Progress Report 4: October 1, 2010 – March 31, 2011
Accessing Brownfield Sustainability: Lifecycle Assessment and Carbon Footprinting
The Western Pennsylvania Brownfields Center at Carnegie Mellon, in collaboration with the Pennsylvania Downtown Center
US Environmental Protection Agency Brownfield Training Research and Technical Assistance Grant
Award: TR – 83417301 – 0
May 6, 2011

A. Background

The primary purpose of this project is to develop the methodology and subsequent tools that stakeholders can use to assess the sustainability of Brownfield development as measured through carbon footprinting, pollutant emissions and energy impacts. The research is intended to apply innovative analytical techniques (such as economic input-output life cycle analysis) to estimate the carbon emissions, pollutant emissions and energy impacts associated with Brownfield development; while documenting the drivers of these impacts given alternative Brownfield development scenarios.

Training and technical assistance efforts complement the primary research purpose. Through training, we intend to educate and disseminate information that will allow the members of the community to better understand the public health risks of unattended Brownfields and the benefits of alternative remediation strategies. Through technical assistance, we intend to provide targeted communities with a prioritization tool that will allow for fair, transparent and equitable Brownfield development decisions.

Our work has been divided into 3 primary Activities:

- *Activity 1: Training – Empowerment Through Knowledge*. Enhance Pennsylvania Downtown Center's (PDC) webpage for Brownfield relevant information, participate in annual PDC events to provide Brownfield related content, and conduct topic specific seminars. As the project proceeds, the target group for training will be expanded beyond PDC's current membership.

- *Activity 2: Research – Quantifying the Sustainable Brownfield*. Develop a life cycle assessment model, including footprinting, for comparison of Brownfield development relative to greenfield development, beta test the tool on sites (preferably) selected in cooperation with PDC members, finalize and validate the model, develop a computer based tool, train PDC members to use the tool, and coordinate with US Environmental Protection Agency to develop strategy for transferring tool to other Brownfield stakeholders.

- *Activity 3: Technical Assistance – Site Selection Through Prioritization*. Assist PDC members in developing inventories of sites, beta test the Site Prioritization tool with select PDC members, finalize Site Prioritization tool, distribute Tool to remainder of PDC members, and coordinate with the Pennsylvania Department of Environmental Protections and the USEPA to develop strategy for transferring both tools to other Brownfield stakeholders.

B. Overall Progress

The official date of the award was March 12, 2009. Pre-award approval from the USEPA Project Officer allowed our work to commence in October 2008 and our first Progress Report was submitted on October 1, 2009. Progress Report 2 addressed the time period between October 2009 and March 2010. Progress Report 3 addressed the time period between April 1 and September 30, 2010. And, Progress Report 4 addresses the time period between October 1, 2010 and March 31, 2011.

Carnegie Mellon personnel working on technical aspects of the project during Period 4 include Professor Chris Hendrickson, Dr. Deborah Lange, and graduate students Amy Nagengast and Yeganeh Mashayekh. PDC personnel working on the project include Bill Fontana and Eddy Kaplaniak; as well as members of the Keystone CORE Services group.

Overall progress with respect to each Activity is summarized as follows:
Activity 1: Training – Empowerment Through Knowledge – we continue to participate in PDC meetings and have shared information with the equivalent of more than 96 communities in Pennsylvania. PDC's brownfield webpage is available at: http://www.padowntown.org/programs-services/brownfields.

Activity 2: Research – Quantifying the Sustainable Brownfield –A paper based on the comparison of 12 brownfield/greenfield pairs has been accepted by the Journal of Urban Planning and Development, American Society of Civil Engineers. Additional ongoing research involves using travel demand models and traffic analysis zones the study examined the effect of residential brownfield developments on vehicle miles traveled (VMT) reduction and the resulting costs (including the cost of driving time, fuel, and external air pollution costs). A paper based on this research has been submitted to Journal of Urban Planning and Development, American Society of Civil Engineers.

During this quarter, the research team prepared:

- A presentation for the 90th annual Transportation Research Board conference in Washington D.C. in January 2011;
- 2 presentations for the April 2011 USEPA National Brownfields Conference, held in Philadelphia Pennsylvania;
- A presentation for the National Association of Environmental Professionals Conference, held in Denver in April 2011; and,
- A presentation for Engineering Sustainability 2011 Conference sponsored by the Mascaro Center for Sustainable Innovation at the University of Pittsburgh and the Steinbrenner Institute for Environmental Education and Research at Carnegie Mellon, held in Pittsburgh in April 2011..

We have completed detailed case analyses on 4 residential developments (two brownfield and two greenfield) in the SW Pennsylvania Region, to assess the environmental emissions associated with both the construction phase and the residential use phase. And, a paper that compiles the results of all 4 detailed cases analyses is in progress.

Activity 3: Technical Assistance – Site Selection Through Prioritization – Activity 3 is based on the implementation of a multi-attribute decision making tool that was in development at the Western Pennsylvania Brownfields Center prior to receipt of the TRTA grant. During the time period covered by the Period 4 report, we have engaged the Keystone CORE Services Group of PDC and initiated a plan for a test implementation of the multi-attribute decision making tool across eligible and interested PDC communities.

C. Efforts and Accomplishments by Activity

Activity 1: Training – Empowerment Through Knowledge. Note that this effort is the primary focus of the PDC. With support from the Pennsylvania Department of Community and Economic Development, the PDC represents more than 150 communities across Pennsylvania, therefore, they represent the opportunity to educate a wide audience.

EDUCATION

Pennsylvania Downtown Center (PDC) continues to educate its members on the environmental, social and economic impacts of small site Brownfields in Pennsylvania's core communities. During this reporting period, the main educational opportunity was PDC's Community Revitalization Academy's Assess Enhancement training.

In early March 2011, PDC trained 18 commercial district and neighborhood managers over two days. One of the sessions was an introduction to Brownfields: what they are and how to redevelop them. In conjunction to the brownfield session, a Real Estate session followed. The real estate session focus on the development process using a brownfield site as a case study for redevelopment. Many questions were asked and a deeper understanding of the benefits associated with redeveloping a brownfield was achieved.

In addition to the above training, PDC continues to reinforce the virtues of small site brownfield remediation at all of its formal trainings and workshops. In this period they are as follows:

- Managers Meeting – 10/13 - 47 people, 10/20 - 54 people
- Managers Meeting – 3/22 – 100 people

- New manager training – 11/15, 2/28 – 10 people
- Community Revitalization Academy, Community Marketing - 11/16-17 - 19 people

WEBSITE

PDC, working with CMU, will continue to add content including videos, progress reports, and educational opportunities, to the Brownfield area of the site. The website will also track the community-initiated feasibility pilot program, which will include a data base of possible small site Brownfields.

Activity 2: Research – Quantifying the Sustainable Brownfield

We are pursuing three sub-activities within Activity 2. In Activity 2A, we are making site specific comparisons between a local brownfield and greenfield development. In Activity 2B, we are looking at census data gathered in year 2000 to evaluate the commuting behavior of people living in census tracts that contain brownfield development as compared to census tracks that contain greenfield developments. In Activity 2C, we are evaluating all vehicular transportation of residents for a number of brownfield/greenfield pairs using regional travel demand models. Beyond transportation analyses, we will begin to gather and analyze data on water and electricity usage.

Activity 2A: Site Specific Comparisons

Completed during this period we analyzed two additional residential case studies: Hidden Brook (brownfield) and The Woodlands (greenfield); both residential developments in Peters Township (located about 20 miles south of Pittsburgh, PA.) The developments are about 5 miles apart.

With all costs are adjusted to 2002 values, the PRELIMINARY results for all 4 case studies are summarized in the following tables:

Item	Unit	Greenfield (Cranberry Heights)	Brownfield (Summerset Phase I)	% Difference from Greenfield	Greenfield (Woodlands)	Brownfield (Hidden Brook)	% Difference from Greenfield
Initial Cost	$ Million 2002	3.4	23.4	688	0.462	.673	45
CO2E Emissions	Metric Ton	2,200	9,090	413	0.45	0.64	42
Allocated Initial Cost (0% interest)	$/person/ year	74	1,176	1589	30	28	-7
Annualized Initial Cost (5% interest)	$/person/ year	203	3,204	1578	75	69	-8
Allocated CO2E Emissions	Metric ton/person /year	0.05	0.46	930	0	0	0

Table 1: Initial Infrastructure Investment Costs and Greenhouse Gas Emissions (50 Year Planning Horizon).

Item	Unit	Greenfield (Cranberry Heights)	Brownfield (Summerset Phase I)	% Difference Relative to Greenfield	Greenfield (Woodlands)	Brownfield (Hidden Brook)	% Difference from Greenfield
Private Vehicle	Miles/year/ person	8230	7350	-11	6970	6250	-11
Public Transit	Miles/year/ person	2040	600	-71	419	152	-64
Other	Miles/year/ person	240	325	35	17	130	764
Private Vehicle	$/year/ person	4100	3700	-10	3485	3625	4
Public Transit	$/year/ person	580	170	-71	119	43	-64
Private Vehicle GHG	Mt CO2E /year/ person	3.9	3.5	-10	3.2	2.9	-10
Public Transit GHG	Mt CO2E /year/ person	1	0.3	-70	0.2	0.1	-50

Table 2: Estimated Travel Differences for Brownfields and Greenfields Residential Developments

Item	Unit	Greenfield (Cranberry Heights)	Brownfield (Summerset Phase I)	% Difference Relative to Greenfield	**Greenfield (Woodlands)**	**Brownfield (Hidden Brook)**	**% Difference from Greenfield**
Average Floor Space	Sq. ft./ residence	2,700	2,460	-9	2800	2800	0
Land Area	Acres/ residence	1.1	0.16	-85	.50	0.44	-12
Natural Gas (monthly)	$/residence	170	89	-52	136	83	-39
Electricity (monthly)	$/residence	133	94	-29	103	57	-45
Water/ Sewer (monthly)	$/residence	79	27	-66	62	41	-34
Total Utilities (monthly)	$/residence	382	210	-45	301	181	-40
Total Utilities	$/person	103	105	3	97	75	-23
Floor Space	Sq. ft./ person	730	1,230	68	903	1167	29
Developm’t Area	Acres/ person	0.3	0.08	-73	0.13	0.18	38
Building Construction GHG	Metric ton	61,400	30,909	-50	11.8	24.5	107
Allocated Building Construction GHG	Metric ton/ person/year	1.3	1.5	15	0	.05	--
Utility GHG	Metric ton/person/ year	5.9	9.6	63	8.6	6.4	-26

Table 3: Residential Building Differences

Given the 4 case analyses that have been conducted the following observations can be made:

- With respect to construction, the emissions associated with housing construction are much greater than emission associated with site development.
- With respect to ‘use,’ emissions associated with utility consumption outweigh those associated with transportation.
- Overall (and over a given planning horizon), emissions associated with the ‘use’ phase greatly exceed those of the construction phase.

In addition to the case analyses, we have been working in parallel to develop a methodology that allows the preparation of case analyses by the acquisition of publicly available information and with out the burden of residential surveys and visits to the municipal engineer. We will revisit this effort during the summer of 2011.

Activity 2B – Commuting Behavior of Residents

The commuting behavior of residents in brownfield and greenfield neighborhoods within six cities was accomplished using the 2000 US Decennial Census and supplemental external data. This research has been completed and is awaiting final publication for the *ASCE Journal of Urban Planning and Development.* Furthermore, an abstract from this research was submitted and accepted for an oral presentation at the Engineering Sustainability 2011: Innovation and the Triple Bottom Line Conference April 10-12 in Pittsburgh, PA. During this reporting period, presentation slides have been completed for this talk to be given by Amy Nagengast.

Activity 2C – Yeganeh Mashayekh, a graduate student in Civil and Environmental Engineering and Engineering and Public Policy at Carnegie Mellon is planning her PhD studies around this topic. She successfully passed her Engineering and Public Policy qualifying examination presenting her work on this topic:

Using travel demand models and traffic analysis zones the study examined the effect of residential brownfield developments on vehicle miles traveled (VMT) reduction and the resulting costs (including the cost of driving time, fuel, and external air pollution costs). Sixteen brownfield and conventional development sites were analyzed in Baltimore, Chicago, Minneapolis and Pittsburgh. Air pollution valuation data was used to estimate external environmental cost savings. Results indicate on average residential brownfield developments reduce VMT by 52% compared to conventional developments. Also on average, brownfield developments result in a time and fuel cost reduction of 60% and an external environmental cost saving of 66%. Comparing these cost savings with the initial one-time cleanup cost of brownfields, it is shown that density and the cost of remediation significantly impact the number of years that would take for the VMT cost savings to offset the remediation cost. The following two tables show the result of commute and non-commute VMT reductions and the contributing elements (distance per trip and number of trips) for the study brownfield and Greenfield sites.

Table 4: Brownfield and Greenfield Developments' Travel Pattern Comparisons – Daily Home Based Work (HBW) Auto Trips per Household

Type	Average VMT (mile/HH)	Average Distance (miles/trip)	Average # of Trips/HH
Brownfield (BF)	6.0	7.0	0.9
Greenfield (GF)	15.0	11.0	1.7
National	12.0	13.0	1.0
Reduction (GF to BF)	60%	36%	47%

*HH: household

Table 5: Brownfield and Greenfield Developments' Travel Pattern Comparisons – Daily Home-Based Non-Work (HBNW) Auto Trips per Household

Type	Average VMT (mile/HH)	Average Distance (miles/trip)	Average # of Trips/HH
Brownfield (BF)	11.0	4.2	2.5
Greenfield (GF)	19.0	6.3	3.0
National	25.0	9.5	3.0
Reduction (GF to BF)	42%	33%	17%

*HH: household

The following table shows the result of costs associated with the aforementioned VMT reductions:

Table 6: Comparison of Direct and Indirect Average Daily Costs per Households between Brownfield and Greenfield Sites[1]

	Average Direct Costs ($/Day)		Average Indirect External Environmental Costs ($/Day)							
Area	**Time**	**Fuel**	**CO_2**	**NO_x**	**VOC**	**CO**	**SO_2**	**PM**	**NH_3**	**Total**
Brownfield (BF)	5.0	1.1	0.1	0.06	0.2	0.2	0.002	0.02	0.4	0.9
Greenfield (GF)	12.0	2.8	0.3	0.09	0.5	0.3	0.005	0.06	1.4	2.6
% Reduction (GF to BF)	60	60	60	40	70	40	60	70	75	67

[1] It is important to note that a percentage of those who live in brownfield developments use transit, therefore they incur cost of transit plus cost of time. Also depending on the level of ridership increase, transportation authorities might increase the number of buses resulting in increased emissions and external environmental costs.

