements, height measurements, and trunk diameter. The model disregards tree species, but instead bases the storage and sequestration estimates on the maturity of the trees at each site by categorizing the population into the following three types:

Type 1: Young population

Type 2: Moderate age population 10-20 years old

Type 3: Even distribution of all age classes

One acre of trees provides enough oxygen for 13 people and absorbs as much carbon dioxide as a car produces in 26,000 miles. (U.S. Department of Agriculture)

Carbon Sequestration Projects

In the Voluntary Reporting of Greenhouse Gases Program, in the year 2000 sixty-six entities reported projects involving forestry or natural resources that sequestered carbon or reduced emissions, including: 55 electric utilities, 3 operating subsidiaries of an independent power producer, 3 non-profit organizations, 2 petroleum companies, a real estate company, a computer chip manufacturer, and a company providing forestry and habitat restoration services. Of all the projects carbon sequestration projects reported in 1999, 66% involved afforestation or reforestation.[52]

Trees reduce carbon emissions directly through sequestration, and indirectly by reducing energy demands.

"A tree planted in the city can be fifteen times more effective at combating the buildup of atmospheric carbon dioxide than one planted in a rural forest. This is because urban trees not only sequester atmospheric carbon — they also reduce energy use and carbon emissions by cooling cities in summer.[57]

In 1992, there were an estimated 225 million tree planting opportunities along streets and private lands in America's 50.3 million acres of urban and built up area.[54]

Each type is assigned a multiplier per acre of canopy for the rate of both storage and sequestration. Type 3 populations have the greatest rate of storage, while Type 1 populations have the greatest rate of sequestration.[55]

Additional carbon benefits are modeled by CITYgreen. The volume of avoided carbon is calculated within the Energy model, measured by the reduction in energy production and emissions that results when trees shade buildings and cool the air. This volume is based on different fuel-mix profiles for each state's electricity production. States that use a higher mix of coal for energy will have higher emissions per Kilowatt hour (kWh) than those that incorporate a cleaner burning fuel source such as natural gas, or a renewable source such as wind. For more information regarding Boulder's trees and avoided carbon benefits, refer to the Energy chapter within this report.

CITYgreen Methods:

32 sites were surveyed in four land use categories (residential, commercial, industrial, and public); the number of sites selected in each category represents the relative amount of land in Boulder covered by that particular land use. Riparian areas were not sampled, but instead canopy in riparian areas was digitized using 1999 black and white aerial photography to determine overall canopy cover. Riparian areas cover less than 6% of the City of Boulder.[59]

Trunk diameters of the trees on each site were measured and then assigned generalized categories in order to determine the overall age distribution of the sites' population. The categories were:

- 1 = less than 10 inches
- 2 = 10-20 inches
- 3 = greater than 20 inches

Canopy cover was measured in acres of canopy on site, and was determined using a combination of Geographic Information Systems (GIS) and aerial photography. Each tree was digitized into the GIS and the overall area occupied by tree canopy was summed.

Using the height and diameter data collected for individual trees in each site, CITYgreen's carbon model calculates carbon currently stored (in U.S. tons) by the site's trees, and the rate at which additional carbon is being sequestered annually to create new growth.

CITYgreen Results:

3605 total trees were surveyed in the four land use classes (not including riparian), and were divided into the following diameter categories:

Diameter Class	Number of Trees	Frequency
1 (less than 10 in.)	2802	77.7%
2 (10-20 in.)	633	17.6%
3 (greater than 20 in.)	170	4.7%
TOTAL:	3,605	100.0%

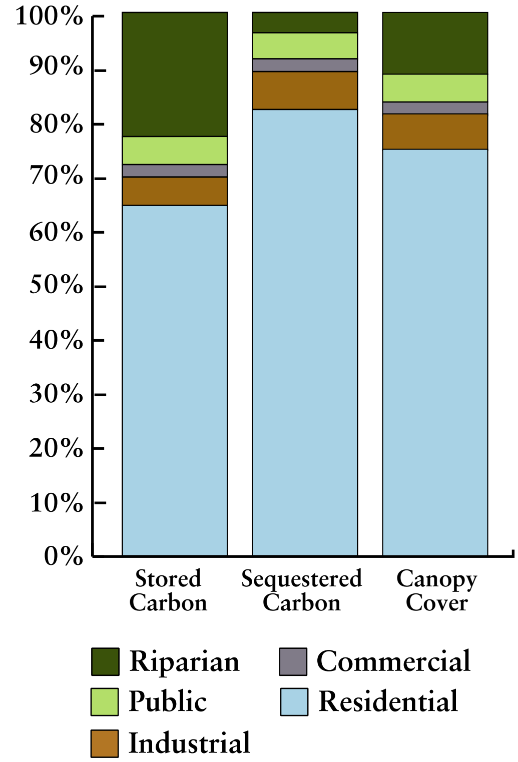
Values for storage and sequestration rates per acre of land use class were averaged and then extrapolated to determine the overall storage and sequestration city-wide.

