CARBON AND CARBON DIOXIDE EQUIVALENT SEQUESTRATION IN URBAN FOREST PRODUCTS

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Introduction

An important function of trees and forests both within and outside of urban areas is carbon sequestration. Nowak and Crane (2002) have estimated that urban trees in the U.S. hold about 774 million tons of carbon. One estimate pegs the sequestration rate of trees in urban areas to about 14% of the overall amount of sequestration by forests. The importance of tree biomass carbon in urban areas is expected to increase over the coming decades, because the urbanized area is expected to increase notably in the U.S. (Nowak and Walton 2005).

Forest product research has demonstrated that wood continues to store carbon (and carbon dioxide equivalent—CO_2e)[1] even after being manufactured into products (Heath et al. 1996, Heath et al. 2011). To date, however, virtually all research on harvested wood products has focused on wood coming from rural woodlots or non-urban forests. As noted above, however, urban forests store substantial amounts of carbon. Consequently, products manufactured from urban trees could contribute to long-term carbon sequestration and help to mitigate the build-up of greenhouse gases. Interest in urban forests and their product and carbon storing potential has increased of late as evidenced in part by the small but increasing number of entrepreneurs, woodworkers, arborists, community foresters and others that are developing or supporting businesses based on urban wood utilization.

This report highlights a recent study completed by Dovetail Partners Inc. with funding from the U.S. Department of Agriculture (USDA) Forest Service Wood Education and Resource Center (WERC). An Excel model, based on a conservative estimate of forest growth and utilization rates, was developed to highlight the potential carbon storing capacity of urban forest products over a 30-year time period.

Urban Trees – A New Opportunity

The current view of urban trees (urban forests) is that their economic value is almost entirely derived when alive and standing. These values and functions include, but are not limited to, aesthetic appeal, energy conservation, storm water mitigation and carbon storage. When an urban tree “comes down” it typically becomes a waste removal problem. Products such as landscape mulch and fuel are often default uses that bypass an urban tree’s potential value as a source for solid wood products. However, solid wood products manufactured from urban trees can continue the cycle of long-term carbon storage, thus reducing the build-up of greenhouse gases in the atmosphere.

Grading Standards for Urban Trees

Urban trees, and subsequent urban forest products, have five unique qualities that distinguish them from products manufactured from lumber graded by the industry-recognized National

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[1] Carbon dioxide formation includes the decomposition and combustion of organic compounds such as wood. When one molecule of carbon is released into the atmosphere, it combines with two molecules of oxygen to form carbon dioxide. Since the ratio of the molecular weight of carbon dioxide to carbon is 44/12ths (or 3.67), the storage of one lb. of carbon (C) in a wood product is *equivalent* to 3.67 lbs. of carbon dioxide (CO_2e).

Hardwood Lumber Association (NHLA). The five unique urban qualities include: provenance; history; figure, color, and dimensions; personal meaning; and community meaning.

Provenance – Provenance refers to the origin of urban trees, specifically the recognizable place where they stood. One example is "zip code labeled" products from felled elm trees on public property in Minneapolis that can be "tracked" to their neighborhood of origin.

History – History means the tree or trees have historical significance that adds market value when branded by that history. An example is the tulip-poplar that stood for centuries on the campus of St. John's College in Annapolis, Maryland. The tree was a rallying place for American colonists during the Revolutionary War. When the tree was removed following a 1999 hurricane, Taylor Guitars used the wood to make a limited series of Liberty tree guitars.

Figure, Color, Dimensions – Highly figured boards streaked with unusual color, boards sawn to non-uniform widths or lengths, or trees sawn into thick slabs are often perfect for unique products although the lumber typically would be unacceptable under NHLA grading standards. The late furniture maker George Nakashima[2] often used slabs to make unique tables with live (natural) edges that frequently contained prominent cracks.

Personal Meaning – Urban property owners who lose trees that have personal value can often opt to have part of the tree transformed into a product, thus retaining some of the sentiment invested into the trees themselves. As an example, Sam Sherrill (author of *Harvesting Urban Timber*) made two dozen pieces of furniture from a 500-year-old bur oak for an Ohio family that since the mid-nineteenth century had owned the property where the tree stood.

