

# From Forest to Fuel

**Overview:** In this lesson, students will calculate and measure the amount of woody biomass in forest residual slash piles, to determine efficacy of processing and transporting methods for biomass energy production.

**Keywords:** *Slash pile*- The accumulation of debris from trimming and manufacturing trees into logs or from cutting brush.

*Woody biomass*- Woody biological material derived from woody plants.

*Biomass*- Biological material derived from living, or recently living organisms.

*Logging residual*- Material left on site after a harvest operation. This material consists of tops, limbs, needles, stumps, and low-grade wood from breakage or defects.

*Mill residual*- Material generated from lumber, pulpwood, and plywood manufacturing.

**Age / Grade Range:** 9<sup>th</sup>- 12<sup>th</sup> Grade

**Background:** In forest management practices, trees are harvested for a variety of economic, ecological, and social reasons. These reasons include improving the health of the forest, controlling the type of trees that grow on the site, attracting certain wildlife species, providing a source of income for the landowner, producing paper, lumber, firewood, and numerous other forest products, and improving access to the area for hikers, hunters and other recreational users (1).

Just as there are many reasons for harvesting trees, there are many different harvesting methods. Each method has its benefits, drawbacks and conditions under which it is the most suitable way to harvest trees. No one harvesting method is ideal for all situations (1).

Typically, when trees are harvested for lumber and pulp, the limbs and branches (commonly termed “forest residuals”) are left on the forest floor or collected in slash piles and burned in order to reduce fire hazard, provide space for tree planting, and to reduce habitat for rodents that eat seedlings. One potential source of biomass is from forest residuals. Forest residuals are one of the largest underutilized residues potentially available for biomass energy production. Biomass energy production from forest residuals can be used to make liquid biofuels that serve as alternatives to oil, such as aviation fuel, or to produce heat or electricity to power our homes. Biomass power accounts for roughly half of all the renewable energy produced in the United States, and we use more of it than any other country in the world (2).

The high cost of collecting, processing, and transporting forest residuals can limit their use as a viable fuel source. However, developing an efficient supply chain of moving woody biomass from the forest to the processing site is critical in biomass energy production feasibility. In order to maximize profit margins an efficient supply chain requires a reliable estimate of slash pile volume. Accurate volume estimates can allow forest managers to plan for the appropriate workforce and equipment needed (3).

**Next Generation  
Science Standards &  
Common Core:**

**NGSS:** HS-PS3-1, HS-LS2-1, HS-LS2-7, HS-ESS3-1, HS-ETS1-1, HS-ETS1-2, HS-ETS1-3

**CCSS:** Math- HSG.GMD.B.4, HSG.MG.A.1, HSG.MG.A.2, HSG.MG.A.3, HSN.Q.A.1

English Language Arts- SL.9-10.1, SL.9-10.4, SL.11-12.1, SL.11-12.3, SL.11-12.4, L.9-10.1, L.9-10.2, L.9-10.3, L.11-12.1, L.11-12.2, L.11-12.3

**Goals:**

In this lesson, students will measure slash pile volumes using geometric shapes and equations. Once students have calculated slash pile volumes they can convert these values into pile mass by estimating packing ratio (ratio of solid wood to total pile volume).

**Objectives:**

Essential Questions

- What are the potential uses of slash piles?
- What are the challenges with using forest residuals as an energy source?
- How can the transportation process of slash piles to production sites be completed in an efficient method?

Enduring Understandings

- Students will be comfortable using mathematical equations to estimate volume of geometric shapes.
- Students will understand the complexity of forest management practices, especially in regards to ecological, social, and economic aspects.
- Students will think critically about various actions and the correlated profit margins.

**Materials:**

- *Smart Tools to Measure Slash Pile Volumes* newsletter

- *An Evaluation of Alternative Measurement Techniques for Estimating the Volume of Logging Residues* article
- Slash pile (OR provided measurements)
- Measuring tape (preferably in feet)
- Notepaper and writing device
- Calculator
- Geometric Pile Shape worksheet with volume formulas for geometric shapes

**Set up:**

Print:

1. Worksheets with geometric pile shapes and volume formulas
2. Newsletter- *Smart Tools to Measure Slash Pile Volumes*
3. Journal article- *An Evaluation of Alternative Measurement Techniques for Estimating the Volume of Logging Residues*