The study furthermore compared the VMT reduction cost savings with the initial cost of remediation. It turned out that the technology used for remediation and the density of developments has a significant impact on the breakeven point between the VMT reduction cost saving and the cost of remediation.

In addition the study compared brownfield developments as a strategy to reduce VMT with other conventional VMT reduction strategies (i.e. carpooling, congestion pricing). The result shows that brownfield developments can be used as a cost effective strategy method to reduce VMT; in comparison to other VMT reduction strategies, brownfield developments have minimal cost to transportation authorities and the benefits are comparable with other strategies. Therefore, it is recommended that public agencies including and not limited to USEPA and US Department of Transportation work collaboratively to choose sites that would optimize remediation cost and travel and environmental cost savings.

A paper (Appendix A) on this research has been submitted to Journal of Urban Planning and Development, American Society of Civil Engineers.

Additional Activities:

- As part of activity 2C, a preliminary study was originally conducted using the same methodology of pollution valuation to measure the environmental cost of traffic congestion in about ninety U.S. metropolitan areas. This study was presented last January (2011) in the 90th annual Transportation Research Board conference in Washington D.C. The paper (Appendix B) has been accepted to be published in Transportation Research Records (TRR) during the Spring of 2011.

- During the 14th National Brownfield Conference cosponsored by EPA, we participated in a panel discussion named "Partnership 101: Working with Universities". Yeganeh Mashayekh from Carnegie Mellon/Western Pennsylvania Brownfields Center was on the panel. Each panelist discussed what they do and what the challenges are. Through an interactive discussion with the audience the panel was able to identify some of the issues related to partnership with universities and discuss some potential solutions.

- From April 26th to April 29th of 2011, Yeganeh Mashayekh attended the National Association of Environmental Professionals 36th Annual Conference in Denver, CO. Yeganeh was speaker presenting some of the work we have done as part of the EPA brownfield project. The title of the presentation was "Evaluating Environmental Emission of Pittsburgh Brownfields" covering an overview of the environmental footprint analysis of the brownfield developments in Pittsburgh compared with Greenfield developments.

Activity 3: Technical Assistance – Site Selection Through Prioritization

The first phase of the revised outreach strategy with Keystone CORE Services has been completed. Main and Elm Street Managers, associated with the Pennsylvania Downtown Center, were asked to complete a site profile (Appendix C) on properties within their respective community that were abandoned, blighted, and/or underutilized. A total of 79 properties from 17 communities were submitted. The profiles span the real estate spectrum from old commercial buildings to churches to gas stations. KCS's Board of Directors reviewed each profile and after some lively discussion chose 30 sites from 16 communities to move to the second phase: project attribute review.

Beginning in May 2011, KCS will work with the chosen communities to complete an attribute review (Appendix D) of each selected site. The review consists of a questionnaire and a site visit. Once all the questionnaires have been completed, CMU will apply a criteria rating system developed independently by KCS's Board of Directors based specifically on how KCS prioritizes the redevelopment factors (i.e. historic value, location to transit, environmental contaminates, etc.). The end result will be a site ranking from 1 to 30, 1 being the overall most desirable site to redevelop. KCS will use the ranking to help determine the 3 properties that will receive the Community Initiated Development charrette.

Action Steps

1) Communities interested in assistance from Keystone C.O.R.E. Services will have to first complete a site inventory of abandoned, blighted, underutilized properties. Communities can submit as many properties as they would like that meet the criteria. Completed: 79 Properties were submitted.
2) From the submitted sites, PDC will chose 30 sites (the intent is that the 30 sites will be in 30 DIFFERENT communities) to move to the next level of evaluation. Completed: February 2011.
3) Working closely with PDC staff, the 30 chosen communities will complete a site attribute profile for each of the sites selected. Site visits are scheduled for May and June 2011.
4) While the site attributed profiles are being completed KCS's board of directors will work with CMU to weight the criteria. Scheduled for May 9” 2011.
5) CMU will combine the completed site attribute profiles with the criteria weighting system. Date TBD
6) KCS's board of directors will choose 3 sites (from the weighted 30) to undertake a community initiated feasibility study. KCS intends on using 3rd and 4th year college interns to help facilitate the data collection on the 3 sites. Dates TBD.

Timeline

- Oct Nov Dec 2010 - Communities complete site inventory.
- Jan 2011 - PDC chooses 30 sites from site inventory list to move to the next stage – site attribute profile.
- Feb 2, 2011 – PDC chooses 20 sites from the site inventory list to move to the next
- Mach April May 2011 - PDC works with the 30 communities to complete the site attribute profile.
- May 2, 2011 – KCS's board works with CMU to weight the criteria.
- May 2011 - CMU applies criteria to the attribute profiles.
- June 6, 2011 - Keystone C.O.R.E Services chooses three (3) communities to move to the next stage – site feasibility analysis
- June July Aug 2011 - Interns gather site specific feasibility information on each site.

- Sept 2011 - KCS conducts its first taskforce visit to complete a community driven feasibility study.
- Oct 2011- KCS conducts its second taskforce visit to complete a community driven feasibility study.
- Nov 2011 - KCS conducts its third taskforce visit to complete a community driven feasibility study.

D. Progress vs Proposed Milestones

The proposed milestones for Years 1, 2 and 3 are presented in our application package are summarized in the following table. Note that this report is intended to summarize the first 6 months of Year 3, however, our Year 3 funding has not yet been authorized by the USEPA.

Completion YEAR	Activity 1: Training – Empowerment through Knowledge	Activity 2: Research – Quantifying a Sustainable Brownfield	Activity 3: Technical Assistance – Site Selection through Prioritization
1	.Participate in PDC regional events .Update PDC webpage with Brownfield related content .Nat'l Brownfields Conference (Fall 2009)	Develop framework and scope for life cycle assessment and carbon footprinting tool	Complete inventories in select Main Street/ Elm Street Communities
2	As above with webpage updates including additional case studies	Finalize transportation, building, electricity and water analysis modules	Initiate ranking process select Main Street/ Elm Street Communities
3	As above with webpage updates including additional case studies .Nat'l Brownfields Conference (Spring 2011)	Demonstrate, troubleshoot and validate model and tool	Complete ranking process select Main Street/ Elm Street Communities

Our progress to date (through the first 6 months of Year 3) can be summarized as follows: Activity 1: We are on track and working with PDC is their regional events. PDC webpage is active and we will need to focus on assuring the accuracy of the information on the webpage and adding case studies. (In addition, we will continue to add case studies to the webpage hosted by the Western Pennsylvania Brownfields Center: www.cmu.edu.steinbrenner/brownfields)

Activity 2: We continue to look for publicly available sources of data that can be used to understand environmental emissions: remediation, site preparation, housing construction, utility consumption (of residents), and transportation behavior (of residents). We have a better understanding of transportation behavior associated with brownfield development vs. greenfield development and we are continuing to develop the best methodology for comparative case analyses to better understand the inputs to the other sources of emissions; particularly electricity and water usage. We will explore sources for supporting data this summer while also working to develop an Excel based assessment tool.

Activity 3: We are working with Keystone CORE Services engage PDC's Main Street and Elm Street managers and provide incentives for those managers to begin to apply the multi-attribute decision making tool.

E. Actual vs, Proposed Expenditures

Actual expenditures continue to lag proposed expenditures due to both delays in getting the award finalized as well as delays in getting students on board. In addition, we were conservative with funding during the October 1, 2010 – March 31, 2011 timeframe because Year 3 funding had not yet been approved.

F. Lessons Learned and Goals by Activity

Activity 1: Training – Empowerment Through Knowledge

We will continue to improve the webpage and participate in PDC regional and statewide events, but It is clear that the interest in brownfield development will only grow if there is an evident economic and/or real estate benefit. For this reason, PDC has moved the Brownfield Taskforce under the purview of its sister real estate organization, Keystone CORE Services (KSC).

Activity 2: Research – Quantifying the Sustainable Brownfield

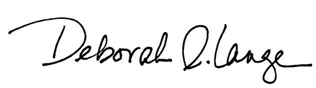
We reported on these 'Lessons Learned' in our last report, but the issues remain unchanged and are therefore reiterated here. The performance of site specific analyses by direct contact with stakeholders (such a the local engineer, developers and residents) is thorough albeit time consuming. The strategy to collect equivalent site specific data through publically available sources may ultimately be less time consuming but sources of the required data are not obvious nor readily accessible. Going forward, we will continue to identify sources of publicly available data so that we can prepare additional site analyses. To date, we have performed 2-pairs (or 4) site analyses. Results are somewhat consistent in suggesting the environmental emissions from the 'operating' portion of the development (ie residential behavior on a brownfield or a greenfield development) greatly exceed the emissions that result from the combination of remediation and construction activities. We will continue to prepare additional analyses, via direct and indirect communications and data collection, to further understand this potential trending.

We have successfully found data for the transportation analyses part of this effort. Going forward, we will be looking at the electricity and water usage analyses.

Activity 3: Technical Assistance – Site Selection Through Prioritization
We will focus our efforts on working with PDC to implementing an alternative approach to reach these communities within the Main Street and Elm Street Programs. Again, interest and participation will be based on incentives that can be generated through the Keystone CORE Services group of PDC.

We note that Progress Report 5 will include efforts performed between April 1, 2011 and September 30, 2011.

Respectfully submitted,



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APPENDIX A – *SUBMITTED FOR PUBLICATION*

The Role of Brownfield Developments in Reducing Household Vehicle Travel

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Abstract

The transportation sector is the second largest source of GHG emissions in the U.S. Reviving underutilized industrial sites can reduce the transportation sector's impact on the environment by lowering vehicle kilometers traveled (VKT).

This study examines the effect of residential brownfield developments on VKT reduction and the resulting costs (including the cost of driving time, fuel, and external air pollution costs). Sixteen brownfield and conventional development sites were analyzed in Baltimore, Chicago, Minneapolis and Pittsburgh. Travel demand models were used to estimate VKT reductions. Air pollution valuation data was used to estimate external environmental cost savings. Results indicate on average residential brownfield developments reduce VKT by 52% compared to conventional developments. Also on average, brownfield developments result in a time and fuel cost reduction of 60% and an external environmental cost saving of 66%. Comparing these cost savings with the initial one-time cleanup cost of brownfields, it is shown that density and the cost of remediation significantly impact the number of years that would take for the VKT cost savings to offset the remediation cost.

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Subject Headings

Remediation, Industrial Facilities, Vehicles, Air Pollution, Environmental Issues, Brownfields, Vehicle Kilometers Traveled

1. Introduction

Brownfields are properties for which expansion, redevelopment, or reuse may be complicated by the presence or potential presence of hazardous substances, pollutants, or contaminants (EPA 2009). An estimated 450,000 to 1,000,000 brownfield sites remain abandoned across the country (US GAO 2004). These sites include former industrial or manufacturing plants, dry cleaners, gas stations, laboratories and residential buildings. Developing brownfields incurs initial assessment and remediation costs and involves barriers such as uncertainty about the presence and type of contamination, uncertainty over cleanup standards, limited cleanup resources, and potential liability issues (HUD 2010; OTA 1995). On the other hand, developing these underutilized lands can positively impact economic development and the environment (Lange 2004). Brownfield developments have been shown to revive communities (Kaufman 2006), increase employment (De Sousa 2005), generate local tax revenue (De Sousa 2005), and keep green spaces intact (GWU 2001)

To make a proper decision about developing a brownfield site, it is important that all benefits and costs are taken into account. In this paper, we analyze the impact of residential brownfield developments on travel activity reduction and the consequential costs including the cost of time and fuel as well as the external environmental costs.

Examining contributing factors such as travel distance and number of trips generated by each of the brownfield and greenfield sites, we compare vehicle kilometers traveled (VKT) for a sample of brownfield and greenfield residential developments in four cities: Chicago, Pittsburgh, Baltimore and Minneapolis. Greenfields are undeveloped lands such as farmlands, woodlands, or fields located on the outskirts of urbanized areas (HUD 2010). In the absence of in-fill developments such as brownfields, greenfield developments are where growth occurs. We also estimate the external air pollution costs of driving for each brownfield and greenfield site using air pollution valuation data (Muller 2007). In addition to the valuation of criteria air pollutants, we include CO_2 costs using existing literature values. Furthermore, we compare the environmental costs with the cost of brownfield remediation. While the VKT reduction benefits of brownfield developments have been evaluated by a number of studies in the U.S., as discussed in the next section, no study to date has performed a comparison between the environmental, time and fuel benefits of brownfield developments and the cost of remediation. Our goal is to determine if the environmental cost savings as well as time and fuel cost savings from VKT reductions offset the extra initial onetime cleanup cost of brownfield developments.

Based on data availability, a sample of 16 U.S. brownfield and greenfield residential developments were selected in the four metropolitan areas of Baltimore, Chicago, Minneapolis and Pittsburgh. With the assistance of expert local representatives managing brownfield programs and local urban planners in each of the cities, two brownfield residential developments and two comparable greenfield residential developments were identified in each of the four cities. Two criteria were considered in the selection process of the sites: (1) minimum of one hundred dwelling units within each development; and, (2) developments must have been completed within the past twenty years. The average distance between the selected brownfield sites and city centers is 6.4 km while the average distance from the selected greenfield sites to city centers is 34 km. Specific information of the sites may be found in the Appendix.

1.1 Vehicle Kilometers Traveled (VKT) and Brownfield Developments

From 1995 to 2008, VKT in the U.S. increased from about 2.1 trillion to approximately 3 trillion, translating to an average annual increase of about 2% (FHWA 2008). It is projected that VKT will continue to increase at an average annual rate of 1.6% over the next twenty years (DOE/EIA 2008), resulting in a VKT of 4.5 trillion by 2030. The projected impact from increasing VKT is expected to outpace gains from improved fuel economy and alternative fuels, resulting in an increase of GHG emissions (AASHTO 2008). As a result, the American Association of State Highway and Transportation Officials (AASHTO) has set a goal of reducing the VKT growth rate to that of population growth, approximately 1% per year, by 2030. In addition, the Federal Surface Transportation Policy and Planning Act of 2009 was introduced to reduce national per capita VKT on an annual basis and to reduce GHG emissions resulting from surface transportation by 40% by 2030 (US FSTP 2009).

