					The Tree Project
					Integrated Urban Environmental Improvement Through Tre
					Scientific Tree Studies-Research Sum
Project/Study Name	**Organization**	**Location**	**Goals**	**Details**	**Relevance to IES**
Scientific Studies					
Estimating the Ozone-Forming Potential of Urban Trees and Shrubs (1)	University of CA, Environmental Science and Engineering	California South Coast Air Basin	To estimate the ozone-forming potential of urban trees and shrubs.	308 tree/shrub species found in Southern CA were used as a case study for estimating ozone forming potential. Hourly isoprene and monoterpenes emission rates for 308 species were combined with temperature and light intensity data to represent a typical summer day in Southern CA. These daily emission rates were broken down into a per-tree basis using factors derived from leaf mass constants and tree canopy volumes. The OFP for each tree/shrub was calculated by combining the daily emission rates with published reactivity levels for isoprenes/monoterpenes.	The selection of low ozone-emitting trees and shrubs may be critical in polluted (or non-polluted) urban airsheds where large-scale tree plantings are considered. The addition of a large number of trees with high ozone forming potential (OFP) may be counter productive and not improve air quality. This study contains a list of 308 plant species and their OFP rates and rankings.
Atmospheric Carbon Dioxide Reduction by Sacramento's Urban Forest (2)	USDA Forest Service	Sacramento, CA	The goal of this study was to increase the understanding of urban forest impacts on atmospheric CO2 levels.	Specific objectives were to estimate the amount of CO2 1) stored in Sacramento's existing forest and 2) removed from the atmosphere over the course of a year. Based on previous research on Chicago's urban forest, but extends the study by also incorporating CO2 released into the atmosphere through tree care activities and including a more comprehensive accounting of emission reductions due to energy conservation. Study Method: 1) Land use and land cover were interpreted from aerial and black and white photographs, then vegetation and other surface data were collected from 675 randomly selected plots. 2) To calculate carbon storage, species data was collected (trunk diameter at breast height, total tree height and tree condition) for 445 trees.	
Urban Forest Impacts on Regional Cooling and Heating Energy Use: Sacramento County Case Study (3)	USDA Forest Service	Sacramento, CA	To extend results from studies of tree impacts on space conditioning of single buildings to a regional scale	To evaluate the regional impact of urban forests on energy use, a large scale analysis framework was developed and applied to Sac County. Tree impacts were estimated by summing energy use calculated for residential and commercial buildings of different types at each sample site over the total number of units (buildings) of each type in the county. Energy use data were combined with numbers of buildings and their size/distribution, tree cover and tree density to estimate impacts. (Part of the Sacramento Urban Forest Ecosystem study)	

ee Selection and Management nmary			
Contacts	**Study Results**	**Limitations/Gaps**	**Notes**
Arthur Winer- California Air Resources Board. Email:	The resulting ranking of trees by OFP provides a more appropriate basis for selection of tree species than using only mass emissions of biogenic hydrocarbons, ignoring the plant-specific differences. (308 species list available in hard copy)	Conducted in Southern California, therefore the climate is not identical to Colorado's Front Range.	The study includes the methodology used in calculating the OFP for each tree
	Findings suggest that trees in residential areas are the principal site of CO_2 storage and sequestration despite the fact that residential landscapes are seldom designed and managed to maximize their ability to serve as CO_2 sink.		
	Sacramento's urban forest was found to be responsible for annual A/C savingsof 157 GWh ($18.5 million) of electricity,which is 12% of total air conditioning and 1.5% of total electrical use. Savings from shading, air-temperature and wind-speed reduction are 6.1%, 6.6%, and -1.8% respectively. Beneficial effects of wind-speed reduction are greater than negative effects of shading for space heating. Study found that potential energy savings per unit area are smaller for newer, more energy efficient buildings, however newer residences will have fewer exisiting trees, providing planting opportunities. Older residences, due to large unit energy density (UED) (the amount of conditioned floor area) will become more important for tree planting projects as existing trees age. Commerical/Industrial areas: also important tree planting opportunities, due to large proportion of energy use and tendency to be located in open areas.		