**Classroom Time:**

One 60-minute class

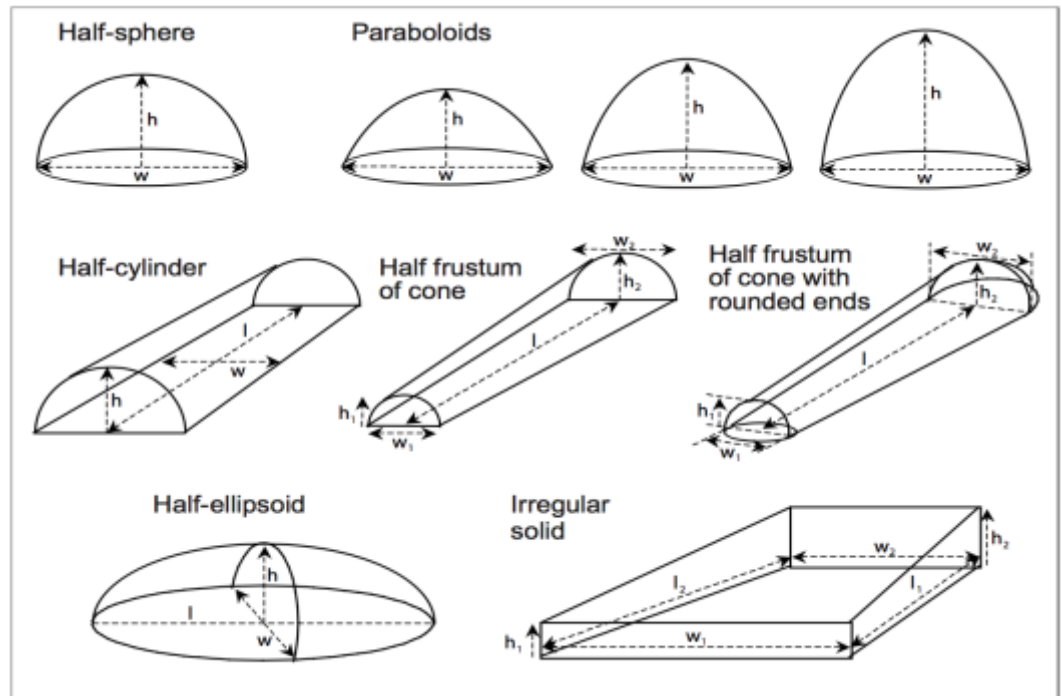
**Introduction  
(Engage):**

Students will get the opportunity to practice geometric mathematics through a hands-on real-world activity. During this lesson students will be tasked with measuring total gross volume of a slash pile and the net volume of the woody biomass.

**Activity (Explore):**

Students will begin this lesson by reading *Smart Tools to Measure Slash Pile Volumes* a newsletter published by the Northwest Advanced Renewables Alliance and a scientific journal article titled *An Evaluation of Alternative Measurement Techniques for Estimating the Volume of Logging Residues*. Once students have read these two papers that will provide background knowledge of the lesson, students will begin by finding a slash pile, preferably one that has a uniform shape. (If a slash pile cannot be used, provide students with the corresponding dimensions based on pile shape). Once students have selected a slash pile to measure:

1. Using the Geometric Pile Shape worksheet (Figure 1), students will select a representative pile shape. The pile can be generalized into one of the seven geometric shapes shown on the worksheet. Once students have selected the slash pile shape with the most similar structure they should record the appropriate dimensions in feet.



**Figure 1.** Geometric pile shapes and required dimensions. Hardy (1996).

2. Once students have selected their slash pile geometric shape and recorded the dimensions, they are ready to **calculate the gross volume**. Slash pile volume can be calculated from the following volumetric formulas, where:

V= gross pile volume (cubic feet)

l= length in feet

h= height in feet

w= width in feet

Geometric shape	Volume formula
Half-sphere	$V = (\pi \times h \times w^2)/6$
Paraboloid	$V = (\pi \times h \times w^2)/8$
Half-cylinder	$V = (\pi \times w \times l \times h)/4$
Half-frustum of cone	$V = \{\pi \times l[h_1^2 + h_2^2 + (h_1 \times h_2)]\}/6$ or $V = \{\pi \times l[w_1^2 + w_2^2 + (w_1 \times w_2)]\}/24$
Half-frustum of cone with rounded ends	$V = \pi\{l[w_1^2 + w_2^2 + (w_1 \times w_2)] + w_1^3 + w_2^3\}/24$
Half-ellipsoid	$V = (\pi \times w \times l \times h)/6$
Irregular solid	$V = [(l_1 + l_2)(w_1 + w_2)(h_1 + h_2)]/8$

**Figure 2.** Volume formulas for geometric shapes. (Wright, Balog, & Kelly, 2010)

3. After students have calculated their slash piles gross volume they are ready to determine the **net volume of woody biomass**. Within a slash pile, much of the gross volume is occupied by air. The ratio of wood volume to total pile volume is called the “packing ratio”. In order to determine the net volume of

woody material in a pile, the gross pile volume has to be multiplied by an appropriate packing ratio.