Reducing VKT and the resulting GHG emissions can be accomplished by various strategies including but not limited to parking management, pricing alternatives, and public transit improvement as well as changing land use patterns. Changing land use patterns can be accomplished through smart growth concepts such as compact developments, mixed-used developments, walkable communities and transit-oriented developments (Johnston 2006). Compact urban development has been correlated to a reduction of 20%-40% in VKT compared to sprawl (Ewing 2008). A National Research Council study concluded that compact developments with a high density are likely to reduce VKT, energy consumption, and CO_2 emissions (NRC 2009). Handy (2005) and Shammin (2010) also support the benefits of compact developments with respect to reducing energy consumption and travel activity. On the other hand, critics of compact developments note the costly effects of increased traffic congestion, higher taxes, higher consumer costs and more intensive developments (O'Toole 2009; Gordon 1997).

Large brownfield developments are typically redeveloped as mixed-use or compact developments, which consist of residential, retail, offices, entertainment centers and community centers (DNR 2006). As Paull (2008) documents, increasing mixed-use and especially residential use of the brownfield sites meets smart growth objectives. A number of studies have documented that brownfield developments are mostly compact. Brownfield developments conserve land in a ratio of 1 acre per brownfield redeveloped to 4.5 acres per conventional greenfields (GWU 2001). De Sousa (2005) reports brownfield residential density of 59 households per acre in Chicago. In addition to density, distance to city centers, access to transit, diversity of land use within the developments, and the design of the mixed-use developments, both internally and in connection with the existing urban grids, are factors that can potentially influence the impact that compact brownfield developments might have on VKT reduction. Several studies show that brownfield developments lower VKT compared to conventional greenfield sites (USCM 2001; EPA 2006; EPA 2010a). Moreover, Nagengast (2010) compares commuting travel times between brownfields and greenfields in six cities and concludes that commuting travel time is less for brownfields compared to greenfields. A comparison of the results of this study and the previous figures is presented in the discussion section of this paper.

1.2 Remediation Cost of Brownfield Sites

To develop a brownfield site, a risk assessment generally followed by site remediation is necessary. The remediation solution largely depends on the types of contaminants found. The cost of remediation varies significantly depending on the type of contaminant, level of exposure, and procedures needed to clean up the contaminants (EPA 2001; Rast 1997). While several studies report the cost of brownfield cleanup as a percentage of public funds or total investment funds, the exact numbers are not reported in most cases. The Council of Urban Economic Development reports the median cleanup cost per acre is $57,000 (CUED 1999). The City of Chicago reports the remediation cost of multiple projects from $25,000 to $530,000 per acre (Chicago 2003). A complete list of remediation costs from multiple studies is presented in the methodology section.

Although incurring initial remediation cost, brownfield developments might require lower initial construction investments as they are typically built compact and, in most cases, benefit from already existing infrastructures such as water pipelines, power supply, roadways and sewer systems (CNT 2004).

2. Methodology

2.1 VKT Data Sources

To determine the average difference in travel activities between residential brownfield and greenfield developments, 2010 travel demand model (TDM) outputs were obtained from the metropolitan planning organizations (MPO) for each city. Travel demand models simulate real world travel patterns. The model takes into account travel behaviors that influence drivers' choice of destination, mode of transportation and selected routes (Wang 2007). TDMs and Geographic Information Systems (GIS) were used to identify Traffic Analysis Zones (TAZ) containing the study sites. A Traffic Analysis Zone is the unit of geography, similar to census tracts, used in travel demand models (Harvey 2001). By analyzing trip productions and attractions (the number of trips produced and attracted to each TAZ), the number of home-based automobile trips and resulting VKTs generated and distributed by the study sites to all other TAZs were calculated. The trips were categorized into two groups: home-based work (HBW) trips and home-based non-work (HBNW) trips. To compare results among brownfield and greenfield sites, VKT estimates were normalized by the number of households. Specific information on each of the four MPOs involved in this study is provided in the Appendix.

2.2 Direct Cost Analysis (Time and Fuel)

To compare costs of brownfield and greenfield developments, costs were categorized into direct (including cost of time and fuel) and indirect (external environmental) costs.

To estimate the direct costs, VKTs associated with each brownfield and greenfield site were first converted to travel times and then to the cost of time. To determine travel times, the percentage of freeway and arterial kilometers for each site was investigated and speed of 97 km/h and 56 km/h was assumed for freeways and arterials respectively (TTI 2009). The average value of time was assumed to be $15.5 per hour for the base case, while a range of values were analyzed to account for uncertainties (TTI 2009).

To calculate the fuel energy and cost of fuel, vehicle emission factors were determined using EPA's Mobile 6.2 (MOBILE6) on-road emissions modeling tool. MOBILE6 determines emissions from fuel combustion, evaporative losses, brake wear and tire wear for light and heavy duty vehicles, trucks, buses and motorcycles (EPA 2003). Since only automobile travel data are analyzed, only light duty vehicles were included in the MOBILE6 analysis. Fuel energy in Megajoules (MJ) per km was calculated for the average speeds of 97 km/h and 56 km/h for freeway and arterial VKTs respectively. A Reid Vapor Pressure of 8.7 psi with July freeway conditions was assumed. The price of gasoline was assumed to be $2.8 per gallon. Fuel use (FU) is a function of fuel energy (FE) and daily vehicle kilometers traveled (DVKT) and fuel cost (FC) is a function of FU and the price of gasoline.

$$FU_{(a)} = (FE_i \times DVKT_{i(a)}) + (FE_j \times DVKT_{j(a)}) \quad (1)$$

$$FC_{(a)} = (FU_{(a)} \times P)/\mathrm{C} \quad (2)$$

where:

$FU_{(a)}$ = Fuel use for site a (MJ/day);

FE = Fuel energy (MJ/km);

$FC_{(a)}$ = Fuel cost for site a ($/day);

P = Price of gas ($2.8/gallon);

C = 121.3 MJ/gallon of gasoline

$DVKT_{(a)}$ = Daily vehicle kilometer traveled for site a (km/day); and

i and j represent freeway and arterial respectively.

2.3 Indirect Cost Analysis (External Environmental Cost)

To calculate the cost of external air emissions, the Air Pollution Emission Experiments and Policy (APEEP) analysis model was used (Muller 2007). APEEP connects county-level emissions of air pollutants through air quality modeling to exposures, physical effects, and monetary damages (NRC 2010). For each county and pollutant, APEEP estimates mortality, morbidity, and environmental (e.g., crop loss, timber loss, materials depreciation, visibility, forest recreation) damages. A value of statistical life (VSL) of $6M, in accordance with EPA's central VSL, is used for the APEEP analysis (Dockins 2004). The cost of CO was assumed to be $520/t (Matthews 2000), as it was not provided by APEEP. Because CO and NO_x are both predominantly tropospheric ozone precursors, the CO value was scaled for each county analyzed using the ratios for NO_x observed in the APEEP data (Mashayekh 2010). A mean CO_2-eq cost of $30/ton was used in this study (NRC 2010). To account for uncertainties, data ranges for the cost of CO, CO2, gas, time and APEEP costs are assumed and will be explained in the results section of this paper.

Joining APEEP specific county level results with the national MOBILE6 vehicle emission factors in grams per km, and freeway and arterial VKTs calculated for each site, the external environmental VKT cost for each of the brownfield and greenfield sites were calculated and compared. Carbon dioxide (CO_2), sulfur oxides (SO_X), nitrogen oxides (NO_X), particulates ($PM_{2.5}$), ammonia (NH_3) and carbon monoxide (CO) emissions were considered in this study based on the availability of pollution valuation data.

MOBILE6 fails to account for speed-specific fuel economy, emissions of SO_2, $PM_{2.5}$, and NH_3 or driving cycles specific to each metropolitan area (Mashayekh 2010). To capture the variation of fuel economy and CO_2 emissions with speed, the relationships developed by Ross (1994) were employed. The amount of fuel consumed by a vehicle and the resulting CO_2 emissions are the result of the power needed to overcome tire rolling resistance, air drag, vehicle acceleration, hill climbing, and vehicle accessory loads

(Mashayekh 2010; Ross 1994). These factors in combination produce a fuel energy-to-speed profile that is used to adjust the MOBILE6 fuel economy and CO_2 emission baseline factors to develop speed-specific factors (Ross 1994).

To address the effects of fleet age, vehicle emission factors were increased by 4.9% annually for CO, 1.4% for NO_X, 4.5% for $PM_{2.5}$ and 5.9% for VOCs (Chester 2010). The average vehicle age is assumed to be 5 years (GREET 2008). Combining the cost of each pollutant from APEEP ($/kg) with emission factors from MOBILE 6 (gram/km) and daily VKTs (km/day), the external environmental cost of each pollutant was calculated for each development using the following equation:

$$C_{i(a)} = DVKT_{(a)} \times EF_i \times C_i \qquad (3)$$

where:

$C_{i(a)}$ = Cost of pollutant i for development a ($/day);

$DVKT_{(a)}$ = Daily vehicle kilometers traveled for development a (km/day);

EF_i = Emission factor for pollutant i (gram/km); and

C_i = Cost factor for pollutant i ($/1000gram).

2.4 VKT and Remediation Cost Comparisons

After direct and indirect costs were calculated and compared between the brownfield and greenfield developments, brownfield cost savings from VKT reductions were also compared with the initial remediation cost. The goal was to examine if the cost savings from VKT reductions offset the extra initial one-time cleanup cost of brownfield developments.

The remediation cost depends significantly on the type of contaminant and the level of exposure, both of which factored in selecting the strategy used to cleanup the site. The cost of cleanup includes direct costs, contractors' overhead and profits, and contingencies. Since these values vary significantly from site to site, a range of remediation costs from multiple studies and references was used:

Table 1: Remediation Cost Based on Various Documentations

Study	Remediation Cost ($/acre)	Note
Chicago 2003	25,000-530,000	Various Projects
Auld 2010	580,000	Pittsburgh
Lehr 2004	250,000-500,000	Capping
CUED 1999	57,000	-
R.S. Mean 2010	45,000	Capping (18")
Terry 1999	22,000	Phytostabilization
Terry 1999	56,000	Soil Capping
Terry 1999	65,000	Asphalt Capping

To compare the one-time remediation cost with the cost savings from the VKT reductions calculated earlier, the average cost of $190,000 per acre was used for the base case and the 95th percentile cost of $550,000 per acre and 5th percentile cost of $24,000 per acre were used for the worst and best cases respectively.

The residential density of the eight selected brownfield sites ranges from 6 to 59 households per acre with the median of 12 households per acre. Great Communities Organization reports a range of 19 to 129 household per acre for compact developments (GCC 2009). Leading studies in compact developments report an average of 11 to 15 households per acre for compact developments (CSI 2009, Ewing 2008, and NRC 2010). In this study an average of 12 households per acre was used to normalize the base remediation cost.

3. Results

3.1 VKT Comparison Results for Brownfield and Greenfield Sites

VKTs were calculated for eight brownfield and eight greenfield sites within the four selected cities of Baltimore, Chicago, Minneapolis and Pittsburgh. Table 2 compares HBW automobile VKTs, trip distance and the number of trips per household for brownfields and greenfields.

Table 2: Brownfield and Greenfield Developments' Travel Pattern Comparisons – Daily Home Based Work (HBW) Auto Trips per Household

Type	Average VKT (Km/HH)	Average Distance (Km/trip)	Average # of Trips/HH
Brownfield (BF)	10.0	11.0	0.9
Greenfield (GF)	24.0	18.0	1.7
National	19.0	21.0	1.0
Reduction (GF to BF)	60%	36%	47%

*HH: household

The results indicate that brownfield commuters drive far fewer daily kilometers than those living in greenfields (60% less). This reduction is statistically significant at greater than 95% confidence (p=0.00004). The difference in VKTs is the result of the differences in the number of trips per household and the differences in the distance of those trips. Tables 2 and 3 also compare the daily VKTs, daily trips and distances with the national average data (NHTS 2009). In the case of HBW trips, the national average VKT falls in between brownfield and greenfield sites, perhaps due to an overall fewer number of trips per household in the nation.

The result of comparisons between HBNW trips shows that brownfield sites on average generate 42% less VKT than greenfield sites (Table 3).

Table 3: Brownfield and Greenfield Developments' Travel Pattern Comparisons – Daily Home-Based Non-Work (HBNW) Auto Trips per Household

Type	Average VKT (Km/HH)	Average Distance (Km/trip)	Average # of Trips/HH
Brownfield (BF)	18.0	7.0	2.5
Greenfield (GF)	31.0	10.0	3.0
National	40.0	15.0	3.0
Reduction (GF to BF)	42%	33%	17%

*HH: household

The reduction is statistically significant at greater than 95% confidence (p=0.005). Due to the general close proximity of shopping centers, schools and recreational sites to greenfields, the difference of VKTs between brownfield and greenfield developments in the case of HBNW trips is not as large as HBW trips.

In the case of HBNW trips the national average data are higher than both groups; perhaps because the national averages include rural areas in which people need to drive farther distances to get to non-work destinations compared to the urban areas used in this study.

The total annual weekday average VKT reduction associated with brownfield sites including work and non-work trips is 52%.

3.2 Direct and Indirect Costs Results for Brownfield and Greenfield Sites

Table 4 shows a breakdown of the average daily direct and indirect costs of brownfield and greenfield sites per household and the percent reduction of each of these costs between greenfield and brownfield sites.

Table 4: Comparison of Direct and Indirect Average Daily Costs per Households between Brownfield and Greenfield Sites

	Average Direct Costs ($/Day)		Average Indirect External Environmental Costs ($/Day)							
Area	**Time**	**Fuel**	**CO_2**	**NO_x**	**VOC**	**CO**	**SO_2**	**PM**	**NH_3**	**Total**
Brownfield (BF)	5.0	1.1	0.1	0.06	0.2	0.2	0.002	0.02	0.4	0.9
Greenfield (GF)	12.0	2.8	0.3	0.09	0.5	0.3	0.005	0.06	1.4	2.6
% Reduction (GF to BF)	60	60	60	40	70	40	60	70	75	67

Direct costs (time and fuel) have higher magnitudes compared to the external environmental costs. Also, in the external environmental costs category, CO_2, VOC, CO and NH_3 costs have higher magnitudes than NO_x, SO_2 and particulates.

Based on the VKT calculations, the results of the cost analyses conducted for the four cities shows that the direct costs of brownfields including time and fuel are about 60% lower than greenfield sites, while the external environmental costs are reduced by about 67%.

Adding up the annual weekday direct and indirect costs for brownfields developments show an annual household saving of $2,900.

It is important to note that a percentage of those who live in brownfield developments use transit, therefore they incur cost of transit plus cost of time. Also depending on the level of ridership increase, transportation authorities might increase the number of buses resulting in increased emissions and external environmental costs.

