VTrans Vermont Agency of Transportation

Report on Shared-Use Path and Sidewalk Unit Costs

Updated November 2010

Photo by Ben DeFlorio http://defloriophotography.com/

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A. Introduction

This report is intended to provide basic unit cost (per foot) information for bicycle or pedestrian facilities and to provide some basic bid costs for items commonly included on projects that provide improved facilities for bicycling or walking. The report builds on the results of a previous Cost Report completed in 2006. The previous report focused on updating cost estimates to be more reflective of typical bid item quantities and total project costs experienced on sidewalk and shared use path projects. This report includes those subjects but also provides more detailed information on project engineering costs, as well as new research regarding on-road bicycle lane costs.

B. Intended use of this data

VAOT staff, RPCs, and municipalities often need to know what the relative cost of proposed bicycle and/or pedestrian infrastructure will be. At the local level, a community may be considering making improvements with a given amount of money and need to determine how much they will be able to accomplish. RPCs sometimes perform or hire consultants to perform feasibility studies for projects in member towns and need to determine if cost estimates are reasonable. VAOT staff often review applications for bicycle or pedestrian improvement projects and must judge whether presented construction costs are reasonable. VAOT staff may also need preliminary costs when considering the inclusion of bicycle or pedestrian facilities as part of a roadway, bridge, or other transportation project. **The information in this report should be used for planning or checking purposes only and is not intended to substitute for "good engineering judgment" and detailed project cost estimates. The latest VAOT Five Year Averaged Price List or Estimator software should be consulted for detailed engineering estimates.**

C. Unit Construction Costs

The unit costs for different configurations of shared-use paths and sidewalks have been factored to include typical project items such as fencing, drainage, lighting, landscaping, mobilization, signs, etc. They **do not account** for extreme topographic conditions, structures (bridges, retaining walls, tunnels), and other site-specific conditions that would result in increased construction expense.

The following assumptions for typical sections were used to develop the unit costs for different sidewalk and shared-use path unit costs:

All sidewalks – 12" of sub-base material
Concrete sidewalks – 5" thick concrete
Bituminous sidewalks – 2" thick lift
Aggregate sidewalks – 3" compacted material

All shared-use paths – 6” of sand or earth and 12” of gravel sub-base material
Bituminous paths – 2” thick lift
Aggregate paths – 4” compacted material

An additional resource to use for early planning of projects is the VAOT Standard Drawings. A full listing of these drawings can be found on the Agency web site at http://www.aot.state.vt.us/CADDhelp/DownLoad/Standards/Standards.htm.

When referencing this data, please cite the source as the VTrans Bicycle and Pedestrian Program Unit Cost Database.

The tables of unit costs represent construction costs only and do not include other costs associated with developing a shared-use path or sidewalk project (see Section D. Other Costs). The following costs include an allowance for associated items such as limited drainage work, signs, fencing, pavement markings, and limited landscaping.

Sidewalk Costs

Although sidewalk and curb can be constructed as a standalone project, it is often included as part of a roadway, bridge or utility project. Savings can result when a sidewalk is incorporated into a larger more comprehensive infrastructure project: when common materials such as concrete or aggregate are purchased in large quantities, the per-unit price is often lower, and when project engineering is completed for a larger project, the ratio of project engineering costs to total costs decreases. The use of different types of curbing, primarily granite compared to concrete, is often a decision that communities struggle with. Although granite curbing has a slightly higher initial cost than concrete, the life cycle cost should be considered. Granite curbing has superior durability and aesthetic qualities and is the preferred curbing treatment in Vermont.

Current prices will be compared to prices and cost estimates from the 2006 Cost Report; unsurprisingly, costs have risen in the previous four years. In Table 1, the per-foot costs of basic construction items and total construction costs for various configurations of sidewalks and paths are compared to each other and to the results of the 2006 Cost Report. Costs are based on a combination of prices recorded in bid analyses over the past four years as well as VTrans Estimator software. Configurations marked with an *asterisk indicate that no projects with this particular configuration were completed during the past four years.

Table 1

Sidewalk/curb configurations (All walks are 5 feet wide)	Total cost per foot	Basic cost per foot	2006 Total cost per ft	2006 Basic cost per ft
Concrete walk with granite curb	$218.00	$79.00	$140.00	$67.00
Concrete walk with concrete curb	$180.00	$65.00	$132.00	$63.00
Concrete walk with no curb	$131.00	$47.00	$87.00	$42.00
Bituminous walk with granite curb	$185.00	$67.00	$106.00	$51.00
*Bituminous walk with concrete curb	$148.00	$53.00	$98.00	$47.00
*Bituminous walk with no curb	$99.00	$36.00	$52.00	$23.00
*Aggregate walk with granite curb	$160.00	$58.00	$94.00	$45.00
*Aggregate walk with concrete curb	$123.00	$44.00	$86.00	$41.00
*Aggregate walk with no curb	$74.00	$27.00	$40.00	$19.00

“Basic” costs of sidewalk construction are only the items that are required to build the sidewalk itself, such as gravel sub-base, concrete, and granite curbing, as well as the excavation of the area in which the sidewalk is built. The “total” cost reflects the combined cost of sidewalk construction with other costs that are incidental to the construction. For example, pavement markings, new signs, traffic control, drainage, and landscaping are included in the non-basic costs.

Figures 1 and 2 show the per-unit prices for various items required for basic sidewalk construction. Typically, these items are the “big-ticket” items, the ones that take up the bulk of construction costs. The per-unit prices from the 2006 Cost Report are shown alongside the per-unit costs obtained from the AASHTO Trns.Port Estimator software used by VTrans and other groups for creating preliminary cost estimates, and the average of actual costs of items in projects completed from 2004 – 2010. The price for all items has increased, with the exception of cast-in-place concrete curb and concrete sidewalk. Estimator figures generally exceed prices from the LTF bid history data.

Bituminous costs are shown in a separate graph (Figure 2), only because VTrans standards dictate that costs for bituminous concrete be measured in tons, which makes the per-unit prices and the per-unit price changes look much larger than the prices and price changes for other items. In general, the price of installation for a bituminous sidewalk is comparable, but slightly cheaper, than that of a concrete sidewalk; however, bituminous walks and paths also tend to require more maintenance and have a shorter service life than concrete.