	Stored Carbon (tons)	Annual Sequestered Carbon (tons)	Canopy Cover
Residential	72,373	1,633	31%
Industrial	5,087	115	7%
Commercial	2,138	48	7%
Public	4,616	104	6%
Riparian	25,886	73	40%
TOTAL:	110,100	1,973	23% Average

The urban forest of an estimated 330,000 trees city-wide currently stores just over 110,000 tons (109,000 metric tons) of carbon in its present state, and sequesters an additional estimated 2000 tons (1980 metric tons) annually. This amounts to an average of approximately 670 lbs. of carbon stored in each of Boulder's trees, and an average of 13.3 lbs sequestered annually by each tree. Trees in residential areas account for 83% of sequestered carbon and 66% of stored carbon.

The CITYgreen carbon model does not place an economic value upon the storage or sequestration rate of carbon. But the benefit that Boulder's urban trees provide can be measured in other ways, such as the offset of carbon produced when residents drive. **Average residential fleet fuel economy** was 21.3 miles per gallon in 1996,[60] and each gallon of gasoline burned produces 19.6 lbs of CO_2, or 5.3 lbs of pure carbon.[61] The 2000 tons of carbon sequestered annually by Boulder's trees is equal to driving approximately 16.1 million miles each year. Boulder's residents travel an average of 2.6 million miles per day, or approximately 950 million miles per year.[62] Therefore, the amount of carbon sequestered by annual growth of Boulder's urban forest is approximately 1.5% of the carbon produced annually when residents drive their cars.

Comparing Citywide Land Use, Canopy Cover, and Carbon Benefits



Average residential fleet fuel economy: the average fuel economy for all vintages of residential vehicles in operation at the time of calculation.

The goal of the Carbon Sequestration Product program, sponsored by the National Energy Technology Laboratory is to reduce the cost of carbon sequestration to $10 or less per net ton of carbon emissions avoided by 2015, using technology such as ocean sequestration, terrestrial sequestration, and conversion. Currently the cost of sequestering carbon using methods other than urban forestry ranges form $100-$300 per ton,[63] *making the carbon stored and sequestered by urban forests all the more valuable.*

In an effort to reduce the threat of global warming from increased CO_2 levels, governments, corporations, and non-profits throughout the world are developing effective and creative carbon "sequestration" projects. Since trees are substantial storehouses for carbon, and since tree planting has been shown to have high rates of public support, increased tree planting is often one of the strategies used to combat global change.[51]

Discussion

The estimation of economic benefits associated with this storage and sequestration is dependent upon the dollar value attached to a ton of carbon. An emerging international market exists for the trading of carbon credits similar to commodities exchange (one credit equals one metric ton of carbon, or 1.012 short tons), where producers of CO_2 emissions can purchase carbon credits in order to offset their environmental impact. This market allows the dollar value of a carbon credit to fluctuate with demand. Some private firms, including one in the United States, are already set to trade carbon credits, and the first U.S. carbon credit sale occurred in April 2001. Companies currently trading carbon have established widely varied values for stored carbon – between $2 to $13 per metric ton of pure carbon ($0.60-$3.50 per metric ton of CO_2).[64] But the price is expected to rise quickly over the next few years.[65]

Societal value of stored carbon is difficult to estimate, but several other methods estimate it to be approximately $10 per ton of carbon. Using the conservative figure of $10 per ton, Boulder's urban forest stores a volume of carbon worth $1.1 million, and sequesters an additional $20,000 per year.

Conclusion

Humans have contributed greatly to increased levels of CO_2 in the atmosphere, and there is a growing need to compensate for this additional anthropogenic carbon. While existing urban forests may never be able to fully mitigate for the imbalance in the carbon cycle created by industrialization and urbanization, increasing the urban forest canopy and lifespan of urban trees does provide additional environmental and economic benefits. Managers of community forests do have the ability to increase the amount of carbon stored within trees in urban areas by not only carefully maintaining the existing urban forest, but also by increasing tree plantings to fill all available planting spaces. Another method of sequestering additional carbon is to examine the species and age composition of the community forest, then choose to plant larger and longer living tree species to maximize the ability to store carbon over time.

Unproductive land in urban areas, planted with trees and converted into new green space, can then function as a sink for atmospheric carbon. Currently forested or natural areas must also be preserved in order to retain the capacity to store carbon in the soil, since removal results in the release of almost all existing below-ground carbon stores.