3.3 Comparison of VKT Costs and Remediation Costs for Brownfield Sites

To examine whether the benefits from the VKT reductions associated with brownfield sites makes up for the initial cost of brownfield sites, an average remediation cost of

$190,000 per acre was assumed. For the remediation cost to offset the benefits from the VKT reduction ($2,900/household) in the first year, a development needs to have at least 65 housing units per acre. With the average density of 12 units per acre (CSI 2009), the benefit will offset the cost in 6 years, assuming a discount rate of 7%. Since the cost of remediation and the density of brownfield developments vary significantly, sensitivity analysis, explained in the next section, was conducted to examine the effect of cost and density variances on the comparison between remediation costs and VKT reduction cost savings.

3.4 Uncertainty – Bounding Analysis

To examine the range of costs associated with the VKT reduction from brownfield developments and to compare the worst and best-case scenarios, a bounding analysis was conducted with the assumptions shown in Table 5. While county specific APEEP emissions costs were used for the base case, for the worst and best-case scenarios lowest and highest U.S. county costs were assumed. CO_2 unit costs are based on about 50 studies showing a mean cost of $30/ton, and 5th and 95th percentile costs of $1/ton and $85/ton (NRC 2010). Cost of CO was assumed to be an average of $520/ton, min of $1/ton and max of $1050/ton (Matthews 2000). Despite the large range of CO cost, the uncertainty analysis shows that cost savings are not sensitive to the cost of CO.

Table 5: Uncertainty - Bounding Analysis Assumptions

	Base	**Best Case**	**Worst Case**
APEEP Emission Costs	County Specific	Lowest County Costs	Highest County Costs
CO_2 Value ($/ton)	30	1	85
Cost of fuel($/Gallon)	2.80	Min (2008-2010)	Max (2008-2010)
Cost of CO ($/t)	520	1	1050
Cost of Time ($/hr)*	15.5	8.25	30.0
Remediation Cost ($/acre)	190,000	24,000	550,000
Density (HH/acre)	12	100	6

*Based on minimum wage and annual salaries.

The results show that the total cost savings of driving associated with brownfields ranges from $1,300 to $5,700 per household. Assuming a 7% discount rate, using the lowest remediation cost ($24,000/acre) and the highest density (100HH/acre), it will only take 1 year to offset the cost of remediation (even with the lowest cost saving of $1,300), while with the highest remediation cost ($550,000/acre) and lowest density (6HH/acre), the remediation cost is never covered by the annual cost savings even with the largest cost saving of $5,700. The highest remediation cost of $550,000 and the lowest cost saving of $1,300 require a density of 55 units per acre to make up for the cost in 10 years.

4. Discussion

4.1 Comparison of VKT and GHG Reductions

Although methodologies to estimate VKT and GHG reduction are different between this study and some previous studies (i.e. TAZ level data vs. Census level data; valuation and accounting vs. life cycle assessments), the existing literature provides an opportunity to compare and validate the results of this study. Relevant existing reported VKT reductions are shown in Table 6:

Table 6: Comparison of VKT and GHG Reductions between Various Studies

Study	Geographic Area	Type of Land-Use	Average Reduction in VKT	Range of Reduction in VKT	Range of Reduction in GHG & Air Pollutants
This Study	Baltimore, Pittsburgh, Chicago, Minneapolis	Brownfield	52%	38% - 63%	35%- 75%
EPA 2010a	Seattle, Minneapolis, St. Paul, Emeryville, Baltimore, Dallas	Brownfield	47%	32% - 57%	32% - 57%
EPA 2001a, EPA 2002, EPA 1999, NRDC 2003, Schroeer 1999, IEC 2003	12 cities: Atlanta, Baltimore, Boston, Charlotte, Denver, Dallas, Nashville, Sacramento, San Diego, Montgomery, Wes Palm Beach, BCD	Brownfield	61%	39% - 81%	-
US Conference of Mayors (USCM), 2001	Baltimore and Dallas	Brownfield	-	23% - 55%	36%-87%*
EPA 2006	Atlantic Station, Atlanta	Brownfield	73%**	14%-52%	-
CSI 2009,	U.S.	Compact	40%	20%-60%	20%-60%
NCR 2010	U.S.	Compact	-	5%-25%	5%-25%
Ewing 2008,	U.S.	Compact	30%	20%-40%	18%-36%
Nagengast, 2010	Minneapolis, Baltimore, Chicago, St. Louis, Pittsburgh, Milwaukee,	Brownfield	***	***	36%

*Actual number reported is 73%. The range was from pre-development model.
** The range is only showing the reduction of VOC and NOx.
*** Nagengast does not directly calculate VKT, but rather focuses on travel time for commuting only and concludes that travel time for brownfields is only 3 minutes less than greenfields for all modes. Modal shares differed between the brownfield and greenfield developments, with transit share higher for brownfields.

The variation observed in the estimates reported in Table 6 can be the result of many factors including methodology used, trip generation assumptions in different jurisdictions, vehicle emission profiles varying in different geographical boundaries, and uncertainties in estimating externalities. While these uncertainties and inconsistencies are inevitable, the literature results show a 43±38% reduction for VKT, which is consistent with the results of this study (38%-63%). Furthermore, the literature results show a 46±41% emissions reduction, which is consistent with the results of this study (35%-75%).

Travel times associated with brownfield sites are further compared to the national averages and census journey to work data in Table 7 (NHTS 2009; Census 2000).

Table 7: Brownfield Sites' Travel Time Comparisons with the National Averages

	Home-Based Work (min)	**Home-Based Non-Work (min)**
This Study	12	19
NHTS 2009 (National Average)	24	18
Census 2000 (National Average)	26	-

While the travel time estimates for HBNW trips used in this study are very similar to the National Household Travel Survey (NHTS) average, the HBW travel time is half of the other estimates, likely due to the close proximity of the small sample size to work and city centers. This difference implies that characteristics of brownfield developments (i.e. location) should be considered as they can impact travel patterns. The following section examines some of these characteristics.

4.2 Brownfield Developments Characteristics and VKT Reductions

As mentioned earlier in this paper, most urban brownfields are developed as mixed-use or compact developments. Compact development characteristics such as density, diversity, design and distance to city centers may all be affecting the reduction in VKT, number of trips and distance per trip. To examine if these characteristics are correlated with the reduction in VKT, using all 16 sites studied in this paper, a number of characteristics associated with compact developments were explored. The result of the correlation analysis shows that as distance to the city center increases, VKT increases; as access to transit improves, VKT decreases; and as walkability improves, VKT decreases. Furthermore, brownfield developments show wider and higher range of density associated with less VKT, while greenfield developments show less dense developments (less than 3 households/acre) with higher VKTs. A detailed discussion of the correlation analysis may be found in the Appendix.

4.3 Brownfield Developments and Other Social and Economic Factors

Although time, fuel and environmental cost savings of brownfield developments are important factors when it comes to making decisions to move to urban areas, vacancy rates of the 16 study developments show the average vacancy rate of brownfield developments is higher (9%) than greenfield developments (1%). So the question is if moving to brownfield developments would save about 60% on the cost of fuel and time, why is the vacancy rate higher in urban cores? Factors such as home value, property taxes, crime rate and quality of schools are known to be among the most significant factors influencing vacancy rates. Examining the average home values and property taxes, it was concluded that for the 16 study sites examined in this paper, property tax and home values are not the major determining factors. Other factors such as crime rate or quality of schools may affect people's decision more significantly. Details on vacancy rates, home values and property taxes may be found in the Appendix.

6. Conclusions

In this paper, we have estimated and compared VKTs and their resulting costs of time, fuel and emissions for eight brownfield and eight greenfield sites in Baltimore, Chicago, Minneapolis and Pittsburgh, showing that residential brownfields generate significant

VKT reduction and cost savings. Brownfield developments on average result in about $2,900 cost savings per household ($2,400/HH from time and fuel savings and $450 form the external environmental cost savings). These estimates can be used in benefit-cost studies to assess the benefits of travel reduction through land use changes and specifically brownfield developments.

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Appendices

A1.Description of Brownfield and Greenfield Sites

To conduct the VKT reduction analysis for this study, with the assistance of local representatives, a sample of 16 U.S. brownfield and greenfield residential developments were selected in the four metropolitan areas of Baltimore, Chicago, Minneapolis and Pittsburgh. In each of the cities two brownfield sites and two greenfield sites were selected (Table A1).

Table A1: Brownfield and Greenfield Sites

Name	City	Type	Kilometers to City Center	Address
Waverly Woods	Baltimore	Greenfield	29	10712 Birmingham Way, Woodstock, MD 21163
RiverHill Village	Baltimore	Greenfield	38	12100 Linden Linthicum Lane, Clarksville, MD 21029
Clipper Mills	Baltimore	Brownfield	5	1472 Clipper Mill Rd, Baltimore, MD 21211
Camden Crossing	Baltimore	Brownfield	2	307 Parkin Street, Baltimore, MD 21201
Woodland Hills	Chicago	Greenfield	56	1538 Longmeadow Ln, Bartlett, IL 60103
Reflections at Hidden Lakes	Chicago	Greenfield	39	8310 Sweetwater Ct, Darien, IL 60561
Homan Square	Chicago	Brownfield	8	3517 W. Arthington St, Chicago, IL 60624
Columbia Point	Chicago	Brownfield	14	Woodlawn Ave & E 63rd St, Chicago, IL 60637
Itokah Valley	Minneapolis	Greenfield	29	1725 Riverwood Drive, Burnsville, MN 55337
Creekside Estate Apt.	Minneapolis	Greenfield	9	200 Nathan Lane North, Plymouth, MN 55441
Heritage Park	Minneapolis	Brownfield	4	502 Girard Terrace, Minneapolis, MN 55405
Mill City	Minneapolis	Brownfield	1	700 S. 2nd Street, Minneapolis, MN 55401
Peters Township	Pittsburgh	Greenfield	22	168 Hidden Valley Rd, McMurray, PA 15317
Cranberry Heights	Pittsburgh	Greenfield	44	78 Winterbrook Dr, Cranberry Twp, PA 16066
Summerset	Pittsburgh	Brownfield	9	1346 Parkview Blvd, Pittsburgh, PA 15215
Waterfront	Pittsburgh	Brownfield	10	West St and W 8th Street, Homestead, PA 15120

A2.Travel Demand Model Specific to Each City

For this study four metropolitan planning organizations were providing data on their Travel Demand Models:

1- Southwestern Pennsylvania Commission (SPC): SPC is the metropolitan planning organization in charge of Pittsburgh and 10 counties in the southwestern Pennsylvania region. SPC in responsible for short term and long term transportation plans within the region. For their TDM SPC uses TP+ modeling software package. The method used is the four step travel demand process.

2- Minneapolis/St. Paul Metropolitan Council: The Metropolitan Council is the regional planning agency responsible for the short term and long term transportation plans within Twin Cities 7 counties. For the TDM, SPC uses TP+ modeling software package. The method used is the four step travel demand process.

3- Chicago Metropolitan Agency for Planning (CMAP): CMAP is the regional planning organization responsible for 7 northeastern Illinois counties. For the their TDM, CMAP uses EMME/2 modeling software.

4- Baltimore Metropolitan Council: The Baltimore Metropolitan Council is responsible for the short term and long term transportation plans of Baltimore City and five other counties. For their TDM, the Baltimore Metropolitan Council uses the Cube/TP+ modeling software package.

A3.Freeway and Arterial Kilometer Allocation

To calculate direct costs associated with brownfields and greenfields, VKTs were converted to travel times. To determine travel times, VKTs were distributed to freeway and arterial kilometers using the Urban Mobility Report data (TTI, 2009). The report done by Texas Transportation Institute (TTI) provides percentages of freeway and arterial kilometers for 90 urban areas in the U.S. Depending on the location of each brownfield or greenfield site, the VKT associated with the site was distributed to freeway and arterial percentages for the associated urban area. For instance, if the sites are in or around Pittsburgh, the same freeway and arterial percentages used in the TTI report for the city of Pittsburgh were applied.

A4.Remediation Strategies

Cost of remediation varies depending the type of remediation strategy chosen for a bronwfield site. As such depending on the type of contaminant and level of exposure either one of the following brownfield remediation strategies is used (Rast 1997).

1- Immobilization of the contaminants (i.e., stabilization, solidification, landfill construction, capping, slurry walls and in-situ solidification),
2- Destruction or alteration of contaminants (i.e., biodegradation, incineration, low temperature thermal desorption),
3- Removal or separation of contaminants (i.e. air stripping, ion exchange, soil washing, soil vapor extraction, solvent extraction).

A5.APEEP Model and Its Values

The Air Pollution Emission Experiments and Policy (APEEP) analysis model is an integrated assessment model connecting air emission pollution through air quality modeling to exposures, physical effects and monetary damages. APEEP is designed to calculate the marginal damages corresponding to emissions of $PM_{2.5}$, VOC, NOx, NH_3 and SO_2 on a dollar-per-ton basis. Damages include adverse effects on human health, reduced yields of agricultural crops and timber, reductions in visibility, enhanced depreciation of man-made materials, and damages due to lost recreation services. Although APEEP includes both county aggregated ground level sources and point sources, due to the nature of this study dealing with vehicles, the county aggregated ground level sources were used. Although in this paper, for the base case study APEEP county specific data were used, for the sensitivity analysis of the paper the lowest and highest county costs in the U.S. were used. This was to assume if a brownfield site is located in the most costly county or the least costly county what would be the impact on the overall cost savings. Table A7 summarizes the lowest and highest county costs in the U.S. for each of the pollutants. It also shows the mean costs across all U.S. counties as well as mean costs across only those counties that were part of this study:

Table A6: Range of APEEP County Ground Level Costs

Pollutant	*Mean Costs Across Counties of this Study ($/kg)*	*Lowest County Cosst ($/kg)*	*Highest County Costs ($/kg)*	*Mean Cost Across all U.S. Counties ($/kg)*
VOC	9.2	0.04	50	1.4
NO_x	3.8	0.05	20	1.8
$PM_{2.5}$	96	0.4	540	14
SO_2	20	0.3	180	6
NH_3	260	0.2	1100	14

A6. Correlation Analysis: Brownfield Development Characteristics and VKT

Most urban brownfields are developed as compact developments; characteristics associated with compact developments such as density, diversity, design and distance to city centers may all be affecting the reduction in VKT, number of trips and distance per trip. Examining all 16 sites studied in this paper, a number of characteristics associated with compact developments and their correlation with VKT reduction were explored.

The density of each site was calculated as a number of households per acre. The distances between the site and the city centers were measured using shortest driving distance. Access to transit was measured in terms of minutes to the city centers using transit. Walkability was measured on a scale of zero to one hundred depending on the number of amenities within 1.6 km of the site (Hoehner 2005).