Figure 1

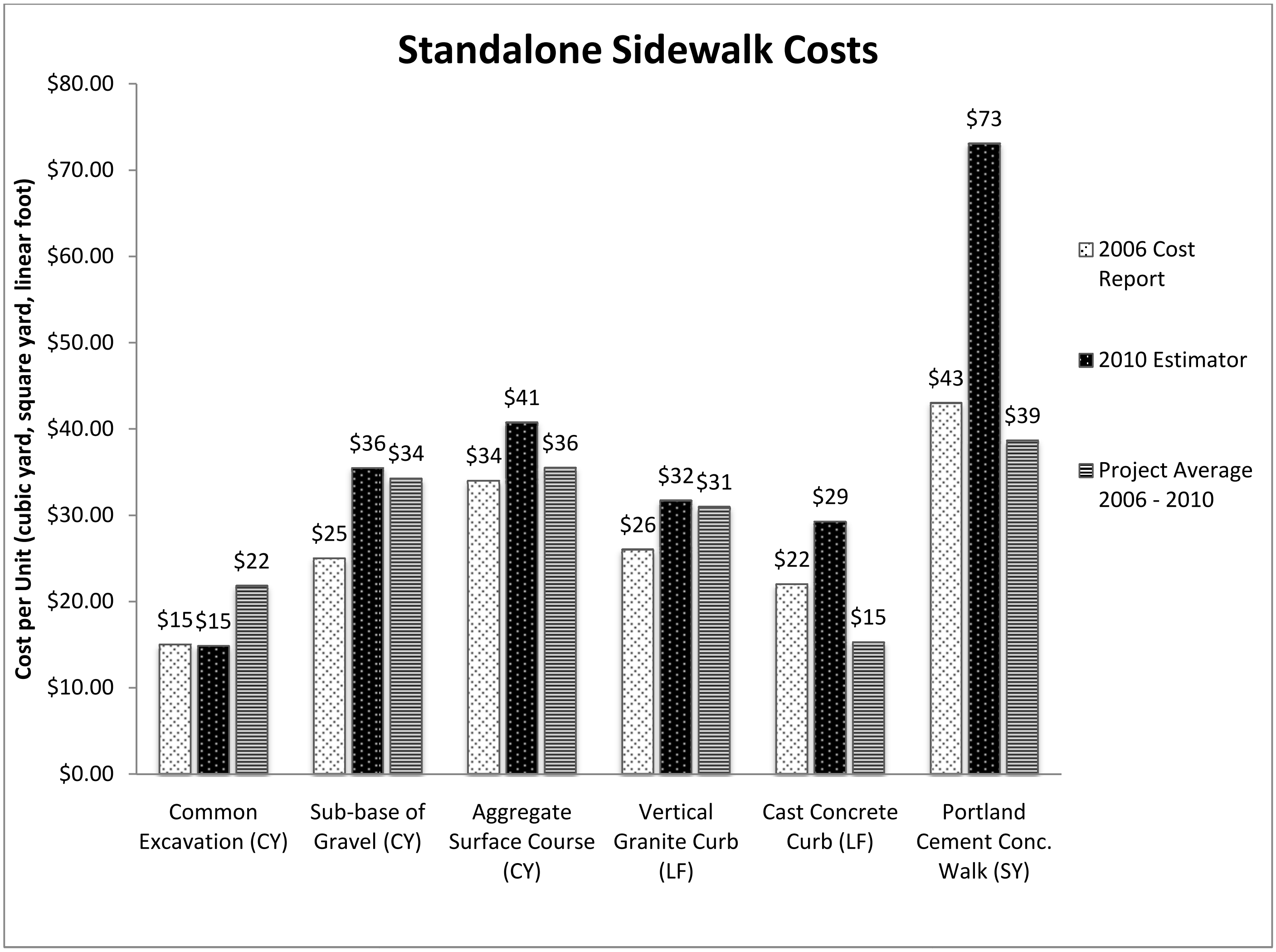
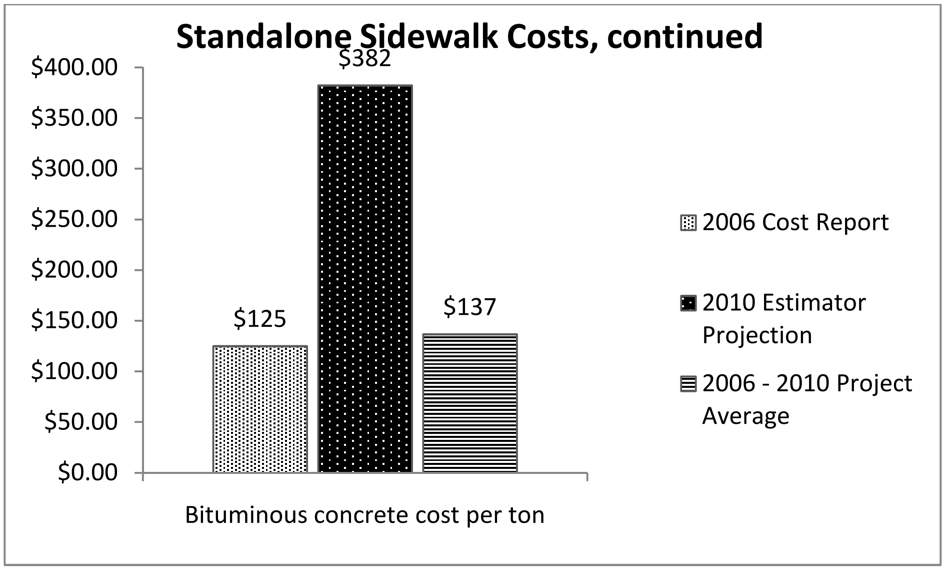

Standalone Sidewalk Costs
Cost per Unit (cubic yard, square yard, linear foot)
$80.00
$70.00
$60.00
$50.00
$40.00
$30.00
$20.00
$10.00
$0.00
$15
$15
$22
$25
$36
$34
$34
$41
$36
$26
$32
$31
$22
$29
$15
$43
$73
$39
Common Excavation (CY)
Sub-base of Gravel (CY)
Aggregate Surface Course (CY)
Vertical Granite Curb (LF)
Cast Concrete Curb (LF)
Portland Cement Conc. Walk (SY)
2006 Cost Report
2010 Estimator
Project Average 2006 - 2010

Figure 2



Shared Use Path Costs

Since 2004, only three projects have been built that incorporate a shared use, or bike path. Of these three projects, one, the West Rutland project from 2006, did not use VTrans standard item codes, so that project was excluded from this study as there was no way to make sure that prices listed on the West Rutland bid corresponded to the prices used by VTrans in other projects and in the Estimator software. Because of the lack of new data, average prices used to generate per-foot and per-unit costs for shared use paths incorporate data drawn from sidewalk projects for items that are common to both types of project, as well as some data from projects built in years prior to 2004, which were also included in the 2006 cost report. All prices from projects built prior to 2010 have been indexed to inflation. Basic and total costs for building a shared-use path are shown in Table 2.