Community Meaning – Like individuals, communities often form attachments to trees in public places. The benches in Figure 1 were made from oak and Osage orange trees removed from a Cincinnati, Ohio park; the benches were placed back in city parks.

Figure 1. Benches made from public park trees in Cincinnati.

The unique qualities of lumber from urban trees (as noted above) and the existing NHLA standards can be used in a complementary way. Combining the two ways of "judging" urban lumber should raise the urban wood recovery factor (increase product output). This in turn would lead to additional carbon storage, especially if the manufactured products were "long-term" such as flooring, furniture, building materials or keepsake works of art.

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[2] For more information on George Nakashima, see http://www.nakashimawoodworker.com/.

Things are Happening

During 2009 and 2010, a series of meetings in the Midwest brought together industry, government and non-profit leaders with a shared vision for urban trees. The outcome of the USDA Forest Service-funded meetings—held in Ann Arbor, Chicago and Milwaukee—was a pledge to form the Urban Forest Products Alliance (UFPA). A goal of UFPA is to assure that urban trees obtain their highest and best use. Currently, UFPA is seeking funding to kick-start the organization.

In May 2011, the first-ever California-wide urban forest products conference was held at the Presidio in San Francisco. The two and one-half day event featured urban forest industry leaders, government officials, university professors, wood workers, entrepreneurs and others. It became clear during the event that an urban forest products industry is beginning to emerge, with an early emphasis on consumers and businesses that focus on being "green." A similar east-coast version of the program is scheduled for October 2011 at the Biltmore Estate in Asheville, North Carolina.

Last year Dovetail Partners completed a project that investigated how urban wood industry clusters were impacting the Twin Cities of Minneapolis and St. Paul. A finding of the study was that key ingredients for industry clusters were in place in the Twin Cities,[3] and that these clusters were contributing to the growth of urban wood utilization businesses.[4]

Urban Forest Products – Carbon and Carbon Dioxide Equivalent Sequestration

Based on the above opportunities, and considering increased attention to climate change issues, we investigated the potential carbon and carbon dioxide equivalent sequestration in long-term urban forest products.[5]

An Excel model (spreadsheet) was created of the nation's urban forest carbon stock and the long-term solid wood products that potentially could be manufactured from urban tree removals.

Specifically, the model generated net cumulative CO_2e estimates for urban forest hardwood products over a 30-year period. Paper products and products made from urban softwoods were excluded from the study. Projections in the model were based on assumptions about the "size" (capacity to sequester carbon)[6] of the urban forest and the "utilization rate" (potential

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[3] Key ingredients for industry clusters include feasibility analysis; education, technical and research support; supportive government including grants; supporting and complementary industries; entrepreneurship and innovation; access to raw materials, markets and transportation networks; leadership, commitment and collaboration; and business climate.

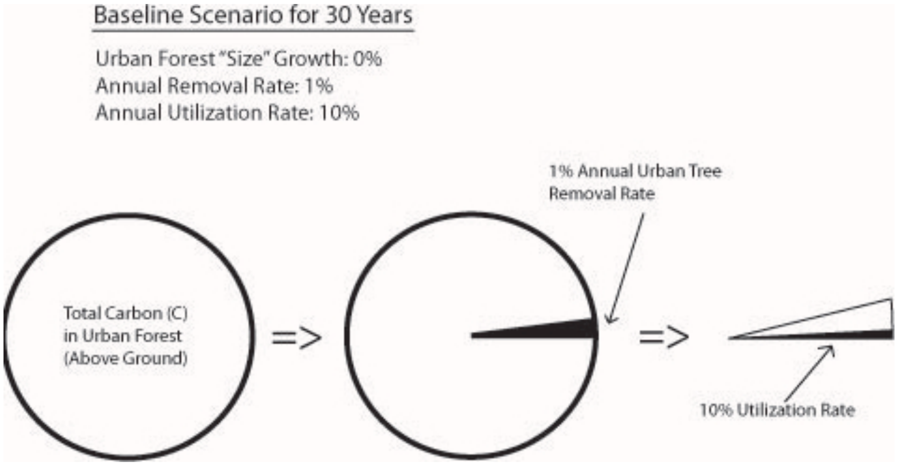
[4] For more information, see http://dovetailinc.org/files/WERC63010FinalReportsm.pdf.