References

44 . U.S. Department of Energy. Energy Information Administration. *Emissions of greenhouse gases in the United States 1999*. Washington, D.C. October, 2000. <http://www.eia.doe.gov/pub/oiaf/1605/cdrom/pdf/ggrpt/057399.pdf>

45. McPherson, E.G; Simpson, J.R. *Carbon Dioxide Reduction Through Urban Forestry: Guidelines for Professional and Volunteer Tree Planters*. General Technical Report PSW-GTR-171. Berkeley, CA. January, 1999.

46. U.S. Department of Energy. Energy Information Administration. *Emissions of Greenhouse Gases in the United States 1985-1990*. DOE/EIA-0573. Washington, DC. September, 1993. Page 16.

47. U.S. Department of Energy. Energy Information Agency. *Colorado State Electricity Profile*. January, 2002. <http://www.eia.doe.gov/cneaf/electricity/st_profiles/toc.html>

48. Huang, Y.J.; Akbari, H.; Taha, H.; Rosenfeld, A.H, 1987. *The potential of vegetation in reducing summer cooling loads in residential buildings*. Journal of Climate and Applied Meteorology (September): 1103-1116.

49. U.S. Department of Energy. Office of Fossil Energy Carbon Sequestration Research and Development. *Carbon Sequestration Research and Development*. December, 1999. <http://www.ornl.gov/carbon_sequestration/>

50. Nowak, D.J. *Atmospheric Carbon Dioxide Reduction by Chicago's Urban Forest*. In: Chicago's Urban Forest Ecosystem: Results of the Chicago Urban Forest Climate Project. Gen. Tech. Rep. NE-186. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station: 83-94. 1994.

51. City of Fort Collins. *Fort Collins Local Action Plan to Reduce Greenhouse Gases*. Section 8: Vegetation Measures. November, 1999. <http://fcgov.com/airquality/pdf/ch8-vegetation.pdf>

52. U.S. Department of Energy. Energy Information Administration. *Voluntary Reporting of Greenhouse Gases, 1999 Report*. Chapter 4: Carbon Sequestration. February, 2002. <http://www.eia.doe.gov/oiaf/1605/publications.html>

53. Akbari, H.; Davis, S.; Dorsano, S. [and others]. *Cooling Our Communities: A Guidebook on Tree Planting and Light-Colored Surfacing*. Washington, D.C.: U.S. Environmental Protection Agency. Office of Policy Analysis, Climate Change Division. January, 1992.

54. McPherson, E.G; Simpson, J.R. *Carbon Dioxide Reduction Through Urban Forestry: Guidelines for Professional and Volunteer Tree Planters*. General Technical Report PSW-GTR-171. Berkeley, CA. January, 1999. http://cufr.ucdavis.edu/products/11/cufr_43.pdf

55. American Forests. *CITYgreen 4.0 Users Manual*. 2000. Washington D.C.

56. Akbari, H.; Rosenfeld, A.H.; Taha, H. S*ummer Heat Islands, Urban Trees, and White Surfaces*. American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE). Transactions 96(1): 1381-1388. 1990.

57. American Forestry Association (now American Forests). *Tree Facts: Growing Greener Cities: The Global Releaf Tree Planting Handbook*. 1992.

58. McPherson, E.G. B*enefits and Costs of Tree Planting and Care in Chicago*. In: *Chicago's Urban Forest Ecosystem: Results of the Chicago Urban Forest Climate Project*. Gen. Tech. Rep. NE-186. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station: 115-133. 1994.

59. Gershman, Mark. *City of Boulder Tributary Greenways Program Riparian Habitat Assessment: Vegetation Evaluation Final Report*. Boulder, CO. 1999.

60. Oak Ridge National Laboratory. Davis, Stacy. C, editor. *Transportation Energy Data Book: Edition 18*. ORNL-6951. Oak Ridge, TN. September, 1998.

61. U.S. Department of Energy. Carbon Dioxide Information Analysis Center. *Frequently Asked Global Change Questions*. Webpage. November, 2001. <http://cdiac.esd.ornl.gov/pns/faq.html>

62. City of Boulder. Transportation Division of Public Works. *Transportation Annual Report of Progress*. Boulder, CO. January 2000. <http://www.ci.boulder.co.us/publicworks/depts/transportation/pdf_documents/2000annual_report.pdf>

63. U.S. Department of Energy. National Energy Technology Laboratory. *Carbon Sequestration Product Webpage*. 2002. http://www.netl.doe.gov/coalpower/sequestration/index.html

64. The Carbon Trader Webpage. *Emissions Trading Growing More Popular*. March, 2002. <http://www.thecarbontrader.com>

65. U.S. Department of Agriculture. *Depositing Carbon in the Bank*. Agricultural Research. P. 4. February, 2001. <http://www.ars.usda.gov/is/AR/archive/feb01/bank0201.htm>