Table 2

Bike path configurations	Total cost/ft	Basic cost/ft	Cost per ft. (2006)	Basic/ft (2006)
8-foot wide bituminous concrete path	$231.00	$72.00	$116.00	$38.00
10-foot wide bituminous concrete path	$265.00	$82.00	$132.00	$43.00
12-foot wide bituminous concrete path	$297.00	$92.00	$150.00	$49.00
8-foot wide aggregate surface path	$200.00	$62.00	$98.00	$32.00
10-foot wide aggregate surface path	$225.00	$70.00	$111.00	$37.00
12-foot wide aggregate surface path	$249.00	$77.00	$124.00	$41.00

Figures 3 and 4 show the per-unit costs of basic construction items associated with the construction of shared use paths. As with sidewalk item costs, bituminous concrete costs, which are measured by the ton rather than the cubic yard, are shown in a separate graph.

Figure 3

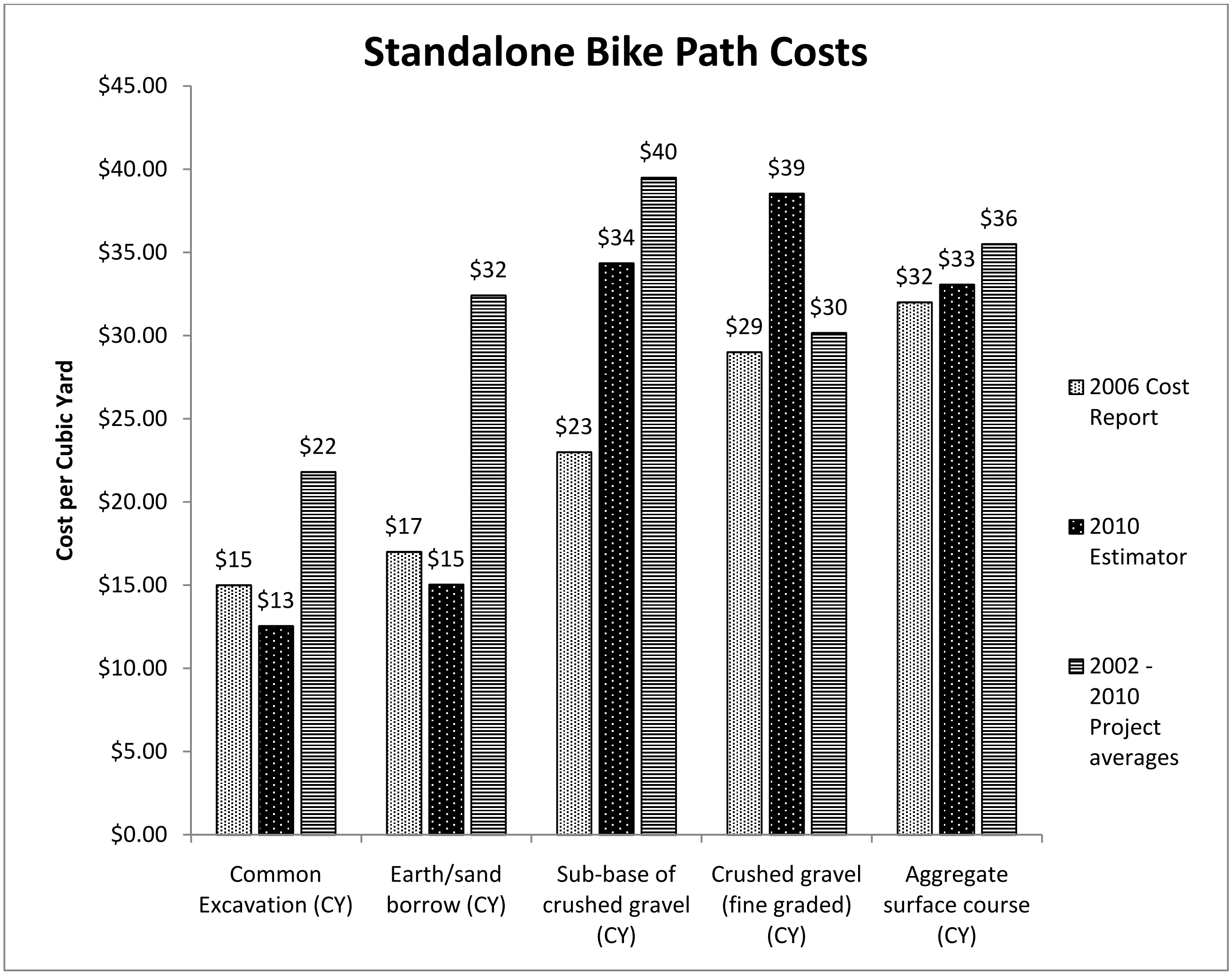
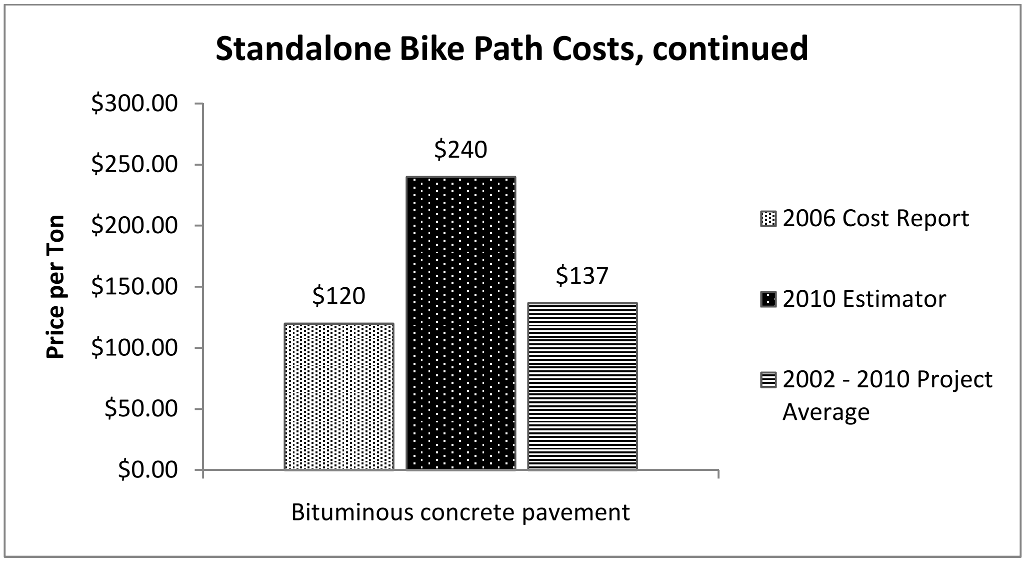