The strongest correlation exists between VKT and distance to the city center, indicating as distance increases, VKT increases (ρ_{HBW} = 0.80; ρ_{HBNW} = 0.73). Access to transit (ρ_{HBW} = 0.78) showes as transit time increases, HBW trips also increase (not as strong for HBNW trips, ρ_{HBNW} = 0.5), and walkability showing as the power of walkability increases, VKT deacreases (ρ_{HBW} = -0.64, ρ_{HBNW} = - 0.4) were also examined. Compared with other factors, density shows a weak correlation with HBW trips (ρ_{HBW} = -0.5) and almost no correlation with HBNW trips (ρ_{HBW} = -0.02). Figure A1 shows that, in general, greenfield developments have lower density (typically below 3 households per acre) and higher VKTs while brownfield developments have higher densities with wider range and fewer VKTs.

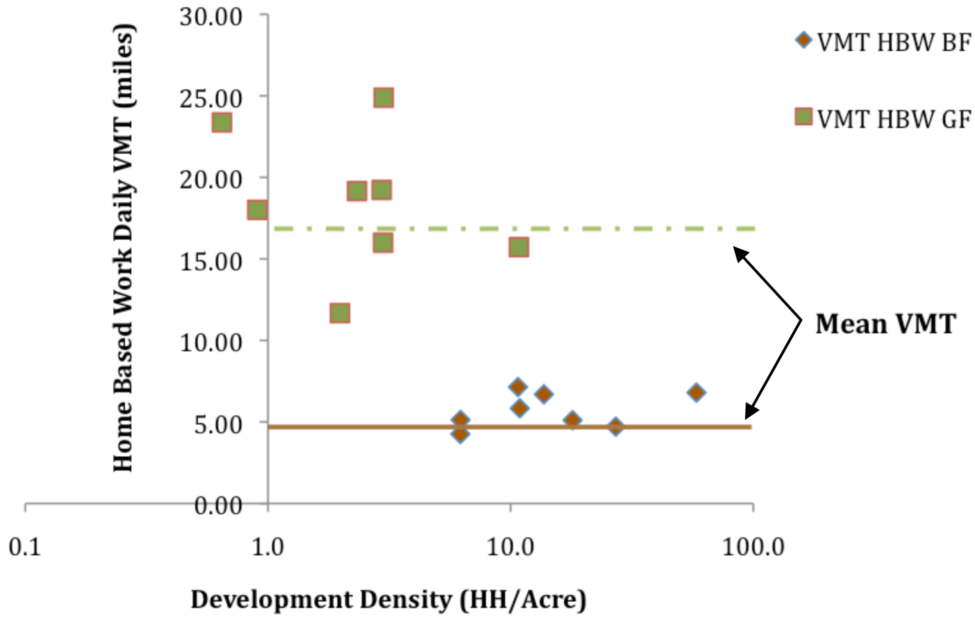

Figure A7: Home Based Work (HBW) Daily VKT vs. Density

A7. Vacancy Rates, Home Values and Property Taxes

Economic and social factors such as home value, property taxes, crime rate, and quality of schools influence people's decisions when it comes to moving to urban cores to live in brownfield developments. Although the focus of this paper is not on the social aspects of brownfield developments, vacancy rates of the 16 study developments were studied to examine what factors might influence people's decisions. The question was if households would save 60% on the cost of time and fuel by moving to brownfield developments, what is stopping them?

Vacancy rates, calculated from the 2010 United States Postal Services data on houses that have been vacant in the past 90 days (HUD, 2010). For brownfield developments, the average vacancy rates is about 9% while for greenfield developments the rate is about 1%. The difference is statistically significant with 95% confidence (p=0.002). To examine if the home value or the property tax is affecting vacancy rates, the 2009 median home values and property taxes were examined. The average home value of the brownfield developments is about

$220,000 while the average home value of the greenfield developments is about $290,000 (TF, 2009). Home values might be simply higher in or around greenfield developments as properties generally have more land resulting in a higher price. The 2009 property tax data for the sixteen sites shows that the average property tax of brownfield developments is 1.4% while the average property tax of greenfield developments is about 1.3% (TF 2009). While we recognize that the sample size is small, we conclude that, for the study sites, property tax and home values are not the major determining factors in making housing decisions. Other factors such as rate of crime or quality of schools may be affecting people's decision more significantly.

APPENDIX B

PAPER PRESENTED IN JANUARY 2011 AT THE 90TH ANNUAL TRANSPORTATION RESEARCH BOARD CONFERENCE IN WASHINGTON D.C. THE PAPER HAS BEEN ACCEPTED TO BE PUBLISHED IN TRANSPORTATION RESEARCH RECORDS (TRR) DURING THE SPRING OF 2011.

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Abstract

Automobile air emissions are a well recognized problem and have been subject to considerable regulation. An increasing concern for greenhouse gas emissions draws additional considerations to the externalities of personal vehicle travel. In this paper, we estimate automobile air emission costs for eighty-six U.S. metropolitan areas based on county-specific external air emission morbidity, mortality, and environmental costs. Total air emission costs in the urban areas are estimated to be $ 145 million/day, with Los Angeles and New York (each $ 23 million/day) having the highest totals. These external costs average $ 0.64/day/person and $ 0.03/vehicle mile traveled. Total air emission cost solely due to traffic congestion for the same eight-six U.S. metropolitan areas was also estimated to be $24 million/day. We compare our estimates with others found in the literature and find them to be generally consistent. These external automobile air emission costs are important for social benefit and cost assessment of transportation measures to reduce vehicle use.

1. Introduction

The modern U.S. urban transportation system has been a resounding success in providing mobility to residents and businesses (Altshuler 1979, VTPI 2009). Nonetheless, there are continuing concerns for secondary effects including accidents, air emissions, congestion, lack of physical exercise, mobility for those without motor vehicles, noise, petroleum dependence, and urban sprawl (Delucchi 1998, Moffet 1993, Maibach 2008, Matthews 2001, Matthews 2000). Previous work has estimated the costs of some of these externalities, notably congestion and accidents (TTI 2009, Saito 2010). In this paper, we estimate the external costs of air pollutant emissions from personal motor vehicles in eighty-six major U.S. metropolitan areas, both in total for all urban travel and for the specific air emission costs due to congestion. Quantifying these external costs can allow society to better understand the total costs of driving. In addition, identifying the external costs associated with congestion can lead to a better understanding of the total benefits that result from congestion management strategies.

Urban air pollution from private vehicles has been declining since the 1970s (Granell 2004, Parrish 2006, Chester 2010), even as the number of vehicles and vehicle miles traveled (VMT) in the U.S. have been increasing (Fairfield 2010). These reductions in overall and per-VMT criteria air emissions have resulted from the introduction of emission regulations and the resulting implementation of exhaust controls. In 2009, for example, only one county in the U.S. (Clark County, NV) had carbon monoxide levels exceeding the National Ambient Air Quality Standard (NRC 2010), a significant improvement from 1995 when 42 areas exceeded the 8-hour Standard (EPA 2010a). At the same time, however, carbon dioxide emissions from private vehicles have been growing: motor vehicle fuel economy, which determines carbon dioxide emissions, has not had major improvements and emissions regulation has not, until recently, targeted carbon dioxide (EPA 2010b). In 2007, the transportation sector accounted for approximately 33 percent of total carbon dioxide emissions from fossil fuel combustion in the U.S., of which about 60 percent resulted from gasoline consumption of personal vehicles (EPA 2010c). Total CO2 emissions are also growing more quickly than other sources of emissions, increasing 29% from 1990 to 2007.

Due to the extensive U.S. effort for emission controls on motor vehicles from the 1970s onwards, external air emission costs are small relative to the overall cost of motor vehicle use including ownership, fuel, insurance, and depreciation. For example, in 2007 dollars, the National Research Council (NRC) estimated that external health effects for criteria air emissions (including SO_X, NOx, CO, PM, VOC and NH_3) was 1.3 to 1.4 cents per VMT for automobiles using gasoline (and 10% ethanol RFG E10) (NRC 2010). Other vehicle fuels had similarly low external costs, ranging from 1.1 to 1.2 cents per VMT for compressed natural gas to 1.5 to 1.6 cents per VMT for hybrid electric vehicles. For 2007, the American Automobile Association (AAA) estimated that the average cost of automobile driving was 52.2 cents per VMT (AAA 2007). Comparing the NRC and AAA findings result in pollution costs that are roughly 2.5% of the direct out-of-pocket cost of driving.

Yet while the costs of external air emissions are small relative to the overall cost of driving, the total external costs imposed on society are substantial. In 2007, 3 trillion VMT (FHWA 2008) multiplied by the NRC (2010) average external cost of 1.3 cents per VMT results in an estimated overall external cost of $ 40 Billion, and this does not include the costs of greenhouse gas emissions. Measures to reduce this social cost should be considered to decrease this burden, particularly on those who choose not to drive and did not contribute to the problem but must deal with the consequences.

Costs of congestion exceed these air emission external costs. The Texas Transportation Institute (TTI) estimates that the cost of congestion was $87.2 billion in 2007, causing urban Americans to travel 4.2 billion hours more and to purchase an extra 2.8 billion gallons of fuel (TTI 2009). While literature such as TTI 2009 Urban Mobility Report evaluates costs of congestion in U.S. urban areas, urban pollution costs associated with driving and traffic congestion are not reported. The much-cited TTI report focuses mostly on time and fuel costs, and could benefit from the inclusion of estimates of pollution costs such as derived here.

In this paper, we estimate external air pollution costs of driving for 86 metropolitan areas utilizing air pollution valuation data (Muller 2007). These cities were chosen from the data reported by the TTI for 90 metropolitan areas (TTI 2009). Four areas from the TTI list of 90 urban areas were excluded due to lack of air pollution valuation data. In addition to the valuation of criteria air pollutants, we include carbon dioxide costs using existing literature on the social cost of carbon. Finally, we estimate the proportion of this external cost that is due to congestion.

2. Existing Transportation External Cost Assessments

The external costs of air emissions have been evaluated and the majority of the literature focuses on the U.S. and Europe. However, no study to date has performed a cross-urban comparison for a country to illustrate how costs can change from dynamics in vehicle travel to congestion effects. Several studies have quantified the economic costs associated with mortality, morbidity, and environmental impacts, among other external cost components. Small (1995) evaluates the regional air pollution costs for Los Angeles considering three main categories: mortality from particulates, morbidity from particulates, and morbidity from ozone. In this region, Small (1995) evaluates several cost accounting frameworks and produces a baseline estimate of 3.28 $¢_{1992}$/VMT. Mayeres (1996) develops external urban transportation costs for air pollution in addition to accidents and noise. For Brussels, Mayeres (1996) estimates air pollution costs at 21-29 $mECU_{1990}$/VKT (an ECU is a European Currency Unit which was replaced by the Euro in 2001) for gasoline cars and 15-30 $mECU_{1990}$/VKT for diesel cars. The study goes on to develop marginal congestion cost estimates under the concept that time is lost when an additional vehicle on the road reduces the speed to other road users. Air emissions external costs of 0.02, 0.04, 0.36, and 0.30 $£_{1993}$/VKT for diesel cars, light goods vehicles, buses/coaches, and heavy goods vehicles are developed by Maddison (1996) for the U.K. Maddison (1996) also considers congestion externalities through lost time evaluation to road users. Focusing on particulate and ozone pollution’s contribution to mortality and chronic illnesses, Delucchi (1999) develops air pollution related costs for light and heavy gasoline and diesel vehicles in the U.S. Additionally, Sen (2010) develops external air pollution cost estimates for Delhi at 0.28-0.31 Rs/VKT (Rs is Indian Rupees) for gasoline cars and 1.03-2.74 Rs/VKT for diesel cars. Some of these studies also develop total cost estimates for their region, similar to TTI (2009), which reports external economic impacts in the U.S. from congestion. While existing air pollution cost studies are sparse and often rolled up into more comprehensive externality assessments (including components such as noise, accidents, and value of time), several existing studies exist that provide some new methodological approaches for improving cost estimates.

Two recent studies quantify air pollution costs by evaluating high-resolution geographic-specific external cost data and improved emissions profiles that account for variations in speed and congestion effects. By combining U.S. county-level air pollution costs (Muller 1997) and vehicle travel, NRC (2010) develops external cost estimates for passenger and freight modes for over 3,000 U.S. counties. These costs range from 1.33-1.8 $¢_{2007}$/VMT for LDAs to 3.23-10.41 $¢_{2007}$/VMT for HDVs. Evaluating the San Francisco, Chicago, and New York City regions, Chester (2010) combines vehicle emission profiles that are dependent on speed and age with travel surveys to evaluate costs. Across the three cities and considering only private transit, the cost range from 0.5-64 $¢_{2008}$/vehicle-trip and are further disaggregated by off-peak and peak times as well as passenger loading. Chester (2010) goes on to include indirect and supply chain life-cycle effects in their assessment which can have larger impacts than emission from operating the vehicle.

Below, we provide a comparison of this study and these past studies with a conversion of all costs to 2008 cents per vehicle mile of travel.

3. Methodology for Estimating External Air Emissions Costs

The external air emissions costs are estimated here from national vehicle emission factors, metropolitan-specific travel data and metropolitan-specific external unit cost damage factors. Vehicle per mile emission factors are used to build regional emissions inventories in both uncongested and congested scenarios using travel data. These regional inventories are then joined with unit external cost damage factors for specific metropolitan areas to determine total damage costs. Carbon dioxide (CO_2), sulfur oxides (SO_X), nitrogen oxides (NO_X), particulates ($PM_{2.5}$), ammonia (NH_3) and carbon monoxide (CO) emissions are considered in this study due to the availability of pollution valuation data.

Vehicle emission factors were determined with the U.S. EPA's Mobile 6.2 (MOBILE6) software [EPA 2003]. MOBILE6 uses vehicle operation and fuel parameters to determine emissions from fuel combustion, evaporative losses, brake wear, and tire wear. The software evaluates the range of on-road vehicles including light and heavy-duty cars and trucks, motorcycles, and buses. For this study 2007 fleet light duty gasoline vehicles were included to match with the most recent TTI (2009) data year. Iterative runs were created in MOBILE6 to evaluate one mile-per-hour incremental speed changes, allowing an estimation of how emissions change when average speed changes due to congestion. All runs were configured with freeway conditions in July and a Reid Vapor Pressure of 8.7 psi. The resulting output was a grams-per-mile emission factor for each vehicle and pollutant at each mile-per-hour increment.