Technical Potential for Shade Tree Planting in Sacramento County (4)	Sacramento Tree Foundation and Sacramento Municipal Utility District (SMUD)	Sacramento, CA	1) To estimate the number of potential tree planting sites assuming current tree siting guidelines and a set of hypothetical guidelines based on a a Forest Service analysis of cost-effectiveness. 2)Describe the planting potential for trees of different mature sizes. 3) Describe the distribution of sites at different directions around buildings. 4) Describe potential sites in terms of proximity to the residences. 5) Map the geographic distribution of sites within the SMUD service area.	Using large-scale aerial photographs of residences, the study classfied existing trees and potential tree plantings sites by tree size, cardinal direction, and distance from buildings. Using STF planting guidelines, each site was evaluated based on restrictions of cost effectiveness and energy efficiency (i.e. guidelines do not permit planting north of buildings or at distances greater than 35 ft. from walls, to promote shade, and small trees were not used, except on the west sides of buildings).	Shade Tree Guidelines and program description may be useful and can be applied to IES project
Trees amd Urban Air Quality (5)	Department of Environmental Protection's Division of Science and Research	Jersey City, NJ	To investigate the effect of urban trees on air pollution	State funded study based on the 1994 Chicago study. 223 plots, each measuring a tenth of an acre were randomly selected and quantified throughout the city. The selection process was organized based on land-use categories including residential, recreational, commercial, industrial, vacant and other.	
A Plan to Integrate Management of Urban Trees into Air Quality Planning (6)	Davey Resources Group	New York, NY	The objective of the study is to provide technical evaluation, documentation, and general programmatic information on the strategy for the increase of urban tree cover as a means to improve air quality.	Study considered ozone non-attainment area of the NYC metropolitan area, includes portions of northeastern New Jersey and southwestern Connecticut to investigate 4 tasks: 1. Determining potential for increasing tree canopy cover in the study area, i.e., quantifying existing tree canopy cover, open space for planting trees, and reasonably achievable tree canopy cover increases. 2. Computer modeling air quality and other associated beneficial impacts due to increasing tree canopy cover and the resulting improvement in air quality 3. Evaluating likelihood that the increase in tree canopy cover is a viable strategy to improve air quality within the framework of the current regulatory environment. 4. Outlining potential strategies to achieve the projected increases in tree cover with associated improvement in air quality, and making recommendations to guide future work	
Calculating the Value of Boulder's Urban Forest (7)	City of Boulder Water Conservation Office	Boulder, CO	Quantify the benefits of trees at 34 urban sites, for carbon storage, air pollution removal, energy benefits and stormwater runoff reduction	Use of CITYgreen software and GIS mapping - the study recorded tree diameter, health, crown size and entered into the software.	Same Climate, Trees, Rainfall