Figure 4



According to Vtrans project managers, the items whose prices fluctuate the most are bituminous concrete and granite curbing. Since bituminous concrete contains liquid asphalt, its price tends to fluctuate along with the price of a barrel of oil. Granite curbing prices fluctuate according to availability. Another example was the 2010 shortage of titanium dioxide (a white pigment) that led to a jump in the price of white pavement markings.

On-Road Bicycle Lanes

There is a paucity of research on the costs of installing bicycle lanes on already existing roadways. This is partially because such projects are rarely undertaken as a stand-alone project, but are usually included as a part of a project with a broader scope of work. Where adequate width exists, the primary cost of converting an existing paved shoulder to a bike lane is the addition of bike lane symbols and some new signs. Note that in the 2009 MUTCD signs are no longer required to be included as part of on-road bike lanes.

The 2006 cost report puts on-road bicycle lane construction between $4,000 and $9,000 per mile. The primary source of the variability in these estimates is durable pavement markings, such as thermoplastic, as opposed to regular paint. Durable pavement markings can be many times as expensive as standard paint.

The town of Shelburne recently completed adding a total of four miles of bike lanes to Spear Street, at a cost of approximately $76,000 per mile. This included adding five feet of shoulder to each side of the road, in addition to a two foot wide gravel shoulder.[1] Using VTrans average bid prices, a cost of $300,000 per mile for the same type of work was estimated. This is typical of the difference seen between prices of projects done at the local level compared with contracts put out by the state.

The FHWA BIKESAFE project compiled research in 2006 indicating a very wide cost range for adding bike lanes, which, adjusted for inflation,[2] would be between $5,411 and $54,111 per mile.[3] The price can change depending on the condition of the pavement, the degree of repainting necessary, the need for upgraded or new signs and the location of the road. One reason that the cost of bike lanes is so variable is that if road widening is necessary, the conditions encountered e.g. ledge, re-ditching or the need for additional Right of Way, will be different in every situation. As was mentioned before, the most cost effective way to add a bike lane is to include it as an element of a new road construction, or road resurfacing or reconstruction project.

For example, the city of South Burlington included bike lanes as part of major road reconstruction projects on Shelburne Road and on Kennedy Drive. These projects involved adding extra lanes to the existing road, necessitating significant expenditures for right of way, excavation, repaving, and moving utilities. In this case, the cost of adding eight extra feet of excavation, paving, and striping was relatively low compared to the overall cost of the projects.[4]

The estimates provided below take these conditions into account. In Table 3, Vermont Agency of Transportation (VAOT) bid prices are used to compare the cost of using regular paint vs. durable pavement markings. For striping a bike lane, the main costs will be the required pavement markings. But for adding a shoulder, excavation, fill, and new pavement will be required. These costs are drawn from both individual items costs generated by this cost report and by the VAOT list of two-year averages for of bid prices. For comparison, a cost estimate generated by an online web application called “Benefit-Cost Analysis of Bicycle Facilities” was also included in Table 4.

This application was created by the Active Communities/Transportation (ACT) Research Group, and can be found at http://www.bicyclinginfo.org/bikecost/index.cfm. The cost estimate generated by the ACT web application compares well with the estimated cost of installing bike lanes using data from the VTrans bid history.

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[1] Gagnon, Bernard. Director of Public Works, Shelburne VT. “Re: ProjAcceptMemo.” Message to Jon Kaplan. 4 June 2010. E-mail.

[2] "CPI Inflation Calculator." *Databases, Tables & Calculators by Subject*. United States Dept. of Labor: Bureau of Labor Statistics, Apr.-May 2010. Website accessed June 24, 2010. http://data.bls.gov/cgi-bin/cpicalc.pl

[3] Federal Highway Administration. Bicycle Countermeasure Selection System (BIKESAFE). U.S. Department of Transportation, FHWA, Washington, DC, 2006. Website accessed June 15, 2010. http://www.bicyclinginfo.org/bikesafe/countermeasure.cfm?CM_NUM=11

[4] Conner, Paul. City Planner, South Burlington VT. "Re: Bike Lanes!" Message to Solvei Blue. 20 July 2010. E-mail.

Table 3

Cost estimate for marking bike lanes on existing shoulders	VAOT estimate (regular paint)	VAOT estimate (durable markings)	ACT Web Application (regular paint)
Striping and signing only (per mile)	$2,700 - $6,000	$8,700 - $10,500	$10,000

Table 4

Cost estimate for widening one mile of road 4 feet on each side to provide bike lanes	Town of Shelburne	VTrans average Bid prices	ACT Web application
Per Mile Cost	$79,000	$300,000	$230,000

Towns may struggle with the decision of whether to use regular paint or durable pavement markings when installing new bike lanes. Recent research has indicated that unless the average annual daily traffic (AADT) on a particular road exceeds 10,000 vehicles per lane per day, durable pavement markings will not be cost-effective. Even on busy roads, careful application of water-based paints can yield service life and visibility similar to that of durable pavement markings. This topic is discussed further in Appendix 1.