Students should select an appropriate packing ratio based on their slash pile composition referenced in the list below.

- Piles with species content dominated by ponderosa pine, with mean diameters of the large woody fuel of less than 10 inches, should use a packing ratio of 10 percent (0.10).
- Piles dominated by short-needled conifers, should use a packing ratio ranging between 15 percent (0.15) to 20 percent (0.20).
- Highly compacted, clean piles with large logs (diameters greater than 10 inches), especially those built with a crane or loader, should use a packing ratio of 25 percent (0.25).

Students should chose a packing ratio based on their slash pile composition. Once they have selected a value they can multiply the gross pile volume determined in step two by the selected packing ratio to calculate net wood volume.

$$\text{Net wood volume} = \text{gross pile volume} * \text{packing ratio}$$

### Explanation:

Now that students have calculated their slash piles wood volume they should have a solid understanding of the challenges associated with transporting woody biomass for energy and bio-based products. Students should have discovered by completing steps two and three that the woody biomass they have measured and worked with is in its raw form of slash and small un-delimbed trees, which provides a low bulk density.



**Figure 3.** Volume Differences of the same Weight Material by Different Product Types (<http://www.extension.org/pages/70315/biomass-transportation-and-delivery#.VTq5mWRVikp>)

*Ask students to think about the challenges associated with transporting a material that has a low bulk density? Low bulk density increases the cost of transportation because air is a major component of the transported volume. Additionally, the complex texture of the slash pile and woody material makes handling technically difficult.*

*Ask students to think about ways in which they could increase bulk density of slash piles if they were a forest manager trying to increase profit margins? Bulk density may be increased and the problems associated with the material's texture reduced by compaction or by chipping, grinding or shredding. However, processing biomass feedstock into small pieces may introduce new problems by decreasing durability and longevity during storage. Transport and delivery are key elements of forest activities. The way they are organized can have implications for the production system as a whole.*

### **Elaboration:**

Slash can be transported to a biomass facility by specialized containers on trailers. Because unconsolidated material is bulky with a lot of air space, trying to compress this material to allow for more biomass to be transferred per given load is important.

Have students think about all the aspects of biomass energy production and forest residuals transportation they have acquired during this activity. Next, students will have the opportunity to apply their knowledge within this field in a new domain.

These questions can be written or discussed in small or large groups:

Discuss the pros and cons of using forest residuals as a viable source for biomass energy production.

Discuss the pros and cons of chipping the slash at the slash pile location in the forest to increase bulk density when transporting the material to the processing site.

### **Evaluation:**

Once students have measured slash pile gross volume and net volume of woody biomass, have them run through these questions to solidify understandings of content.

There are many methods and ways to transport forest products and harvesting material. Open-end bulk vans are occasionally used to transport forest residuals. Bulk vans usually can carry approximately 3,000 cubic feet of wood residue.

*If we were to remove and transport everyone's slash pile in our class to the production facility a ton at a time, how many trips would be necessary if the pile was left as is (gross volume) and compressed (net wood volume)?*

Haul Distance	\$/Ton
45 miles	\$5.40
75 miles	\$9.00
100 miles	\$12.00

**Figure 4.** Transportation cost per ton. (<http://www.forestbioenergy.net/training-materials/fact-sheets/module-4-fact-sheets/fact-sheet-4-7-cost-factors-in-harvesting-woody-biomass>)

$$\text{Yd}^3 = \text{ft}^3 / 27$$

$$\text{yd}^3 \text{ to tons} \rightarrow \text{tons} = \text{yd}^3 * \text{weight in lbs} / 2000\text{lbs}$$

$$1 \text{ yd}^3 \text{ of wood} = 169 \text{ lbs}$$

#### Additional resources:

- Northwest Advanced Renewables Alliance-  
<https://www.nararenewables.org/about/about>

#### References:

1. Rochester, M. (2007). Timber Harvesting Methods. Retrieved April 23, 2015, from [http://maineforestry.net/Forestry Items/timber\\_hvt\\_methods.htm](http://maineforestry.net/Forestry%20Items/timber_hvt_methods.htm)
2. Long, J. J., & Boston, K. (2014). An Evaluation of Alternative Measurement Techniques for Estimating the Volume of Logging Residues. *Forest Science*, 60(1), 200-204.
3. Smart Tools to Measure Slash Pile Volumes. (2014, March). *Northwest Advanced Renewables Alliance Newsletter-March*. Retrieved April 23, 2015, from <https://nararenewables.org/feature/newsletter-14>
4. Wright, C. S., Balog, C. S., & Kelly, J. W. (2010). *Estimating volume, biomass, and potential emissions of hand-piled fuels*. Portland, OR: US Department of Agriculture, Forest Service, Pacific Northwest Research Station.
5. Hardy, C. C. (1996). *Guidelines for estimating volume, biomass, and smoke production for piled slash* (p. 28). US Department of Agriculture, Forest Service, Pacific Northwest Research Station.