	Key findings include the amount of existing trees (872,287) and there sizes, located at all directions within the 60 ft. shading envelope of residential units in the study area. The study also determined the tree planting potential, which was estimated at 678,371 planting sites.	Aerial photographs are merely a snapshot of a current condition, so they may not be completely accurate. Constraints such as power lines, decks, patios, drainage swells, underground utility lines, and existing small shrubs/trees that need space to grow may have been undected by aerial views. Also, possible legal restrictions as far as site planting, or resident willingness to plant may not have been included. Finally, the main focus of the tree planting program was energy use; stormwater runoff, habitat, water conservation and air quality were excluded even though they indirectly benefit.	Study includes detailed description of how sites were identified, guidelines and how program was implemented. Note: STF guidelines for tree sites include Potential Energy-conserving Growing Space (PEGS) that are untreed areas with grass or soil cover that are within 40 ft. or east or west-facing walls and 20 ft. of south-facing walls. The shade tree program was marketed through media advertisements, community presentations, STF field work (having tree receipients tell their neighbors) news articles and planting schedules published in local papers.
Dr, Majorie Kaplan, Dr. David Nowak (research forester w/ USDA Forest Service)	Yes-Prelimiary findings reveal that Jersey City's trees remove 758 tons of carbon from the immediate atmosphere per year.	Unpublished final report?	Dr. Nowak created UFORE research model for cities under study: **Urban Forest Anatomy**: quantifies forest structure, including species composition, tree density and health, leaf and tree biomass. **B**VOC Emissions: quantifies hourly urban forest VOC
	Based on 4km grids, the maximum land area in the urban areas that could support an increase in tree canopy cover is 402,165 acres (1628 km2) or 12.6% of the total land area in the modeling domain and 32.1% of the urban area. By consensus of the cooperating agencies, it was determined that a realistic increase in canopy cover was 125,300 acres (507 km2) or 3.9% of the total land area in the modeling domain (10% in the urban land classifications). This 10% increase would result in a total tree canopy cover in the urban land classifications of 41%. Urban lands that were included in this classification were commercial-industrial-transportation, low density residential, and high density residential.	The greatest practical impediment to relying on tree planting as the primary strategy for canopy increase is the lack of reliable mortality data. Some data exist for street trees (e.g. Gilbertson and Bradshaw, 1990; Nowak et al, 1990; Ip, 1996; White, 2001), but the annual mortality rates reported vary widely (from 3 to more than 30%) and rely on data from only 3-4 years. Also, street trees make up only 3-10% of the urban forest (Miller,1997), and for the remainder there are few published data.	Study notes significant cost issues: i general half-life of the urban forest is about 20-30 years (Miller, 1997). Such a turnover rate suggests a 2:1 planting strategy is needed, i.e., planting 2 trees for every tree needed after 30 years. The high number of trees involved raises operational obstacles ranging from tree stock supply and cost, program administration, and planting logistics. Planting costs, could range from $3 to $300 per tree, depending on whether seedlings (high mortality) or balled and burlapped trees (lower mortality) were used. Therefore, a planting
Jennifer Sherry, Consultant to the WCO	Actual data entered into computer modeling software (CITYgreen) - Avg tree canopy found to be 23%. One site results- 5 homes, 110 trees, 60% tree canopy: Carbon storage=29 tons/yr, air pollution removal = $151ur. 52lbs/yr. (Figure based on alt. removal costs such as industrial scrubbers and avoided health care costs.) Energy Benefits saved $390/6400kWh/yr. Avoided carbon= 3660 tons/yr. Stormwater= 2813 cubic ft of avoided runoff. Runoff reduction = 55%. Benefits not quantified: benefits of trees over parking lots- trees provide a cooler place to park a car, reducing air temps of interior of vehicle. High ambient temps in parking lots cause the evaporation of VOCs from vehicles and compounds the air pollution issue. Trees in/around parking lots help reduce ambient temps through evapo-transpiration and therefore help reduce this type of emission. Trees that shade parking lots can extend the life of asphalt and reduce maintenance costs.Trees reduce the turf grass water demand.		Note: The five criteria air pollutants modeled by CITYgreen are: Ozone (O3), P10, (Sulfur Dioxide) SO2, (Nitrous Oxide?) (NO2), and Carbon Monoxide (CO)

Chicago's Urban Forest Ecosystem: Results of the Chicago Urban Forest Climate Project (1991) (8)	USDA Forest Service	Chicago	Quantify the benefits and costs associated w/ tree planting and care in Chicago over a 30 yr. Period.	Costs/benefits estimated w/ a computer model- C-BAT,, (Green ash is the tree studied) Scope is limited to 5 typical locations, parks, residential yards, streets, highways, and public housing sites. 30-yr. stream of annual costs and benefits associated with planting 95,000 trees was estimated using the C-BAT and discount rates of 4,7, and 10%.	
Ecosystem Analysis for Metropolitan Denver (9)	American Forests	Front Range	CITYgreen analysis of tree benefits	Detailed Analysis specific to the Front Range of Colorado. The study analyzed effects of urbanization on the Denver area ecology by comparing land use and tree cover from 1986 to 1998	Common Goals, however no tree planting initiative, just data and economic estimates
Benefit-Cost Analysis of Fort Collins' Municipal Forest (10)	USDA, Forest Service, Center for Urban Forest Research, Pacific Southwest Research Station	Fort Collins, CO	To discover if the accrued benefits from Fort Collins' urban forest justify an annual municipal budget that is nearly $1 million.	Growth rate modeling information was used to perform computer-simulated growth of the existing tree population for one year, and account for the associated annual benefits. Prices were assigned to each benefit (heating/cooling energy savings, air pollution absorption, stormwater runoff reduction) and cost (planting, pruning, removal, irrigation, infrastructure repair) through direct estimation and implied valuation as environmental externalities. (WTP)	Same Climate, Trees, Rainfall. Useful relative performance index (RPI) for each species.
Green Parking Lots: Can Trees Improve Air Quality? (11)	California Urban Forest	Sacramento, CA	To determine whether trees affect air quality in parking lots	Microclimate measurements were taken to quantify the moderating influence of tre canopy on parking lot microclimates via shading and evaporative cooling from leaves. Estimates were used to calculate potential temperature-dependent emissions reductions from parked vehicles. Automated weather stations and instrumented cars were located in unshaded and shaded portions of lot. Air temp, solar and net radiation, wind speed/direction + vehicle cabin and fuel tank temps were measured.	