MOBILE6 has several weaknesses relevant to our goals, including failing to account for speed-specific fuel economy, emissions of SO_2, $PM_{2.5}$, and NH_3 or driving cycles specific to each metropolitan area. To capture the variation of fuel economy and CO_2 emissions with speed, the relationships developed by Ross (1994) were employed. The amount of fuel consumed by a vehicle and the resulting CO_2 emissions are the result of the power needed to overcome tire rolling resistance, air drag, vehicle acceleration, hill climbing, and vehicle accessory loads (Ross 1994). These factors in combination produce a fuel energy-to-speed profile that is used to adjust the MOBILE6 fuel economy and CO_2 emission baseline factors to develop speed-specific factors (Chester 2010, Ross 1994).

To convert the estimated air emissions to cost, the Air Pollution Emission Experiments and Policy (APEEP) analysis model was utilized. APEEP is designed to calculate the marginal human health and environmental damages corresponding to emissions of $PM_{2.5}$, VOC, NO_X, NH_3 and SO_2 on a dollar-per-ton basis (Muller 2007, NRC 2010). The APEEP model evaluates emissions in each U.S. County with their exposure, physical effects, and the resulting monetary damages. APEEP evaluates emissions at different release heights and the ground level subset is used to evaluate vehicle effects. For each county and each pollutant, APEEP estimates mortality, morbidity, and environmental (e.g., crop loss, timber loss, materials depreciation, visibility, forest recreation) damages. APEEP factors for a value of statistical life of $6M are used for this paper. Population weighted average APEEP factors are determined for each urban region analyzed in this study.

The cost of CO, since not provided by APEEP, was assumed to be $0.7/kg (Matthews 2001). This value was regionally scaled for each urban area analyzed using the ratios for NOx observed in the APEEP data, since both pollutants are predominantly tropospheric ozone precursors. CO_2

costs are based on a literature survey performed by NRC 2010. A summary of CO_2-eq units costs from roughly 50 studies shows a median cost of $10/ton, mean cost of $30/ton, and 5th and 95th percentile costs of $1 and $85/ton [NRC 2010]. The mean $30/ton cost is implemented for vehicle CO_2 emissions here.

Vehicle emission factors were increased by 4.9% annually for CO, 1.4% for NO_X, 4.5% for $PM_{2.5}$ and 5.9% for VOCs to capture the effects of fleet age and improving emissions trends due to more stringent emissions standards and improved fuel programs (Chester 2010). The average vehicle age is assumed to be 5 years (GREET 2008).

The above calculated emission factors and costs were then applied to the 2007 TTI mobility data (TTI 2009) for 86 urban areas. As previously discussed, four urban areas in TTI (2009) were discarded due to lack of valuation data in the APEEP model. Volume and speed (congestion and free flow) data utilized in the TTI report were all collected from freeway operation centers in various urban areas. TTI provides the percentage of miles travelled in each urban area during peak times and non-peak times. For non-peak miles, free flow speeds of 60 and 35 miles per hour (mph) for freeways and arterials, respectively, were used in this analysis. For peak times, TTI provides the percentage of travel that is congested and an average congested speed. Rather than unrealistically assuming constant speed under congested conditions, it was assumed that some percentage of vehicles operating during congested peak times drove at a stop and go speed of 5 mph and the remaining vehicles drove close to free flow speeds (free flow speed less one mile per hour). The percentages were estimated so that the weighted average speed matched the congested speed given by TTI. For non-congested peak travel, free flow speeds prevailed.

4. Results for External Air Emissions Costs

The total external air emissions costs of light duty vehicle travel for the 86 urban areas used in this analysis is estimated to be $145 million per day in 2007 U.S. dollars. This averages to around 1.7 million dollars per day per urban area. Normalizing the results by population and VMT, the external cost of driving is $0.64 per person per day or $0.03 per VMT. These estimates are higher than the national average of 1.3 cents/VMT in NRC (2010) because we are only considering urban areas and we are including a cost for carbon dioxide emissions. Table 1 shows a subset of the urban areas with the top 10 external costs (due to a combination of large populations and high external cost factors). The complete list of the external air emissions costs is available from the authors.

Table 8: External Air Emission Costs, population, per capita vehicle miles traveled, and percentage of peak travel that is congested of Driving for Top 10 Urban Areas

Urban Area	Million $/Day	$/Day/Person	$/VMT	Population	VMT/ person	% Peak travel congested
Los Angeles-Long Beach-Santa Ana CA	23	1.8	0.086	12,800,000	21	86
New York-Newark NY-NJ-CT	23	1.3	0.10	18,225,000	12	69
Chicago IL-IN	10	1.2	0.10	8,440,000	12	79
Philadelphia PA-NJ-DE-MD	4.9	0.9	0.058	5,310,000	16	63
Washington DC-VA-MD	4.6	1.1	0.057	4,330,000	19	81
San Francisco-Oakland CA	4.5	1.0	0.056	4,480,000	18	82
Atlanta GA	4.3	1.0	0.046	4,440,000	21	75
Dallas-Fort Worth-Arlington TX	4.2	0.95	0.042	4,445,000	23	66
Detroit MI	3.9	1.0	0.045	4,050,000	21	71
Houston TX	3.9	1.0	0.043	3,815,000	24	73
Total*	145			158,355,000		
Average*	1.7	0.64	0.034	1,841,000	19	48
Maximum*	23.0	1.8	0.10	18,225,000	30	86
Minimum*	0.038	0.18	0.013	145,000	10	8.0

***Average, total, maximum and minimum values are for all 86 urban areas.**

Los Angeles and New York have the largest population among the 86 urban areas and their total external emissions cost, each around $23 million/day, are roughly twice as large as the next largest cost area (Chicago, $10 million/day). After Chicago, another halving occurs to Philadelphia, Washington DC, San Francisco, and so on. The largest driver for having large external costs is clearly population, as 8 of the top 10 most populous metropolitan statistical areas (MSAs) are represented in the top external cost list—only Miami and Boston MSAs are not and they represent the 12^{th} and 13^{th} rank on external costs. Looking at the normalized data shows a wide variation between the top 3 areas—Los Angeles, New York, and Chicago—and the others, though some other areas have high per capita (Washington DC) or per VMT (Philadelphia) costs. The differences between normalized values are attributable to density and the APEEP factors, which evaluate pollutant transport, chemistry, and impact on nearby populations (Muller 2007).

Table 2 shows the $145 million total external emissions cost of driving and congestion disaggregated by pollutant for all 86 urban areas. Carbon dioxide emissions valued at $ 30/mt are comparable in external costs to VOCs, CO and NH_3 costs, while three other pollutants (nitrogen oxides, sulfur dioxide and particulates) have lower magnitudes.

Table 9: External Emissions Cost of Driving per Pollutant (Million $/Day)

	CO_2	NOx	VOCs	CO	SOx	PM	NH3
Total Cost of Driving	32	7.6	39	31	0.65	3.4	31

Figures 1 and 2 illustrate the total external air emission costs of driving and cost per VMT for each urban area.

Figure 1: Total External Air Emissions Cost of Driving for each Urban Area (Million $/Day)

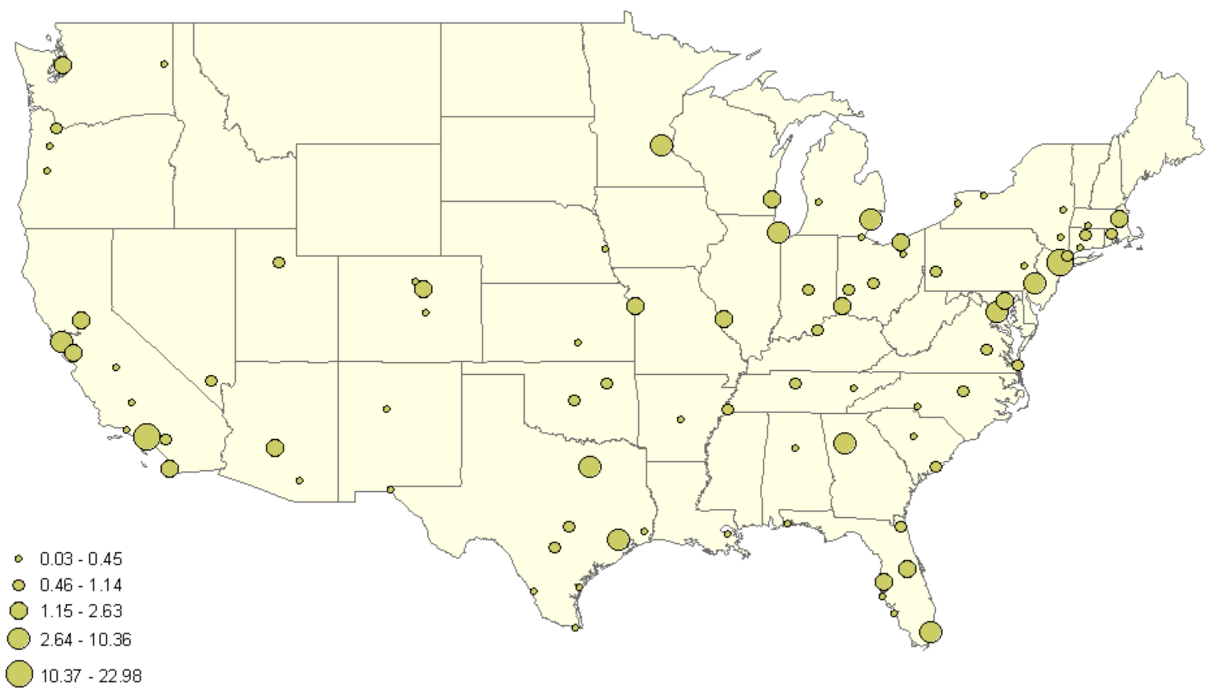
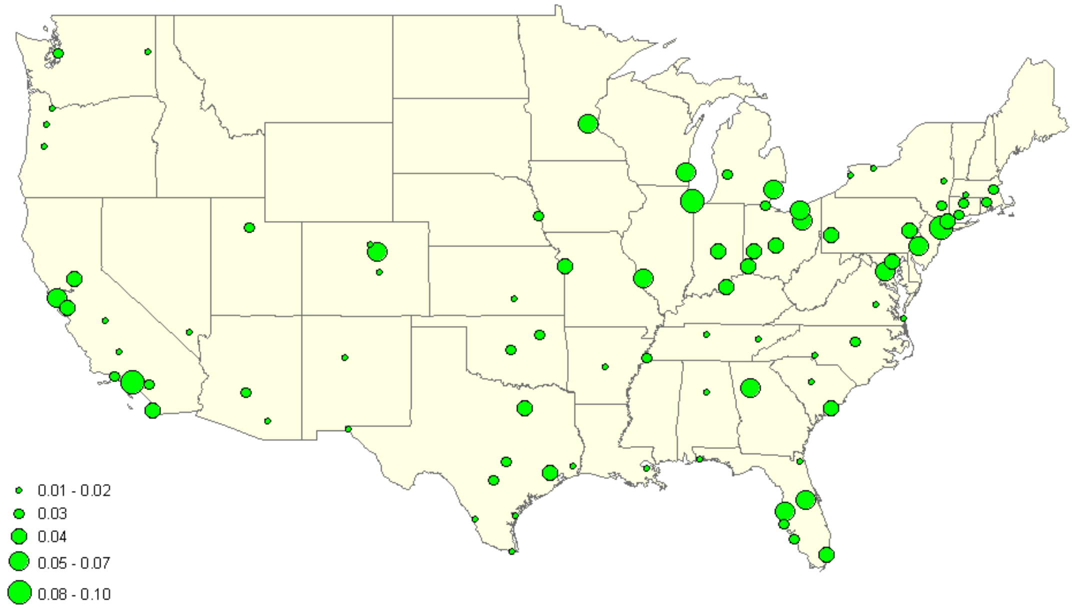


Figure 2: Total External Air Emissions Cost of Driving for each Urban Area ($/VMT)



Using all 86 regions, some explanatory variables were explored for potential causation, such as per kg cost factors for emissions, population density, VMT per capita, and percent of peak travel that is congested. The strongest correlations between per capita external costs were found to be the average damage factor for emissions (ρ = 0.76), percent of peak travel congested (ρ = 0.54), and per capita VMT (ρ = 0.30).

5. Comparison of Results for External Air Emissions Costs

The existing literature provides an opportunity to externally compare and validate results. The cost estimates in the literature typically focus on light duty vehicles and subsets of criteria air pollutants (some studies include GHGs). Relevant existing reported costs are shown in Table 10 and normalized to $¢_{2008}$/VMT:

Table 10: Comparison of External Cost Estimates

Study	Geographic Area	Vehicle Set	Air Pollutants Included	Cost in ¢$_{2008}$/VMT
This Study	U.S. Urban Areas	LDVs	CO_2, CO, NOX, SO_2, PM2.5, VOCs, NH_3	1.15 – 10.28
Small 1995	Los Angeles Region, U.S.	LDGVs	NOX, SOX, PM10, VOCs	2.12 - 18.28
Mayeres 1996	Brussels, Belgium	Gasoline Cars Diesel Cars	CO_2, CO, NOX, SOX, PM10, VOCs	7.25 - 11.51 5.28 - 10.37
Maddison 1996	U.K.	Diesel Cars	NOX, SOX, PM10, VOCs (+Benzene), Lead	2.80
Delucchi 1999 (1)	U.S.	LDGVs	O_3, CO, NO_2, PM, Toxics	0.89 - 11.83
Sen 2010	Delhi, India	Gasoline Cars Diesel Cars	CO, NOX, PM, HC	1.07 - 1.23 4.09 - 10.87
NRC 2010	U.S. Counties	LDAs	NOX, SOX, PM2.5, VOCs	1.37 - 1.87
Chester 2010 (2)	San Francisco, Chicago, & New York City, U.S.	LDVs	GHGs, CO, NOX, SO_2, PM10, VOCs	2.70 - 3.50

Notes: All costs are adjusted to ¢$_{2008}$ based on USBLS 2010. Currency conversion factors of 1.7 £$_{1993}$ per \$$_{1993}$, 1.3 ECU$_{1990}$ per \$$_{1990}$, and 44 Rs$_{2005}$ per \$$_{2005}$ are used. (1) The Delucchi (1999) cost range is for vehicle emissions while the study also reports upstream impacts. (2) The Chester (2010) cost range is for vehicle emissions only while the study also reports life-cycle emissions and associated costs.

The variation in estimates in the literature can be the result of many factors. The differing temporal and geographic boundaries imply varying vehicle emissions profiles. The vehicle fleet sets evaluated can also change emission profiles. Most studies acknowledge the uncertainty in estimating mortality and morbidity costs including the effects of using different values of statistical life. The air pollutant damages considered across the studies are also inconsistent. Some studies include human health impacts only while others capture climate, vegetation, visibility, material, and aquatic damages as well. While these factors lead to an inconsistency in external cost comparisons, the literature results produce a range of 5.1±4 ¢$_{2008}$/VMT. This range is consistent with the results of this study at 1.15-10.28 ¢$_{2008}$/VMT.