Structure Costs

If a proposed path project requires a bridge, the cost can vary widely depending on which design choices are made. The most commonly used materials in Vermont for pedestrian bridges are weathering steel and treated wood decking. The most common alternative to weathering steel is galvanized steel, which is more expensive but is more resistant to corrosion and has a longer service life. Alternatives to treated wood decking include ipe wood, and wood-plastic composite (WPC) decking. All of these have trade-offs regarding service life, cost, and environmental impact. Ipe wood is an extremely dense, extremely hard wood from tropical forests in South America; it requires no treatment and yet has a service life of 30-40 years, as compared to the 15-20 year service life of treated wood, and it is more expensive than treated wood. WPC is generally more expensive, longer-lasting, and stronger than treated wood, but its specific design parameters vary greatly, depending on its manufacturer. See Appendix 2 for more in-depth discussion of the costs and benefits of these types of decking, as well as the merits of weathering vs. galvanized steel.

In Table 5, the average costs for different types of pre-fabricated bridges are shown. The cost of constructing a shared-use path bridge can vary anywhere between approximately $89 and $142 per square foot, which comes out to roughly $900 - $1600 per linear foot, assuming a length of 100 feet and depending on which materials were chosen. Increasing the width or length of a pre-fabricated bridge can cause the price to increase dramatically: for example, a 14-foot wide bridge would need to be split into two pieces for shipping, which could add up to 30% to the transportation costs. These figures are the result of estimates for pre-fabricated bridge construction provided by five different bridge construction companies.

Table 5

Assumed length of bridge: 100 feet	**Weathering steel, treated decking**	**Weathering steel, ipe decking**	**Galvanized steel, treated decking**	**Galvanized steel, ipe decking**
10' width: Cost per square foot	$87	$98	$112	$132
12' width: Cost per square foot	$90	$102	$113	$132

There have been five state-funded shared-use path bridge projects in Vermont during the past decade; one of these was a renovation of a century-old cable foot bridge in Hardwick, and another, a project in Williamstown, included two smaller bridges, each 30-40 feet in length, which were both constructed on site, using locally recycled materials. These two projects do not fit well with the typical pattern of shared-use path bridge construction, so it is difficult to compare prices on these projects to the quotes provided by engineering/construction firms above. However, the remaining projects can be compared to these professional estimates. Corrected for inflation, these figures, shown in Table 6, reveal a wide variation in the per-square-foot cost, which is generally higher than the estimates offered above. Whether this is because of costs incurred during construction that are not reflected by initial estimates, or because prices of bridge materials have gone down in the past few years (which seems unlikely), it is worth it to remember that initial estimates are almost always lower than actual costs.

Table 6

Town	**Year**	**Length**	**Width**	**Cost per square foot**
Brattleboro	2006	90	10	$167.14
Burlington	2004	67	12	$140.78
Essex	2003	125	12	$79.36

Other structures that could significantly increase the cost of a project are retaining walls or underpasses. The variability of costs given different site conditions makes it impossible to provide estimates for the costs of such structures.

D. Other Project Costs

It is important to note that the construction cost of a project is only a portion of the overall cost. Other costs that are associated with a shared-use path or sidewalk project include:

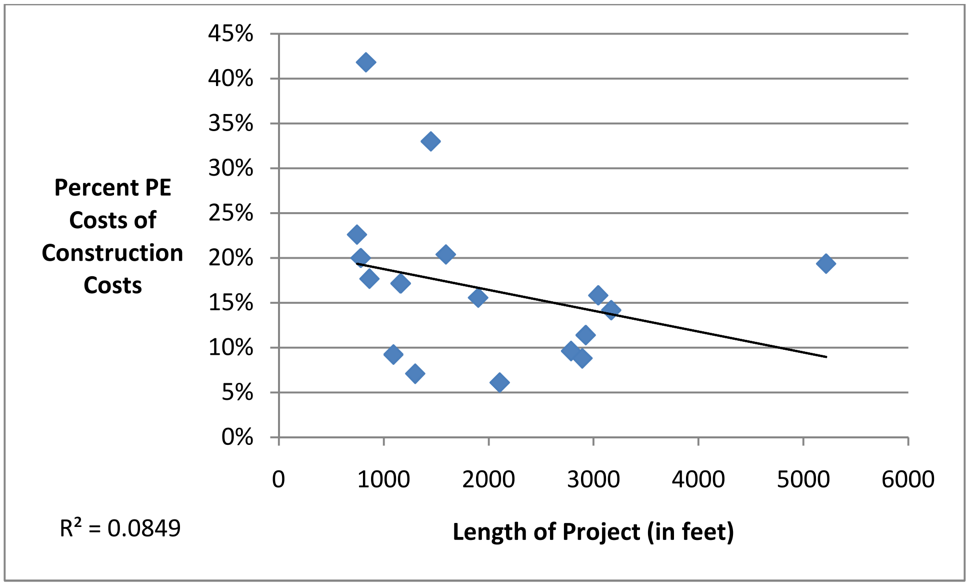
- Engineering costs (more on this below)
- Municipal project management costs (generally range from 10% to 15% of construction)
- Right of Way costs (extremely variable)
- Construction inspection costs (generally range from 10% to 25% of construction costs, depending on the complexity of the project and the amount of oversight that is needed)

These percentages should be used as rough guidelines only. For simpler, more straightforward projects, the lower range can be used, but for more complex projects, the upper end of the range is appropriate.

Engineering Costs

The 2006 Cost Report indicated that engineering costs of a project can be expected to account for between 10% and 30% of construction costs. Conversations with LTF project managers suggested that this estimate might be low, which prompted an investigation into the relationship between Project Engineering (PE) costs and total construction costs. In fact, the previous estimate turned out to be fairly accurate. While the spread of the ratio of PE costs to total construction was quite large, ranging between 6% and 42%, the average percentage was 16%. There is a slight correlation between increased length of the project and the decreasing ratio of PE to construction costs. It generally costs just as much to complete project engineering for a project 500 feet long as it does for a project one mile long.