Greg McPherson, cited often for energy simulations	No-computer modeling based on research	*Biogenic hydrocarbon emissions from planted trees can contribute to O3 pollution, however reducing city temperatures with trees can lower O3 production and hydrocarbon emission (these costs and benefits are assumed to be offsetting). Other Limitations: C-BAT- considerable variability in the quality of information upon which C-BAT results are based (e.g. cost data for maintenance is variable). Limitations in tree valuation method include 1) need to extrapolate value to large trees for which transplants of similar size are unavailable. 2) lack of research-based guides for adjusting basic value by species, condition and location and 3) $ amount demanded for damaged tree may be greater than perceived value of tree prior to damage	Appendix A lists average shading coefficients (% of sunlight intercepted by foliated tree canopies) of a number of tree species.
Don Woodward, PE-hydrologic engineer w/ NRCS, customized formula for CITYgreen for stormwater benefits. David Nowak, Ph.D USFS, Air pollution model. Comm. Dir.: Rachel Brittin (202) 955-4500 x234 rbrittin@amfor.org	Yes- Computer modeling based on 39 site assesments. See report for results.		
	Economic analysis - Computer modeling and estimations based on sampling information. Results indicate that the benefits residents obtain from Fort Collins' forest exceed management costs by a factor of 2.18. 31,000 trees are estimated to provide $1.17 million annually. For every $1 invested in tree management, residents receive $2.18 in benefits for increased property values, reduced stormwater runoff, cleaner air, reduced atmospheric carbon dioxide.	Uncertainty is greatest in estimating the amount of air pollutant uptake by trees, the value of BVOC emissions, and property value/other benefits. The pollutant uptake estimates were derived from results from urban forestry studies in Chicago,Sacramento and Modesto, but the ability to accurately estimate the extent to which shade trees produce air quality benefits is impaired by uncertainties regarding rates of pollutant deposition and release. They used canopy resistance values for *rural* forests because data is lacking for urban trees. Researchers expect urban trees to have a lower canopy resistance value, and therefore have higher pollutant uptake rates.	Methods of calculating costs and benefits are clearly defined in the Appendicies and may be useful. Appendix C has an extensive tree species list but no values associated.
	Peak daytime air temps at the shaded parking lot averaged 1 to 2 degrees C cooler than the unshaded site; fuel tank temps of the shaded car were 2 to 4 degrees C cooler than fuel tank temps of unshaded car. Larger temp differences between fuel tanks of shaded and unshaded cars, compared to air temp differences between the 2 lots indicate that direct shading of the vehicle influenced fuel tank temps, (therefore HC evapo rates) as much as or more than the effect of trees on temps in that area.	Parking lot site design makes it difficult to add trees after construction, though many western municipalities have ordinances that require 50% tree cover in parking lots within 15yrs. Of construction	The observed air temps at the parking lots were used to design base case and treatment cases for hypothetical changes in parking lot tree canopy. (Used info as input in computer modeling to simulate vehicle emissions in Sacramento County. Reactive organic gases were estimated to be reduced by 2% for an increase in canopy cover from 8% to 50%. Nox emissions from