6. Estimation of External Air Emissions Costs Due to Congestion

By disaggregating congestion costs from total costs, external cost estimates associated with low-speed and higher per-VMT emissions were assessed. To calculate this cost, we started by using a non-congested scenario in which all miles in the urban areas are driven at free flow speeds to establish a baseline. The difference between the costs of this non-congested scenario and the existing costs of pollution at congested speed provides an estimate of the incremental external cost of congestion. Using a speed distribution profile where a fraction of vehicles drive at 5 mph during congested peak times and the remaining vehicles drive close to free flow speed, a weighted average congestion speed was determined that matches those reported by TTI (2009). This methodology is believed to provide a more realistic and accurate result than assuming a single congested speed applies to all vehicles driving during congested times.

Table 4 shows comparable estimates for the external air emissions costs due solely to congestion in urban areas. The total estimate of $24 million/day due to congestion is a portion of the $ 145 million/day in total external emission costs. These amounts are relatively small compared to travel time costs of congestion since emissions do not vary substantially with changes in average speeds. However, this small variation may be due to limitations in the MOBILE 6 model—as discussed above many of the emissions factors do not vary with speed. Nevertheless, they represent savings that could be realized in at least some portion by effective congestion management schemes.

Table 11: External Air Emission Costs of Congestion

Urban Area	Million $/Day	$/Day/Person	$/VMT	Population	VMT/ person	% Peak travel congested
Los Angeles-Long Beach-Santa Ana CA	5.3	0.42	0.020	12,800,000	21	86
New York-Newark NY-NJ-CT	4.4	0.24	0.020	18,225,000	12	69
Chicago IL-IN	1.3	0.15	0.012	8,440,000	12	79
San Francisco-Oakland CA	0.95	0.21	0.012	4,480,000	18	82
Washington DC-VA-MD	0.87	0.20	0.011	4,330,000	19	81
Atlanta GA	0.77	0.17	0.008	4,440,000	21	75
Houston TX	0.73	0.19	0.008	3,815,000	24	73
Dallas-Fort Worth-Arlington TX	0.72	0.16	0.007	4,445,000	23	66
Miami FL	0.71	0.13	0.008	5,420,000	17	82
Philadelphia PA-NJ-DE-MD	0.69	0.13	0.008	5,310,000	16	63
Total*	24			158,355,000		
Average*	0.28	0.08	0.004	1,841,000	19	48
Maximum*	145	0.42	0.02	18,225,000	30	86
Minimum*	0.03	0.0042	0.0002	145,000	10	8.0

***Average, total, maximum and minimum values are for all 86 urban areas.**

The top 10 highest external congestion cost cities are clearly quite similar to total costs—9 of the top 10 are on both lists. In terms of congestion Los Angeles and New York score high above all other cities, particularly related to per capita external costs where Los Angeles nearly doubles its closest competitor, $0.42/person-day compared to second-ranking New York at $0.24/person-day. As might be expected, the difference between the maximum and minimum per capita and per VMT cost values (~2 orders of magnitude) are higher for congestion costs than for total costs (~1 order of magnitude), since in some cities congestion is a much larger problem than others. Calculating similar correlations as for total costs, the most important variables explaining a high congestion cost were percent of peak travel congested (ρ = 0.84), pollution cost (ρ = 0.76), and population density (ρ = 0.52).

Table 5 shows the total external emissions cost of congestion for each specific pollutant for all 86 urban areas. NH3 and VOC have the largest estimated costs for criteria pollutants. Carbon dioxide valued at $ 30/mt shows the largest total of external cost due to congestion.

Table 12: External Emissions Cost of Congestion per Pollutant (Million $/Day)

	CO_2	NOx	VOCs	CO	SOx	PM	NH3
Total Cost of Congestion	9.4	0.4	6.9	2.0	0.0	0.0	0.0

Figures 3 and 4 graphically illustrate total external air emission costs due solely to congestion for each urban area and the cost per VMT.

Figure 3: Total External Air Emissions Cost of Congestion for each Urban Area (Million $/Day)

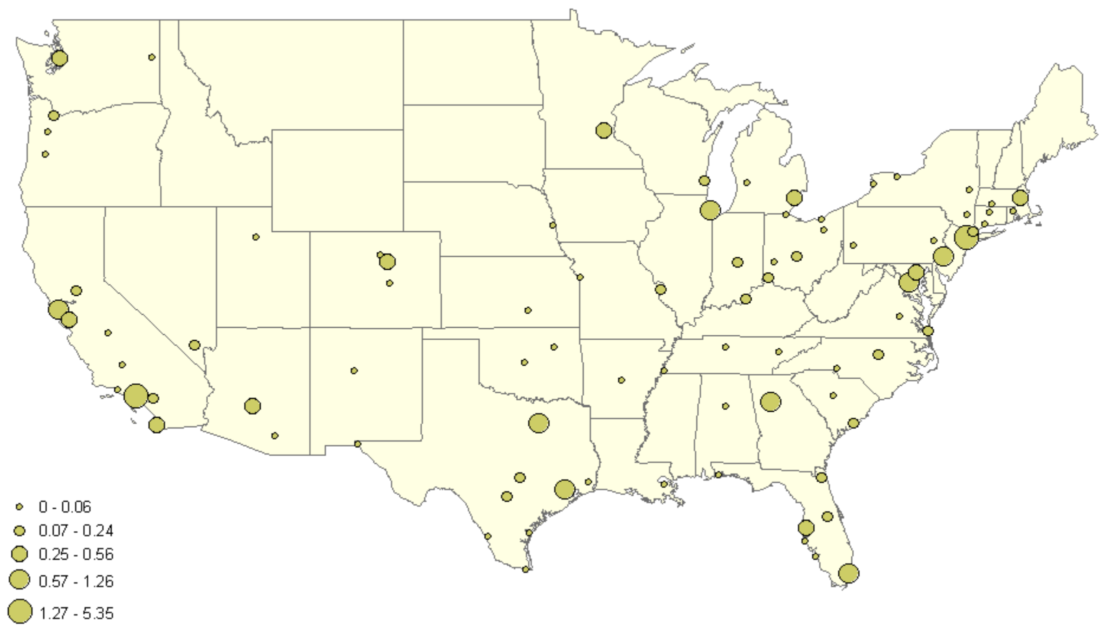
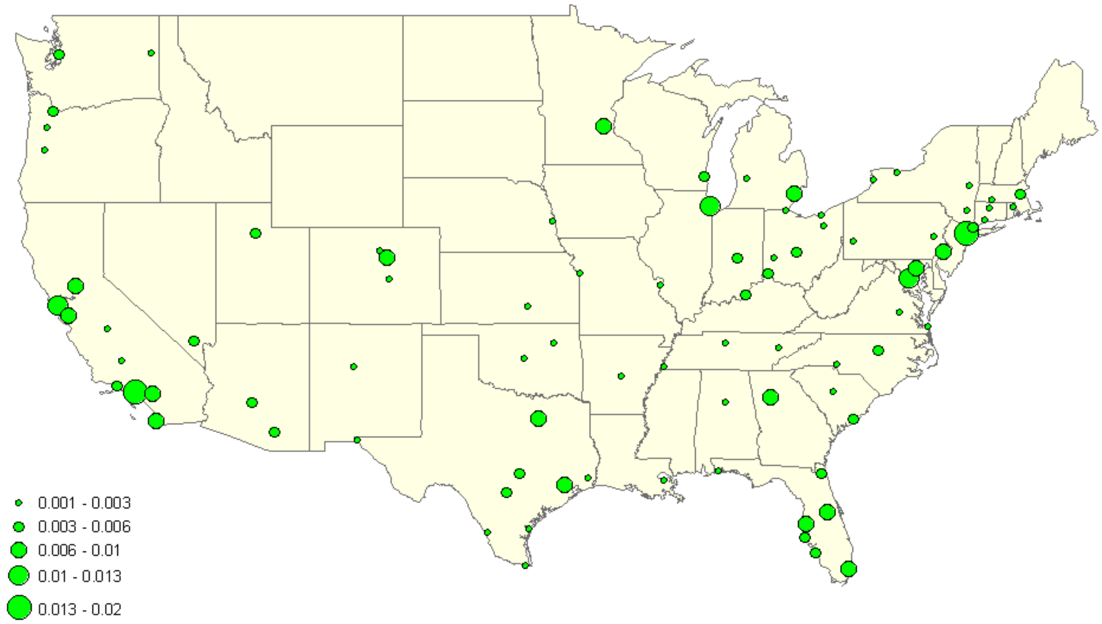


Figure 4: Total External Air Emissions Cost of Congestion for each Urban Area ($/VMT)



7. Conclusions

In this paper, we have estimated external air emissions costs associated with light vehicle automobile travel in urban metropolitan areas. These estimates can be used in benefit/cost studies to assess the benefits of travel reduction, congestion management and the like. While other external costs such as congestion time are larger in magnitude, the external air emission costs are still appreciable, amounting to $9 billion annually with a total cost of driving estimated at $ 53 billion annually. Thus, emissions due to congestion contribute roughly 10% of the total costs of urban congestion when compared to the estimate of $87 billion in 2007 by TTI (2009). Efforts to rein in congestion and decrease urban driving will clearly thus have important impacts on fuel consumption, time, and environmental damages.

Acknowledgements

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APPENDIX C

PDC'S PROPERTY PROFILE

te on per property - fill in as much information as possible.

GENERAL INFORMATION Date: ________________________

Name and title of person completing the profile: ________________________

Name of organization: ____

Address: ______________________ Phone number: _______________________

E-mail: ____

PROPERTY OWNER

Name of site (if applicable): ____

Address: Street: ____

City: ______________________________ Zip: ____________________

County: _________________ E-mail: _____________________________

Is the owner open to redevelopment options? Yes___No____Not sure____

SITE INFORMATION

Name of site (if applicable): ____

Address: Street: ____

City: ______________________________ Zip ____________________

County ____

Municipality: ____

Tax parcel ID# ______________________ Tax millage rate: ___________________

Are there any tax liens currently on the property? Yes___No____Not sure____

SITE INFORMATION (CONTINUED)

Are there any ongoing operations on the property? Yes___No____Not sure____

Size of property (acres): _______________________ Zoning: _______________________

Is the property more the 25% vacant? Yes___No____Not sure____

Number of structures on the property: 0_______ 1-5
5+________

Condition of structures: good (#_____) fair (#_____) poor (#_____) NS_____

Age of structures: < 10 yrs:_____ 10 to 20 yrs: _____ >20 yrs: ____ NS:
______

Does the property have historical value? Yes___No____Not sure
______

Has a phase I ESA been preformed? Yes___No____Not sure____

Has a phase II ESA been preformed? Yes___No____Not sure____

Has there been any US EPA or PA DEP environmental response to the site?

Yes___No____Not sure____

If YES please explain: ____

____

____

____

Describe surrounding uses/neighborhood:_________________________________

____

____

____

Please include pictures of the site, and if available, site plan, floor plan, and other report that might be available.

APPENDIX D – SITE ATTRIBUTE QUESIONNAIRE

Site Attribute Questionnaire

Pennsylvania Downtown Center and The Western Pennsylvania Brownfields Center at Carnegie Mellon is designing a multi-attribute decision making tool to assist in prioritizing sites in Core Communities for redevelopment. The tool will allow Keystone C.O.R.E Services (KCS) to optimize their site selection process by weighting criteria of local and immediate interest as they determine where to allocate **environmental assessment and predevelopment** funds.

KCS first develops a weighting system to emphasize what is important to them. Then the tool uses a comprehensive list of factors to measure a site's redevelopment potential and assigns each site a score. These scores are adjusted according to the weighting scheme dictated by KCS. The weighted scores are then ranked to determine which sites would yield the greatest benefit.

For your convenience, the survey has been split into two parts; the first part was the property profile you completed which is necessary for a score to be calculated. The second part is the site attribute questionnaire which is attached. The questionnaire asks for information which is publicly available. KCS will work with the community to fill out the questionnaire as completely as possible. The community's participation and input will help us to improve the questionnaire and prepare it for broad distribution.

Thank You,
Eddy Kaplaniak
Keystone C.O.R.E. Services

Before you begin

Omitted Answers

This questionnaire was designed to be as user friendly as possible; to that end there is the option to submit a "not sure" response. Please submit this answer if you are unsure instead of leaving the question blank.

It is important to remember that there is no right or wrong answer to each question, the questionnaire is meant to evaluate the situation, not test your knowledge of the site. Please only select one answer per question.

For some quantitative questions, the answers are split into sections, for example "5-10 years". If you know the exact answer, please write that down.

Understanding the "actors"

There are several key people in this prioritization process.

The decision maker – They use the tool to prioritize the sites and decide how the assessment/predevelopment funds will be allocated. The decision maker is the entity that has access to funding. In this case the decision maker is Keystone C.O.R.E. Services

The information provider – He or she completes the questionnaire for specific sites. This person is unbiased towards the site and understands the role the site plays in the community.

The site owner –It is not necessary for the site owner to be involved in the data collection or prioritization process unless their data is needed to provide an accurate survey of the site. Should their site be ranked among the top and chosen for fund allocation, then the owner should be notified and further steps can be taken.

Indicator Questions

A. Development Driver/Champion Indicator

The champion is an entity, preferably an individual, who takes on the role of the organizer, the instigator, the cheerleader and the connecter. He or she "drives" the redevelopment effort. They might be part of a private sector developer, a community-based organization, or a local redevelopment authority.

1. To what level has a developer (or other private sector investor) expressed an interest in the site?
   - ☐ Interested, and has funds for redevelopment
   - ☐ Interested, but does not have adequate funding
   - ☐ Somewhat, but only has a preliminary interest
   - ☐ No one has expressed an interest

2. OPTIONAL QUESTION 2: To what level has the municipality or other non-profit NGO expressed an interest in the site?
   - ☐ Interested, and has funds for redevelopment
   - ☐ Interested, but does not have adequate funding
   - ☐ Somewhat, but only has a preliminary interest
   - ☐ No one has expressed an interest

B. Development Potential Indicator

This indicator assesses the likelihood that a site will be redeveloped. There are five sub-indicators within development potential: end use, funding, time, labor market and property ownership. Using your answers, we will be able to assess what sites stand a better chance of redevelopment.

End Use

The end use plan is a realistic plan that integrates important details like current land use, demographics, community master plans, historical development patterns, etc… The existence of an end use plan indicates that site champions have put some level of thought into the site.