Figure 5



E. Methodology

Data for this report was obtained from the following sources: first, bid analyses and plans of sidewalk projects completed between 2004 and 2010 and shared use paths completed between 2000 and 2010. Those projects that were completed prior to 2006 were funded through the Transportation Enhancements program and their data were not included in the 2006 cost report figures. To obtain average prices and compare prices from projects completed in several different years, costs were adjusted for inflation, using inflation indices obtained from the US Dept. of Labor Statistics. In order to compare total project costs to construction costs, the cost of built structures was excluded from the total price of the project, as bridges or other structures can significantly increase the cost of a project. Only two projects between 2004 and 2010 included bridges in their plans. One shared use path project included sidewalk construction as well; the costs and length of the sidewalk segments of this project were excluded from the total in order to obtain more accurate results regarding shared use paths, which occur much less frequently than sidewalk projects.

In order to create estimated costs for a hypothetical sidewalk and a hypothetical shared use path 1500 feet in length, with various materials involved in its construction, the average item prices from completed projects were combined with estimated prices from AASHTO's Trns.Port Estimator software. This average was weighted to tilt the result closer to the actual price average from completed projects. The specs for these hypothetical walkways were based on VTrans standard drawings, which are available at the VTrans website at http://www.aot.state.vt.us/CADDhelp/DownLoad/Standards/Standards.htm. Certain configurations of sidewalk and path construction have not been used during the past four years.

For example, no sidewalk projects with aggregate surfaces were completed during the past four years. All shared use paths recently completed have used bituminous concrete surfaces. Therefore, there was a lack of data on prices of items used for such projects. In these cases, there were no actual project cost averages to use, so the VTrans Estimator price was averaged with VTrans 2-year price averages to obtain a reasonable estimate of the price for that particular item, i.e. aggregate surfacing for a sidewalk project. The Estimator is also accessible at the VTrans website: http://www.aot.state.vt.us/CostEstimating/EngResrc.htm.

Since there were no data from completed projects that included construction of on-road bicycle lanes, a different process was used to obtain price estimates for the construction of bicycle lanes on already existing roadways. This time, the length of the hypothetical project was 1 mile of bike lanes, on one side of the street only. The specs were again based on VTrans standard drawings. For a 1 mile stretch of bicycle lane on an already paved road that required no re-paving, only marking pavement to indicate a bicycle lane, no costs for construction were involved besides those for on-road markings. For a 1 mile stretch of bicycle lane where the shoulder was widened to provide enough space for a bike lane, costs for excavation, gravel fill, and bituminous concrete were included. For items that were common between bicycle lanes and sidewalk construction, such as excavation, gravel fill, and concrete, the unit price was based on the same calculations as were used for sidewalks and paths. For items unique to on-road bike lane construction, such as pavement markings, the VTrans 2-year price average was used to obtain unit prices. Then, using an online web application called “Cost-Benefit Analysis for Bicycle Facilities,” created by the Active Communities/Transportation Research Group for calculating estimated costs for bicycle lanes and paths, prices and specs for on-road bicycle lanes were obtained and these were compared to the prices from VTrans and the 2010 cost report. The Cost-Benefit Analysis for Bicycle Facilities online application was created using research detailed in Report 522 by the National Cooperative Highway Research Program.[5]

Research revealed numerous studies on the efficacy, service life, and cost-effectiveness of standard paint compared to durable pavement markers, so the results of this research were incorporated into the section on bicycle lane construction in order to help town boards and planners make decisions about what materials to use, should they decide to increase the number of bicycle lanes in their area.

Engineering costs were taken from VAOT’s project database and reflect actual costs incurred by towns; these costs were compared to bid costs of the same projects in order to compare engineering to construction costs.

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[5] United States Department of Transportation. National Cooperative Highway Research Program. *Guidelines for Analysis of Investments in Bicycle Facilities*. Washington DC: Transportation Research Board, 2006. Print. Report 522.

Cost estimates for pre-fabricated pedestrian bridges were provided by five different engineering and construction companies. In speaking to the engineers at these companies, it became apparent that there is a large range of opinion about the ideal materials to use for a pre-fabricated bridge in Vermont. Providing cost estimates for different combinations of the most popular materials options was a good way to demonstrate the trade-offs and possibilities of choices such as treated wood vs. tropical hardwood (ipe), and weathering vs. galvanized steel. An appendix was added in order to provide more in-depth discussion of the relative merits of each of these choices.

F. Results

That costs of materials and labor will increase over the years is a fact that most people take for granted. Thus, it is not surprising that the cost of constructing shared use paths or sidewalks has increased since 2006. It is, however, interesting to note which items have increased the most, and how the costs of basic construction compare to incidental costs of project completion. The per-foot total construction cost of building a sidewalk has nearly doubled since the 2006 Cost Report. But the individual item costs—excavation, gravel fill, cement, etc.—have not increased that much and in some cases, such as concrete curbs, the costs have actually decreased. The increase in costs of basic materials does not explain the entire increase in construction costs. Analysis of built projects showed that this is because the proportion of basic costs to incidental costs for a sidewalk project has decreased. In 2006, the average percentage of funds devoted to basic materials was 48%, but in 2010, analysis of costs of sidewalk projects showed that basic costs composed on average only 36% of the total construction costs.

For shared use paths, the proportion of basic construction costs to incidental costs for bike path has not changed that much: in 2006, it was 33% and in 2010 it is 31%. However, given the lack of new projects since 2006, one should not read too much into the small change in the percentage of basic costs of the total project cost. Since many of the basic and incidental items required to build a shared use path are the same as those required to build a sidewalk, it is likely that shared use path projects going into construction today will encounter many of the same price increases as sidewalk projects.

These results suggest that incidental costs of sidewalk construction, such as fencing, drainage, labor, mobilization, signage, flagging, and landscaping have increased faster than the costs of basic materials. In particular, LTF project managers have noted that the costs of mobilization and uniformed traffic officers are two of the most often underestimated items in project bids.[6] In both cases, planners and town select boards should bear in mind that basic construction costs will generally compose only about a third of the total construction costs.

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[6] Preis, Bill, Curtis Johnson, and Ande DeForge. "LTF Project Managers on Project Cost Trends." Personal interviews. June 17 2010.

G. Future Data Needs

The VTrans database, of project engineering costs, is not always populated with reliable data, since towns sometimes find other ways to pay for engineering, or fold the engineering costs into the engineering for a separate project. VTrans is making changes right now to ensure more reliable cost reporting for engineering, so it will be interesting to revisit these numbers in a few years to see whether the anecdotal evidence from LTF Project Managers, or the evidence from the database, is more accurate with regards to PE costs.