[5] A detailed description of the USDA, Forest Service WERC-funded study can be found at: http://www.na.fs.fed.us/werc/, and the full study report can be downloaded via: http://www.dovetailinc.org/files/UrbanCarbonWERCReport2011.pdf

[6] Urban forest size (capacity to sequester carbon) can be measured by the number of trees for a given area based on net tree replacement, by changes in the mix of species that sequester different amounts of carbon, or by the weighted average age of the trees that comprise the forest. In addition, urban forests can grow by annexing rural forestland at the periphery of expanding urban areas.

sequestration amount) of removed trees. To obtain a conservative estimate of net CO_2e, our baseline scenario for the 30-year period assumed no growth in the size of the urban forest; a 1% annual tree removal rate; and 10% utilization of the removed trees (i.e., we assumed 10% utilization of 1% annual removals, equivalent to a 0.1% "utilization rate").

Figure 2. Baseline Scenario



Assumptions of the Model

In addition to the baseline scenario, the following key assumptions were made for the Excel model. Additional assumptions can be found in the main report (see footnote 5).

Carbon Storage in Urban Trees

The starting point for our analysis was based on estimates provided by Nowak and Crane (2002). Converting their metric values into short tons (2,000 lbs/ton), it was estimated that urban trees in the U.S. hold about 774 million tons of carbon (see Appendix A for a state-by-state breakdown). The above-ground portion of urban tree carbon is 74% (per Nowak and Crane), or approximately 573 million tons.

Tree Parts Usable for Hardwood Products

Based on estimates by Jenkins et al. 2003 and Wenger 1984, 50 percent of the above-ground biomass was assumed to be suitable for solid hardwood products. The unusable portions for purposes of this study consisted of small branch wood, crooked stems, twigs, etc. (see Figure 3).

Updating the work of Birdsey (1996), Smith *et al.* (2006) created look-up tables for forest and harvested carbon stocks that include estimates of the proportions of tree carbon that end up

Figure 3. Tree removal in Minneapolis.

sequestered in primary hardwood products. The estimates start with the proportion sequestered in the first year and then provide diminishing proportions (as products go out of use) for the next 100 years. The first 30 of the 100-year estimates used in this report (grouped by geographic region) are given in Appendix B.

Business as Usual and Carbon Emissions

In a typical urban forestry scenario, trees that must be removed due to wind damage, disease, insect infestations or other reasons are felled, limbed, bucked, chipped, and transported to a final or intermediary destination. All of these activities generate emissions—and all of these activities are considered "business as usual" for urban forestry managers and tree service firms.

An assumption in this study is that urban trees that are felled and sawn into hardwood lumber (typically by a portable band mill) create no more emissions than a "business as usual" scenario. In other words, the emissions from a portable band mill (and accompanying transportation emissions) are equal to (or even less than) traditional chipping and grinding operations (including hauling).

Kiln Drying of Urban Hardwood Lumber

Kiln drying is unique (beyond "business as usual") when producing usable material for urban wood products. In general, kilns for drying urban wood are small and use electric motors to power fans and dehumidification units. Because the electricity is largely generated by the nation's fossil fuel plants, estimated emissions from drying were subtracted from gross sequestration estimates, resulting in an estimate of net CO_2e sequestration. Based on personal experiences and knowledge of the industry, we assumed that 80% of urban hardwood lumber is kiln-dried, a percentage that may be on the high side of reality.

Carbon (C) and Carbon Dioxide Equivalent (CO_2e)

Calculations in the Excel model were converted from carbon (C) to carbon dioxide equivalent (CO_2e) in the following manner:

> Atomic mass of C = 12; atomic mass of oxygen (O) = 16;
> Molar mass of CO_2 = (C) 1x12 + (O_2) 2x16 = (CO_2) 44;
> 44/12 = 3.67 is the multiple by which 1 atom of C stored in the biomass of a tree reduces atmospheric CO_2;
> Hence, 1 lb. of C (stored in a wood product) x 3.67 (CO_2/C) = 3.67 lb. CO_2e removed from the atmosphere.