Winter Rainfall Interception by Two Mature Open-Grown Trees in Davis, California (12)	Hydrologic Sciences, Dept. of LAWR University of CA, Davis	Davis, CA	To measure and analyze rainfall interception by two trees during a winter season on an open range (non-forested area)	Researchers developed a rainfall interception measuring system including direct measurements of gross precipitation, throughfall (rain that falls through tree) and stemflow (rain flowing down stem to ground). Data was sampled every second and recorded for one 9yr old pear tree and one 8yr old oak tree.	
Rainfall Interception by Santa Monica's Municipal Urban Forest (13)	USDA Forest Service, Center for Urban Forest Research	Santa Monica, CA	To simulate (and quantify) rainfall interception by street and park trees in Santa Monica, CA.	Researchers used data from the above study (Xiao, 1999) performed on the two open-grown trees and created a single-tree rainfall interception model of each street or park tree at each annual, seasonal, and storm level.	
The role of biogenic hydrocarbons in urban photochemical smog: Atlanta as a case study	Georgia Institute of Technology	Atlanta, GA		The effects of natural hydrocarbons was considered in order to develop a reliable plan for reducing ozone in the urban atmosphere. Trees can emit significant quantities of hydrocarbons to metropolitan areas such as Atlanta, and model calculations indicate that these natural emissions can significantly affect urban ozone levels. By neglecting these compounds, previous investigators may have overestimated the effictiveness of an ozone abatement strategy based on reducing anthropogenic hydrocarbons.	
Low-Emitting Urban Forests: A Taxonomic Methodology for Assigning Isoprene and Monoterpene Emission Rates	Environmental Science & Engineering Program, UC Davis	Los Angeles, CA	To describe a methodology for assigning biogenic emission rates based on taxonomic relationships.	Direct emission rates from 124 trees and shrub species in the SoCAB are used to assign emission rates to 253 other species, and rank them according to total isoprene and monoterprene emission hourly emission rates.	Study recognizes negative potential of urban trees, and ranks emission potential. SoCA climate similar to front range
Estimating Urban Forest Impacts on Climate-Mediated Residential Energy Use	Western Center for Urban Forest Research and Education	Sacramento, CA	To evaluate shade impacts of urban trees on residential energy use	Shade impacts on building space conditioning energy use were simulated for 254 homes and the immediately surrounding trees.. Detailed information was gathered for each building and surrounding trees to use as model input. Solar gain reductiuon was calculated by using the Shadow Pattern Simulator (SPS) program developed by McPherson. Data used for the model - 1) building energy use characterisitics like conditioned floor area, window area, & insulation, and 2) hourly annual weather data. The study also recognizes that large-scale tree planting not only reduces energy use by providing shade, but also by providing on increased canopy, air temperature and wind speed are affected. This was estimated based on 1) predicted increase in tree canopy by planting trees 2) expected climate changes 3) temperature and wind sppeed effects on space conditioning based on computer simulations.	Study focuses on energy reduction through both wind speed reduction and shade. The model used in the study and computer programs would be applicable to a climate such as Colorado's.

1) Benjamin, M., Winer, A. (October 1997). Estimating the Ozone-Forming Potential of Urban Trees and Shrubs. Atmospheric Environment Vol 32. No. 1, p 53-68. Elsevier Science, Ltd. Great Britain.
2) McPherson, E.G. (July, 1998). Atmospheric Carbon Dioxide Reduction by Sacramento's Urban Forest. Journal of Arboriculture 24(4). P215-223.
3) Simpson. J. (July 1998). Urban Forest Impacts on Regional Cooling and Heating Energy Use: Sacramento County Case Study. Journal of Arboriculture 24(4). http://cufr.ucdavis.edu/products/cufr_25_JS98_45.PDF
4) http://cufr.ucdavis.edu/products/cufr_32_EM95_70.PDF