Data about on-road bike lanes is still difficult to obtain. Projects including bike lanes have been rare, and those that were completed did not use or preserve typical plans or sections. Research about on-road bike lanes has advanced somewhat in the past four years, so there are more resources for towns wishing to incorporate bike lanes into their road construction projects, such as the Cost-Benefit Analysis of Bicycle Facilities (http://www.bicyclinginfo.org/bikecost/index.cfm) which was used to generate part of the on-road bike lane cost estimate. Data about the costs of maintaining facilities is another area which is lacking, and perhaps deserves its own report.

Appendix 1: Cost Effectiveness of Paint v. Durable Pavement Markings

The inclusion of durable pavement markings instead of standard paint, increases the cost of installing a bike lane considerably. Towns must weigh the costs and benefits of paint vs. durable markings. Durable markings are recommended by MUCTD because they are reputed to last longer, require less maintenance, and provide better visibility via increased retroreflectivity at night.[7] However, the data do not necessarily support the automatic assumption that durable pavement markings such as thermoplastic and epoxy will surpass waterborne paints in terms of service life and retroreflectivity.

Although there have been several studies done to determine the cost-effectiveness of various types of pavement marking materials, their results have been extremely inconclusive due to the variability inherent in the application of road paint and markings. There are many factors creating this uncertainty: first, there are varying standards from state to state regarding the composition and application of pavement markings. That is, a Transportation Agency may require that a longitudinal marking be composed of low-VOC waterborne paint with glass beads to catch and reflect the light, it may not necessarily dictate the size of the beads or the particular composition of the paint. Also, weather conditions and traffic conditions have a huge effect on the service life of pavement markings—severe winter weather and high volume of traffic can reduce service life by a lot.

Research on this topic revealed two interesting results: first, a National Transportation Product Evaluation Program (NTPEP) study of standard vs. durable pavement markings found that application of materials can make a big difference in service life of the materials. Pavement marking materials are generally applied at a thickness of 15 mm. However, waterborne paint, with a high volume of water and volatile chemicals, loses a significant portion of its volume as it dries, leaving its final thickness at around 9 mm. Thermoplastic, epoxy, pre-cut tape, and other durable pavement marking materials are typically applied in an already dry state and so remain at 15 mm of thickness.[8]

The NTPEP study showed that by increasing the thickness of application of waterborne paint to 30 mm, which then dried to a thickness of 18 mm, they could increase the service life and retroreflectivity of waterborne paint to the point that it was comparable with that of durable pavement markers. In addition, recent research on paint application in cold weather has shown that new advances in waterborne paint binders now means that waterborne paints can be applied

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[7] Federal Highway Administration: *Manual on Uniform Traffic Control Devices for Streets and Highways*. Washington, DC, December 2009.

[8] Shay, Greg. “Paint Winner.” *Roads & Bridges* March 2004 Volume: 42 Number: 3. Website accessed June 18, 2010. http://www.roadsbridges.com/Paint-Winner-article4974.

in cold temperatures without sacrificing drying time. Compared to solvent borne paints, these new waterborne paints have improved durability, slightly degraded retroreflectivity, and much lower VOC content.[9] A study by the National Cooperative Highway Research program advised that unless there is an AADT of at least 10,000 vehicles per day per lane, durable pavement markings are probably not cost effective.[10]

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[9] Kosto, Kimberly B., and Donald C. Schall. *Low Temperature Waterborne Pavement Marking Paints: A Road Assessment of This Low-VOC Option*. Spring House, PA: Rohm and Haas Company, 2007. Presented at 2007 Future Coat! Conference.

[10] United States Federal Highway Administration: National Cooperative Highway Research Program. *Long-Term Pavement Marking Practices: A Synthesis of Highway Practice*. Project 20-5, Synthesis 306. Washington DC: Transportation Research Board, 2002.

Appendix 2: Cost Effectiveness and Environmental Impacts of Pedestrian Bridge Materials

A. The Superstructure: Weathering Steel vs. Galvanized Steel

While weathering steel is an extremely popular choice in Vermont for bridge construction, there has been a lot of controversy about its efficacy and its vulnerability to salt, moisture, and debris.[11] Some weathering steel structures have corroded so badly that they experience catastrophic failure within a decade of construction.[12] These failures first became apparent in the 70s, about a decade after weathering steel first came into widespread use by state transportation agencies, and they led some states and municipalities to radically reduce or outright ban the use of weathering steel in bridge construction.[13] However, during the intervening years, research has shown that most of these failures can be attributed to improper detailing of the structure's joints and bearings, failing to provide adequate drainage, or locating the structure in an inappropriate environment.[14]

Weathering steel resists corrosion without the need for external coatings because of its chemical composition, which includes a small amount of copper, chromium, silicon, or nickel.[15] The composition of this changes the way in which rust forms on the surface of the structure. In carbon steel, rust typically forms a crystalline structure which allows air and moisture to penetrate ever further into the material, creating a self-reinforcing cycle of degradation of structural integrity. In weathering steel, the rust forms a granular, tightly packed layer which effectively protects the steel beneath it from exposure to air and moisture. The formation of this protective oxide layer, or patina as it is sometimes called, relies on a regular cycle of wet and dry weather, and it is vulnerable to salt as well as industrial pollutants such as sulfur dioxide.[16]

Given these vulnerabilities, it is obvious that weathering steel is not well suited for all environments. Anywhere within a few miles of the coast is not a good setting, but since Vermont is landlocked, this is not a concern. Industrial pollutants are fairly rare in Vermont, and have also been decreasing nationwide since the advent of clean air regulations. However, areas in close proximity to water, with high precipitation and humidity, and poor sun exposure are a definite

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[11] McDad, Bashar, David C. Laffrey, Mickey Dammann, and Ronald D. Medlock, P.E. *Project 0-1818: Use of Weathering Steel in TxDOT Structures*. Texas Department of Transportation, 2 June 2000.

[12] Ibid.

[13] Ibid.

[14] "Chapter 23: Corrosion Protection of Steel Bridges." *Steel Bridge Design Handbook*. Chicago: National Steel Bridge Alliance, 2010. National Steel Bridge Association. Web. 9 Aug. 2010. <http://www.aisc.org/contentNSBA.aspx?id=20244>.