Results

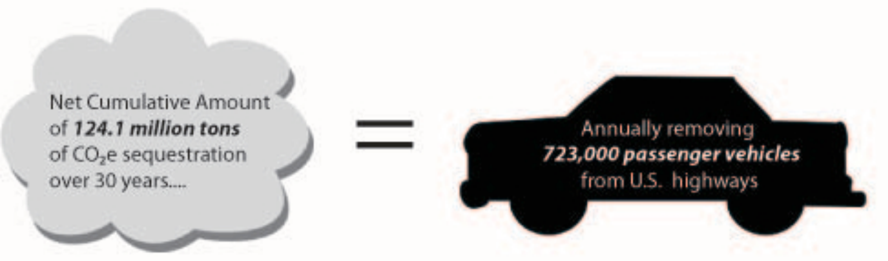
Table 1 provides an estimate of the baseline scenario of net cumulative CO_2e sequestration in urban hardwood products for a 30-year period – **124.1 million tons**. As noted earlier, this estimate is based on conservative assumptions of a 0% growth rate in the size of the urban forest, 1% annual tree removal and 10% utilization of the removed trees. If the "size" of the urban forest increases modestly over 30 years (1% and 2% in Table 1) while holding tree removal and utilization rate constant, the net cumulative CO_2e sequestration in urban hardwood products increases to 139.3 and 157.2 million tons, respectively. These numbers represent a 12.2% and 26.7% increase above the baseline, respectively.

Table 1. Net Cumulative CO_2e Sequestration in Urban Hardwood Products for 30 Years with Fixed Utilization Rate

Change in Size of Urban Forest (Sequestration Capacity)	Utilization Rate (Sequestration Potential) (10% use of 1% annual removal)	Net Cumulative CO_2e Sequestration in Urban Hardwood Products (30 years)
0.0%	**0.1%**	**124.1 million tons**
1.0%	0.1%	139.3 million tons
2.0%	0.1%	157.2 million tons

The baseline scenario of 124.1 million tons of sequestrated CO_2e over 30 years is equivalent to the annual emissions of 21.7 million U.S passenger vehicles;[7] this approximates to removing over 723,000 vehicles from U.S. highways per year for three decades. Additionally, the 124.1 million tons of CO_2e sequestered over 30 years provides a conservative benchmark or "floor" for comparison to other urban hardwood product scenarios.

Figure 4.
Urban Forest Products CO_2e Sequestration and Comparison to U.S. Automobiles



In Table 2, net cumulative sequestration is estimated with a fixed urban forest size (0% growth) and three different utilization rates (sequestration potential): the baseline of 0.1% (10% use of 1% removals), and 0.2% (20% of 1%) and 0.3% (30% of 1%). This scenario represents growth in the urban forest products industry as the level of utilization increases with a fixed "size" of the urban forest. At a 0.2% utilization rate net CO_2e sequestration by the end of 30 years has doubled from the baseline amount of 124.1 million tons to 248.1 million tons. At a 0.3% utilization rate, net CO_2e sequestration has tripled to 372.2 million tons.

Table 2. Net Cumulative CO_2e Sequestration in Urban Hardwood Products for 30 Years with Fixed Size of Urban Forest

Change in Size of Urban Forest (Sequestration Capacity)	Utilization Rate (Sequestration Potential)	Net Cumulative CO_2e Sequestration in Urban Hardwood Products (30 years)
0.0%	**0.1%**	**124.1 million tons**
0.0%	0.2%	248.1 million tons
0.0%	0.3%	372.2 million tons

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[7] Based on 5.72 short tons of CO_2e emitted per year by the average U.S. passenger vehicle.

Table 3 illustrates an optimistic scenario of sequestration (at least within the constraints of the Excel model). The resource base (urban forest size) and utilization rate (urban wood using industry) are growing modestly. In other words, over a 30-year span, the expansion of the urban forest yields more usable hardwood trees and the urban forest industry utilizes these trees at a higher annual rate. For example, an increase in the size of the urban forest over 30 years of only 1%, coupled with a doubling of the utilization rate to 0.2% (using 20% of the 1% annual tree removals), results in cumulative net sequestration increasing to 278.7 million tons, a 125% increase above the baseline of 124.1 million tons. If the urban forest increases in size by 3% over 30 years and the utilization rate increases to 0.3% (using 30% of the 1% annual tree removals), then at the end of three decades the total cumulative net CO2e sequestration has reached 471.6 million tons, almost four times the baseline of 124.1 million tons.