3. How consistent is the proposed end use with the surrounding land use?
   - ☐ Very consistent
   - ☐ Consistent

- ☐ Somewhat consistent
- ☐ Inconsistent
- ☐ No end use has been determined

4. Given today's economic and development climate in the area, how beneficial will the proposed end use be to the community?
   - ☐ Very beneficial
   - ☐ Beneficial
   - ☐ Neither beneficial nor detrimental
   - ☐ Detrimental
   - ☐ No end use has been determined

5. How many long term jobs would be supported on this site?
   ☐ 0 – 25 ☐ 26 – 50 ☐ 51 – 75 ☐ 76 – 100 ☐ 100 +

Funding

Finding sufficient funding for a project can be challenging due to a variety of reasons, including the lenders' fear of environmental liabilities. However, there are a variety of available funding sources – both public and private – that are specifically targeted at brownfields.

6. Are there at least partial funds for the environmental investigation?
   ☐ Private ☐ Public ☐ Both ☐ None ☐ Completed
7. Are there at least partial funds for the environmental remediation?
   ☐ Private ☐ Public ☐ Both ☐ None ☐ Completed
8. Are there at least partial funds for pre-development costs; such as engineering and permitting?
   ☐ Private ☐ Public ☐ Both ☐ None ☐ Completed
9. Are there at least partial funds for construction costs?
   ☐ Private ☐ Public ☐ Both ☐ None ☐ Completed

Time

Please answer the following questions as if the necessary funds were available.

10. If the environmental investigation would begin today, how long would it take to complete? (in months)
    ☐ 0 – 6 ☐ 7 – 12 ☐ 13 – 18 ☐ 18 – 24 ☐ 25 +

11. Estimated time to complete the remediation (in months)

☐ 0 – 6 ☐ 7 – 12 ☐ 13 – 18 ☐ 18 – 24 ☐ 25 +

12. Estimated time to complete the infrastructure (in years)

☐ 0 – 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 +

Property Ownership

The number of owners a piece of property potentially influences the ease of property acquisition. Getting permission from the owner(s) to assemble all sites and/or occupy them can be challenging.

13. How many entities own the property of interest?

☐ 0 ☐ 1 ☐ 2 ☐ Multiple ☐ Unknown

14. Has a plan that includes site acquisition, site assembly, etc. been completed?

☐ Yes ☐ No ☐ Not sure

Community Support

Brownfields have been shown to be an integral component of the fabric of the communities in which they sit. Historically, community involvement has an obstructionist reputation – especially in federally influenced redevelopment activities. But due to the complexity of the site histories, legal and financial issues and environmental contamination, community engagement is very important to brownfield redevelopment.

15. How supportive is the surrounding community of the redevelopment plan for this specific site **(generally speaking)**?
    - ☐ Very supportive
    - ☐ Supportive
    - ☐ Indifferent
    - ☐ Unsupportive
    - ☐ Very unsupportive
    - ☐ No current redevelopment plan exists

16. How interested is the community in promoting brownfield development **(generally speaking)**?
    - ☐ Very interested
    - ☐ Interested
    - ☐ Indifferent

- ☐ Uninterested
- ☐ Very uninterested

Quality of Life

Many times, and especially in older communities, the land occupied by brownfields can be a key asset to the community.

17. If the end use is determined, will the redevelopment provide more recreational opportunities for the community?
    - ☐ Many more recreational opportunities
    - ☐ Some recreational opportunities
    - ☐ No recreational opportunities
    - ☐ No end use has been determined

18. If the end use is determined, will the redevelopment provide more green space for the community?
    - ☐ Much more green space
    - ☐ Some green space
    - ☐ No green space
    - ☐ No end use has been determined

C. Environmental Indicator

The environmental indicator is designed to estimate both the likelihood and magnitude of environmental contamination of a site, either real or suspected. It is often very difficult and laborious to get site specific environmental data related to potential contamination, so we used the following qualitative metrics to assess the potential level of environmental impact and implications for public health.

Contamination

19. Is there any perceived contamination on the site?

    ☐ Yes ☐ No

    If YES, please check all relevant Hazardous/Petroleum products
    - ☐ Controlled Substances
    - ☐ Asbestos
    - ☐ PCBs - Polychlorinated Biphenyls (see appendix A for more information)
    - ☐ VOCs -Volatile Organic Compounds (see appendix A for more information)
    - ☐ Lead
    - ☐ PAHs - PPolycyclic Aromatic Hydrocarbons (see appendix A for more information)

- ☐ Radioactive materials
- ☐ Other Metals: ______________________
- ☐ Other Contaminants: _________________

20. Please give the number of documented releases of contaminants from the site:

☐ 0 ☐ 1 ☐ 2 ☐ Multiple ☐ Unknown

Previous Use of Site

Identifying and documenting the historical uses of the site can play an important role in estimating the source and type of contamination with the eventual goal to determine an appropriate remediation strategy.

21. Please check the types of activities that the site has been used for:
    - ☐ Industrial – What type of industry? ____
    - ☐ Residential
    - ☐ Commercial - What type of commercial? ____
    - ☐ Green Space
22. Is the previous/current owner a documenter polluter?

    ☐ Yes ☐ No ☐ Not sure
23. How long has the site been vacant? (in years)

    ☐ 0 ☐ 1 – 5 ☐ 6 – 10 ☐ 11 – 15 ☐ 16 +
24. How long has the site been underutilized? (in years)

    ☐ 0 ☐ 1 – 5 ☐ 6 – 10 ☐ 11 – 15 ☐ 16 +
25. Are there any deed restrictions on the property?

    ☐ Yes ☐ No ☐ Not sure

Public Utilities

Does the site have curb connection/access to the following?

26. Municipal water:

    ☐ Yes ☐ No

27. Power grid:

    ☐ Yes ☐ No

28. Sewage system:

    ☐ Yes ☐ No

29. Septic:

☐ Yes ☐ No

30. Cable/DSL:

☐ Yes ☐ No

31. Phone:

☐ Yes ☐ No

32. Cellular service:

☐ Yes ☐ No

33. Fiber Optic:

☐ Yes ☐ No

D. Market Information

Labor Market

The population that is available for the 'labor market' is defined as the population that is between ages 16 and 64.

1) In Pennsylvania, the statewide average unemployment rate is 8.5%[i]. How would you describe your municipality's unemployment rate?

   ☐ lower ☐ approximately the same ☐ higher

2) If you know the unemployment rate for your municipality, please provide it here:_______________%

3) The percentage of Pennsylvanian residents, 25 years of age and older, with at least a high school diploma is 81.9%. The percentage of your municipality's population, 25 years and older, with at least a high school diploma is…

   ☐ lower ☐ approximately the same ☐ higher

Property and Wage Values

In order to better understand the surrounding community in which the brownfield site is located, please provide answers to the comparisons of this site with other (non-brownfield) properties in the area.

4) What is the difference in the surrounding property values from that of this site?
   a) Surrounding property values are significantly higher than site's

b) Surrounding property values are moderately higher than site's
c) Surrounding property values are slightly higher than site's
d) Surrounding property values are comparable to site's
e) Surrounding property values are lower than sites

5) What is the difference in potential tax revenue from surrounding sites from that of this site?
a) Surrounding properties have significantly higher tax revenue than site's
b) Surrounding properties have moderately higher tax revenue than site's
c) Surrounding properties have slightly higher tax revenue than site's
d) Surrounding properties tax revenue is comparable to site's
e) Surrounding properties have lower tax revenue than site's

Environmental Justice

As defined by the EPA, environmental justice "will be achieved when everyone, regardless of race, color, national origin or income, enjoys the same degree of protection from environmental and health hazards and equal access to the decision-making process to have a healthy environment in which to live, learn, and work"Redeveloping brownfields may be a step towards achieving environmental justice.

6) In Pennsylvania, the statewide percent of people identified as non-white is 14.3%. How would you describe your municipality's percentage of non-white people?
☐ lower ☐ approximately the same ☐ higher

7) In Pennsylvania, the statewide percent of residents below the poverty line is 11.6%. How would you describe your municipality's percentage of residents below the poverty line?
☐ lower ☐ approximately the same ☐ higher

8) In Pennsylvania, the statewide percent of rental units is 28.7%. How would you describe your municipality's percentage of rental units?
☐ lower ☐ approximately the same ☐ higher

Location

The locations referred to in the following series of questions are all centers of human activity and/or important resources for the community. The distance that contamination lies away from these locations may dictate the urgency of remediation. **Note that if all of the brownfields you are comparing are in the same area geographically, the answers to the below questions would all be the same and so it is unnecessary to fill them out.**

9) Please give the shortest distances (in miles) to each as accurately as possible.

Distance to:
a) Schools: ________________________ miles
☐ 0 – 2 ☐ 3 – 5 ☐ 6 – 8 ☐ 9 – 11 ☐ 12 +

b) Public recreation areas ________________________ miles
☐ 0 – 2 ☐ 3 – 5 ☐ 6 – 8 ☐ 9 – 11 ☐ 12 +

c) Properties with high market value: ____________________miles
☐ 0 – 2 ☐ 3 – 5 ☐ 6 – 8 ☐ 9 – 11 ☐ 12 +

d) Residential neighborhoods: ___________________________ miles
☐ 0 – 2 ☐ 3 – 5 ☐ 6 – 8 ☐ 9 – 11 ☐ 12 +

e) Closest water source (river, lake, stream): ____________________________ miles
☐ 0 – 2 ☐ 3 – 5 ☐ 6 – 8 ☐ 9 – 11 ☐ 12 +

Infrastructure Indicator

The infrastructure indicator estimates the availability of infrastructure adjacent to a site. A great benefit of redeveloping brownfields instead of greenfields is that brownfields will often have existing infrastructure. The required resources for creating new infrastructure on a greenfield may be saved and used to improve other areas of a brownfield. **Note that if all of the brownfields you are comparing are in the same area geographically, the answers to the below questions would all be the same and so it is unnecessary to fill them out.**

10) Please give the distances (in road miles) to each as accurately as possible. Distance to:

a) Interstate
☐ 0 – 2 ☐ 3 – 5 ☐ 6 – 8 ☐ 9 – 11 ☐ 12 +

b) Highway
☐ 0 – 2 ☐ 3 – 5 ☐ 6 – 8 ☐ 9 – 11 ☐ 12 +

c) Railway
☐ 0 – 2 ☐ 3 – 5 ☐ 6 – 8 ☐ 9 – 11 ☐ 12 +

d) River
☐ 0 – 2 ☐ 3 – 5 ☐ 6 – 8 ☐ 9 – 11 ☐ 12 +

e) Airport
☐ 0 – 2 ☐ 3 – 5 ☐ 6 – 8 ☐ 9 – 11 ☐ 12 +

f) In what condition are the access roads?
☐ Excellent ☐ Good ☐ Fair ☐ Poor

Thank you for completing the WPBC Brownfield Prioritization Method Questionnaire

What happens next?

You're done!

Thank you so much for the time and effort that you've put into this part.

The information's journey

The information gathered will be scored and weighted according to the preferences KCS has defined. The final score will ultimately be ranked against the scores of yours and other sites. You will receive a report of the final scores.
Thank you for your patience and continued support. In the near future, the questionnaire and tool will be put online for your convenience. Feel free to contact us if you have any questions or concerns.

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Appendix A

Polychlorinated Biphenyls
Although no longer commercially produced in the United States, PCBs may be present in products and materials produced before the 1979 PCB ban. Products that may contain PCBs include:

- Transformers and capacitors
- Other electrical equipment including voltage regulators, switches, reclosers, bushings, and electromagnets
- Oil used in motors and hydraulic systems
- Old electrical devices or appliances containing PCB capacitors
- Fluorescent light ballasts
- Cable insulation
- Thermal insulation material including fiberglass, felt, foam, and cork
- Adhesives and tapes
- Oil-based paint
- Caulking
- Plastics
- Carbonless copy paper
- Floor finish

The PCBs used in these products were chemical mixtures made up of a variety of individual chlorinated biphenyl components, known as congeners. Most commercial PCB mixtures are known in the United States by their industrial trade names. The most common trade name is Aroclor. *– U.S. EPA website*

Volatile Organic Compounds
VOCs are organic compounds that can be isolated from the water phase of a sample by purging the water sample with inert gas, such as helium, and, subsequently, analyzed by gas chromatography. Many VOCs are human-made chemicals that are used and produced in the manufacture of…

- paints
- adhesives,
- petroleum products
- pharmaceuticals
- refrigerants

They often are compounds of

- fuels
- solvents
- hydraulic fluids
- paint thinners
- dry-cleaning agents

VOC contamination of drinking water supplies is a human-health concern because many are toxic and are known or suspected human carcinogens. **-** *U.S. Geological Survey, 2005*

Polycyclic Aromatic Hydrocarbons
PAHs are a group of chemicals that are formed during the incomplete burning of coal, oil, gas, wood, garbage, or other organic substances, such as tobacco and charbroiled meat. There are more than 100 different PAHs. PAHs generally occur as complex mixtures (for example, as part of combustion products such as soot), not as single compounds. PAHs usually occur naturally, but they can be manufactured as individual compounds for research purposes; however, not as the mixtures found in combustion products. As pure chemicals, PAHs

generally exist as colorless, white, or pale yellow-green solids. They can have a faint, pleasant odor. A few PAHs are used in medicines and to make dyes, plastics, and pesticides. Others are contained in asphalt used in road construction. They can also be found in substances such as crude oil, coal, coal tar pitch, creosote, and roofing tar. They are found throughout the environment in the air, water, and soil. They can occur in the air, either attached to dust particles or as solids in soil or sediment.

Although the health effects of individual PAHs are not exactly alike, the following 17 PAHs are considered as a group in this profile:

- acenaphthene
- acenaphthylene
- anthracene
- benz[a]anthracene
- benzo[a]pyrene
- benzo[e]pyrene
- benzo[b]fluoranthene
- benzo[g,h,i]perylene
- benzo[j]fluoranthene
- benzo[k]fluoranthene
- chrysene
- dibenz[a,h]anthracene
- fluoranthene
- fluorene
- indeno[1,2,3-c,d]pyrene
- phenanthrene
- pyrene

These 17 PAHs were chosen to be included in this profile because (1) more information is available on these than on the others; (2) they are suspected to be more harmful than some of the others, and they exhibit harmful effects that are representative of the PAHs; (3) there is a greater chance that you will be exposed to these PAHs than to the others; and (4) of all the PAHs analyzed, these were the PAHs identified at the highest concentrations at NPL hazardous waste sites. – *Center of Disease Control - Agency for Toxic Substances and Disease Registry*

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[i] U.S. Bureau of Labor Statistics, February 2011