[15] Kogler, Robert. "Weathering Steel & Painted Steel: Complementary Corrosion Protection Solutions for Highway Bridges." *Journal of Protective Coatings and Linings.* January 2005.

[16] "Chapter 23: Corrosion Protection of Steel Bridges." *Steel Bridge Design Handbook*. Chicago: National Steel Bridge Alliance, 2010. National Steel Bridge Association. Web. 9 Aug. 2010.

hazard for weathering steel structures. Also, when building on or over a roadway, planners and municipalities should keep in mind that high average daily traffic means that there will be higher volumes and more frequent applications of deicing salt, more splash, spray, and runoff from same, as well as increased debris, all of which can upset the chemical balance required for the formation of a protective patina. In these cases, it may be worth considering investing in a more expensive galvanized steel structure, or to make careful, detailed plans for the design, installation, and maintenance of the structure. With that said, weathering steel, when properly designed and maintained, can be generally considered a reliable, durable material for bridge building in Vermont.

B. The Decking: Cost-Effectiveness and Environmental Impacts

There are many options to consider when deciding what material to use for the decking of a pedestrian bridge. The most common material used in Vermont for pedestrian bridges is pressure treated wood, usually Douglas fir or Southern Yellow pine. These types of wood are typically harvested domestically or in Canada, and are chemically treated to prevent rot and insect damage. In the past, this treatment has usually been done with a chemical compound called Chromated Copper Arsenate (CCA). The use of this treatment was restricted by the EPA for residential purposes in 2003, due to the danger of people absorbing arsenic or chromium through physical contact with the wood, though it is still allowed for commercial purposes where direct contact with the wood will be limited. [17] Putting a sealant on pressure treated wood can lessen this danger, but such treatments must be reapplied annually, which increases maintenance costs.[18] There are also less toxic wood treatments available, such as Alkaline Copper Quaternary (ACQ), which is well-suited for outdoor applications and can be coated or painted more readily than CCA. Its downside is that it is more corrosive than CCA treated lumber, even to galvanized steel – hot-dipped or stainless steel fasteners are recommended. In either case, there should be a barrier between any treated wood decking and any weathering steel structure, as direct contact between them can prevent the weathering process from taking hold and hasten the corrosion process.[19] The service life of treated wood is estimated by bridge engineers at around 15-20 years, as long as maintenance is kept up.

Ipe tropical hardwood is extremely dense and hard. It requires no treatment at all, yet will last longer than treated wood. It poses no health or environmental hazards once installed, but its harvesting can pose significant environmental risks to the sensitive tropical rainforests from which they come, where deforestation is a serious environmental problem.[20] These risks can be lessened by using only timber from companies that have an independent certification for

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[17] United States Environmental Protection Agency. *Regulating Pesticides: Chromated Copper Arsenate (CCA)*. EPA, Nov. 2008. Web. 10 Aug. 2010. <http://www.epa.gov/oppad001/reregistration/cca/>.

[18] United States Environmental Protection Agency. *Studies Provide Public With Updated Information on CCA-Treated Playground and Decks*. EPA Newsroom. 11 May 2005. 5 Aug. 2010. <http://yosemite.epa.gov/opa/admpress.nsf/d9bf8d9315e942578525701c005e573c/eabcba60dbba6cfe8525702e0059bd15!OpenDocument>

[19] Dopp, John. U.S. Bridge. "Discussion of the Merits of Weathering vs. Galvanized Steel in Pedestrian Bridges." Telephone interview. 14 July 2010.

[20] Parry, Wayne. "From Brazil to Boardwalk: Rain Forest Wood Splinters Community." *Courier Post* [Ocean City, NJ] 8 Apr. 2007.

practicing sustainable forestry. There are several companies offering sustainable forestry certifications, but the most reputable of these is probably the Forestry Stewardship Council (FSC). Anyone purchasing FSC-certified timber should check to make sure the company they are using is in fact certified, as there have been cases in the past where companies have fraudulently claimed such certification.[21] Ipe wood is easily the most expensive material to use for decking, but the initial expense is offset by its durability—its service life is estimated at 30-40 years—and its low maintenance requirements.

Wood-plastic composite (WPC) decking is composed of plastic and wood particles. The appeal of WPC timber is that reduces environmental impacts by preventing the harvesting of forests, and recycling plastic and waste wood products. Beware greenwashing, however; not every composite product uses recycled materials[22]. Since wood-plastic composites are relatively new to the market, and have mostly been used thus far for railings and residential decks, its design standards are still evolving and are not yet entirely codified[23]. A list of products, with load ratings, is available online at www.wpcinfo.org/consumers/products. WPC is more resistant to rot and insects than wood, but not completely immune. The material is composed partly of wood, so the decking will be vulnerable to rot and mildew and will thus require treatment with some sort of preservative, probably zinc borate (another alternative to CCA for treated wood), which is toxic to humans and animals, particularly in aquatic environments.[24] Wood plastic composite is generally stronger than wood and requires less maintenance, but there is so much variation in individual products that it is difficult to say whether using it in pedestrian bridges is a prudent design decision. There are also concerns about it warping and/or cracking when exposed to extreme weather. WPC has definite advantages, particularly from the stance of trying to reduce environmental impacts, but planners, planning commissions, and towns should be prepared to do a good deal of research before settling on a particular brand or product to use.

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[21] Hance, Jeremy. Mongabay.com (April 07, 2008). *The FSC responds to its critics.* <http://news.mongabay.com/2008/0407-hance_fsc_interview.html>

[22] *Recycled Plastic and Composite Lumber.* Build It Green. Online publication. May 27 2005. http://www.builditgreen.org/attachments/wysiwyg/22/Recycled-Plastic-And-Composite-Lumber.pdf

[23] Bender, Donald A., P.E.; Wolcott, Michael P.; Dolan, J. Daniel. *Wood Plastic Composites: Structural Design and Applications.* Structure Magazine, Vol. 46. March 2007.

[24] *Flame Retardants Fact Sheet: Zinc Borate*. Rep. European Chemical Industry Council: European Flame Retardants Association, Jan. 2006. Web. 19 Aug. 2010. <http://www.flameretardants.eu/Objects/2/Files/ZincBorateFactsheet.pdf>.