Table 3. Net Cumulative CO_2e Sequestration in Urban Hardwood Products for 30 Years with increasing Size of Urban Forest and Utilization Rate

Change in Size of Urban Forest (Sequestration Capacity)	Utilization Rate (Sequestration Potential)	Net Cumulative CO_2e Sequestration in Urban Hardwood Products (30 years)
0.0%	**0.1%**	**124.1 million tons**
1.0%	0.2%	278.7 million tons
2.0%	0.3%	471.6 million tons

Table 4 provides estimates based on growth in two regions of the U.S., the Northeast and the West, while holding the other U.S. regions at the baseline scenario. At a 2% increase in urban forest size (sequestration capacity) and a 0.3% utilization rate (sequestration potential) in these two regions, nationwide cumulative net sequestration increased to 255.6 million tons, more than a doubling of the baseline 124.1 million tons. This illustrates that a relatively strong nationwide increase in urban hardwood product sequestration over three decades is possible even if growth does not occur in all or even a majority of regions (see Appendix A for a breakdown of the regions).

Table 4. Net Cumulative CO_2e Sequestration in Urban Hardwood Products for 30 Years with Change in Urban Forest Size of 2% and Utilization Rate of 0.3% for Two of Six Regions

Change in Size of Urban Forest (Sequestration Capacity)	Utilization Rate (Sequestration Potential)	Net Cumulative CO_2e Sequestration in Urban Hardwood Products (30 years)
0.0%	**0.1%**	**124.1 million tons**
2.0%	0.3%	255.6 million tons

Summary

Urban forests (urban trees) store substantial amounts of carbon. Converting a portion of annual urban tree removals into solid wood products can contribute to long-term carbon sequestration and help mitigate the build-up of greenhouse gases. The recent surge in urban tree utilization is supported by the growing interest in manufacturing products with one or more of the five unique qualities of urban forest products: provenance; history; figure, color and dimensions; personal meaning; and community meaning. The formation of regional and national alliances and the development of multi-day conferences, all focused on urban forest products, suggests utilization of urban forests is likely to increase in the near future.

This project examined the CO_2e sequestration benefits of manufacturing solid hardwood products from felled urban trees. A major assumption of the study was that CO_2e emissions from a tree removal "business as usual" scenario (tree felling, limbing, bucking, chipping, grinding, hauling, etc.) were equal to a "tree utilization" scenario where trees were milled into lumber products (lumber, slabs, etc.) by a portable sawmill. Estimates of kiln drying emissions, however, were subtracted from gross sequestration amounts to provide an estimate of net cumulative CO_2e sequestration in urban hardwood products over a 30-year period.

A baseline (conservative) scenario of no growth in the size of the urban forest and a utilization rate of 0.1% (using 10% of annual tree removals of 1%) provided an estimate of 124.1 million tons of CO_2e sequestration in solid hardwood products over 30 years. This estimate is realistic and achievable in the next three decades, and would contribute to the reduction of CO_2 in the atmosphere and move our nation closer to making the highest and best use of urban tree removals.

Bottom Line

Based on the findings of this project, we offer the following recommendations.

- Urban forest products utilization should be encouraged through promotion, education, demonstrations and funding, because the potential benefits attributable to CO_2e sequestration are significant.
- Additional research should be conducted on carbon sequestration in urban forest products because, with the exception of this study, all research to date has focused on rural forests and rural-sourced forest products.
- Regional or multi-state efforts (including opportunities in specific urban areas) deserve proper attention since significant contributions to CO_2e sequestration are possible.
- Enthusiasts of urban forest utilization efforts should use the unique qualities of urban wood in combination with the CO_2e sequestration benefits as "selling points" in advancing their goals.