Qingfu Xiao email: qxiao@ucdavis.edu	15% of gross precipitation was lost as a result of crown (of tree) interception for the pear tree and more than 27% for the oak tree. Interception losses decreased with increasing rainfall magnitude and increased with increasing rainfall duration. The higher the wind speed, the less either tree was able to intercept. 77% of gross precipitation for the pear tree was "throughfall" and 58% for the oak, as the oak tree was in-leaf during the rainy season (winter) when measurements were taken, and the pear was not. Most branches on both trees were vertical, which led to less stem drip to the soil below, showing that tree architecture does make an impact.	Season limited to Winter, and two trees in non-forested area.	"Rainfall frequency is more significant than rainfall rate and duration in determining interception loss." (Xiao, et al, 1999)
	Annual rainfall interception by 29,299 street and park trees was 193,168m^3, or 1.6% of total precipitation. The annual value of avoided stormwater treatment and flood control cost associated with the reduced stormwater runoff was $110,890. Large trees and evergreens had the greatest interception rates.		
Michael Benjamin and Arthur Winer, School of Public Health, UC Davis CA	Emission rates between species varied by as much as 4 orders of magnitude, most species examined (total 316) were skewed towards low and moderate emitters, very few were high emitters. An average, assuming 5million new trees added to SoCAB over the next 20 yrs., on a typical summer day, a mix of high-emitters would contribute an additional 35 TPD of biogenic VOCs as compared to 0 TPD for the same number of low emitters	"Research determining species-specific emission rates is needed to provide a more complete coverage of BVOC emissions from tree species, but the taxonomic relationships provides a cost and time effective basis for focusing future experimental emission rate measurements on the most important data gaps" (Benjamin, et al, 1996)	"The selection of low-emitting tree species can be critical in urban airsheds where large-scale tree planting programs are being implemented for energy conservation, heat island mitigation, and air pollution abatement. Unfortunately BVOC emission rates have been measured for only a fraction of relevant plant species, due to high cost & effort involved in measurement.
James R. Simpson, USDA Forest Service, Western Center for Urban Forest Research, c/o Dept. of Environmental Horticulture, UC Davis, CA 95616	Results presented on annual heating/cooling based on 2 scenarios-exiting shade and adjacent buildings, and then exisiting conditions plus the added trees. Results are grouped by building age and number of program trees, on a per property and per tree basis. Wind speed reduction was estimated at about 5% for every 10% increase in tree canopy. Building vintage played a part in heating/cooling reductions, as the newer buildings were more efficient. A/C use on properties with existing shade increased with building age from 1689 to 3507 kWh per property, as did savings when trees were added (447 kWh or 26% to 572 kWh or 16% per property). Regarding climate impacts-a 7% increase in tree canopy cover was estimated 30 yrs. after SMUD planted 500,000 trees, assuming 58% survival rate, but study simulated that 10% increase in canopy would result in reduced temperatures of .7 degrees C. Wind speed reduction estimated at 5%.	Not a 30yr study, computer simulated.	Many factors taken into account to ensure an accurate study, I.e. building age, survival rate of trees, adjacent building shade, and climate patterns

5) Nowak, D. (n.d.). Trees and Urban Air Quality. NJ's First Correlative Study. Accessed via: http://www.state.nj.us/dep/dsr/gcc/Trees%20and%20Urban%20Air%20Quality.pdf
6) http://www.cleanairinfo.com/airinnovations/Additional%20Information/Nowak/Final_report_March2002_Davey.pdf
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9) www.americanforests.org
10) http://cufr.ucdavis.edu/ McPherson, E.G. , J.R. Simpson, Q. Xiao, P.J. Peper, and S.E. Maco. 2003. Benefit-Cost Analysis of Fort Collins' Municipal Forest. Internal Report. CUFR-2. USDA Forest Service, Pacific So
11) Klaus, S., Simpson, J., McPherson, G. Green Parking Lots: Can Trees Improve Air Quality? USDA Forest Service, California Urban Forests Council Newsletter. Accessed via: http://cufr.ucdavis.edu/products/cufr_7
12) Xiao, Q, McPherson, E.G., Ustin, S, Grismer, M., Simpson, J. (June 1999), Winter Rainfall Interception by Two Mature Open-Grown Trees in Davis, California. Hydrological Processes. 14. 763-784 (2000).
13) Xiao, Q., McPherson, E.G., (18, September, 2003). Rainfall Interception by Santa Monica's Municipal Urban Forest. Urban Ecosystems. 291-302. Kluwer Academic Publishers.

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APPENDIX G

Background Research-2

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Southwest Research, Center for Urban Forest Research. 2: 1-39
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