APPENDIX A. Carbon Sequestered in Urban Areas by States and Regions

Regions/States	Carbon Storage (short tons)	States	Carbon Storage (short tons)
North East			
Connecticut	9,060,700	New York	27,099,600
Delaware	2,666,400	Ohio	38,670,500
Maine	14,011,800	Pennsylvania	29,272,100
Maryland	18,462,400	Rhode Island	838,200
Massachusetts	17,744,100	Vermont	1,523,500
New Hampshire	8,383,100	Washington, DC	526,000*
New Jersey	29,133,500	West Virginia	4,662,900
Subtotal	202,054,800		
South East			
Florida	34,461,900	South Carolina	17,737,500
Georgia	46,916,100	Virginia	31,856,000
North Carolina	28,019,200		
Subtotal	158,990,700		
North Central			
Illinois	31,427,000	Missouri	17,606,600
Indiana	15,873,000	Nebraska	2,278,100
Iowa	10,601,800	North Dakota	363,000
Kansas	5,371,000	South Dakota	1,205,600
Michigan	22,646,800	Wisconsin	11,983,400
Minnesota	25,781,800		
Subtotal	145,138,400		
South Central			
Alabama	41,622,900	Mississippi	13,216,500
Arkansas	8,737,300	Oklahoma	11,715,000
Kentucky	11,466,400	Tennessee	32,973,600
Louisiana	13,834,700	Texas	28,389,900
Subtotal	161,956,300		
West			
Arizona	10,692,000	Nevada	3,218,600
California	30,331,400	New Mexico	1,130,800
Colorado	5,747,500	Utah	3,670,700
Idaho	2,515,700	Wyoming	291,500
Montana	21,940,600		
Subtotal	79,538,800		
Pacific West			
Oregon	7,052,100		
Washington	19,415,000		
Subtotal	26,467,100		
Total US	**774,146,100**		

Combined Sources: Smith, James E. *et al.* Methods for Calculating Forest Ecosystem and Harvested Carbon with Standard Estimates for Forests Types of the United States. General Technical Report NE-343, Table 1, p. 2. Nowak, David J. & Daniel E. Crane. Carbon storage and sequestration by urban tress in the USA. (2002). 116, Table 3, p. 386. Excluded from the Nowak *et al.* estimates are 492 square kilometers plus the District of Columbia.

*The District of Columbia was separately added back in from Nowak, David J. *et al.* Washington, DC's Urban Forest. (2006). Forest Service. Resource Bulletin NRS-1.

APPENDIX B

Average Proportions of Carbon Sequestered in Hardwood Products In-Use by Region For a Thirty Year Period

Year	North East	South East	North Central	South Central	West	Pacific West
0	0.614	0.609	0.585	0.587	0.568	0.531
1	0.572	0.565	0.544	0.543	0.529	0.481
2	0.534	0.526	0.507	0.503	0.494	0.438
3	0.500	0.491	0.473	0.468	0.464	0.400
4	0.469	0.459	0.443	0.437	0.437	0.367
5	0.440	0.431	0.416	0.409	0.412	0.338
6	0.415	0.405	0.391	0.383	0.390	0.312
7	0.391	0.381	0.368	0.360	0.369	0.289
8	0.369	0.359	0.347	0.338	0.350	0.268
9	0.349	0.339	0.328	0.319	0.332	0.248
10	0.331	0.321	0.310	0.301	0.316	0.231
11	0.317	0.307	0.296	0.288	0.304	0.220
12	0.303	0.293	0.283	0.275	0.292	0.208
13	0.289	0.279	0.269	0.261	0.280	0.197
14	0.275	0.252	0.256	0.248	0.268	0.185
15	0.260	0.243	0.242	0.235	0.256	0.174
16	0.250	0.234	0.233	0.226	0.248	0.168
17	0.224	0.225	0.224	0.218	0.240	0.162
18	0.230	0.216	0.215	0.209	0.233	0.155
19	0.220	0.207	0.206	0.201	0.225	0.149
20	0.212	0.201	0.197	0.192	0.217	0.143
21	0.205	0.195	0.191	0.186	0.211	0.139
22	0.198	0.189	0.185	0.180	0.205	0.135
23	0.191	0.183	0.179	0.174	0.200	0.130
24	0.184	0.175	0.172	0.168	0.194	0.126
25	0.178	0.170	0.165	0.162	0.188	0.122
26	0.173	0.165	0.160	0.158	0.183	0.119
27	0.168	0.160	0.155	0.153	0.179	0.116
28	0.163	0.155	0.150	0.149	0.174	0.113
29	0.152	0.150	0.145	0.144	0.170	0.110

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