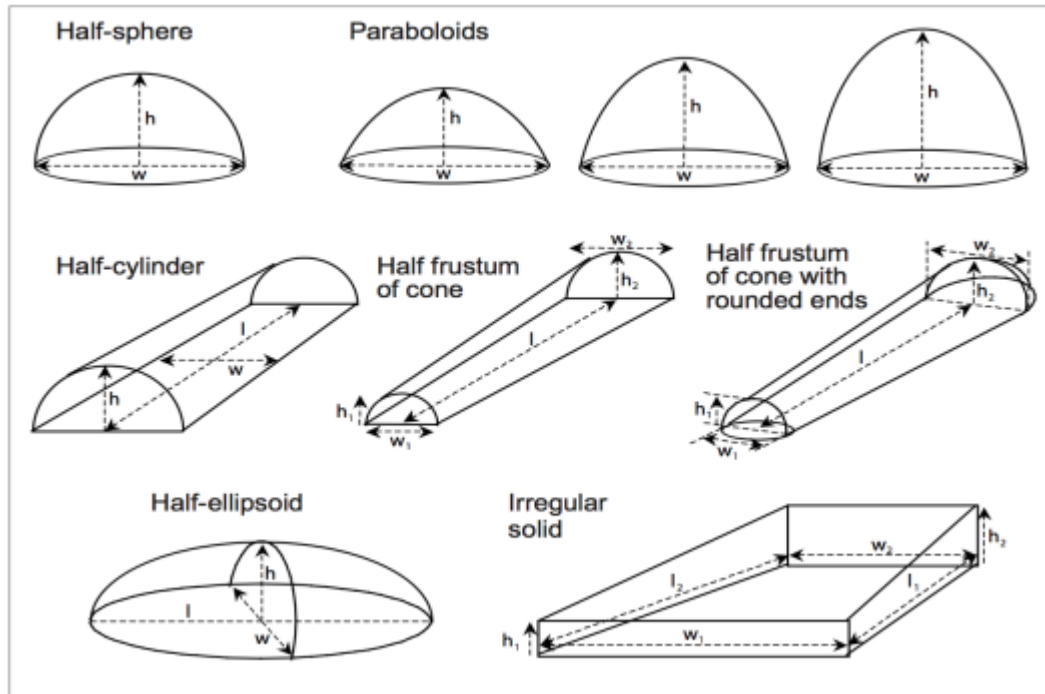


Student: \_\_\_\_\_

Date: \_\_\_\_\_

## From Forest to Fuel Worksheet

### 1. Identify your slash pile geometric shape (circle the shape of your pile)



### 2. Record the dimensions of your slash pile

Length: \_\_\_\_\_ ft      width: \_\_\_\_\_ ft

Height: \_\_\_\_\_ ft      gross pile volume: \_\_\_\_\_ ft<sup>3</sup>

Geometric shape	Volume formula
Half-sphere	$V = (\pi \times h \times w^2)/6$
Paraboloid	$V = (\pi \times h \times w^2)/8$
Half-cylinder	$V = (\pi \times w \times l \times h)/4$
Half-frustum of cone	$V = \{\pi \times l[h_1^2 + h_2^2 + (h_1 \times h_2)]\}/6$ or $V = \{\pi \times l[w_1^2 + w_2^2 + (w_1 \times w_2)]\}/24$
Half-frustum of cone with rounded ends	$V = \pi\{l[w_1^2 + w_2^2 + (w_1 \times w_2)] + w_1^3 + w_2^3\}/24$
Half-ellipsoid	$V = (\pi \times w \times l \times h)/6$
Irregular solid	$V = [(l_1 + l_2)(w_1 + w_2)(h_1 + h_2)]/8$



### 3. Determine the net volume of your slash pile

Net wood volume = gross pile volume X packing ratio

Packing ratio:

- Ponderosa pine (mean diameter < 10 inches) = 0.10
- Short-neededled conifers = 0.15 to 0.20
- Highly compacted with large logs (mean diameter > 10 inches) = 0.25

\_\_\_\_\_ (ft<sup>3</sup>) = \_\_\_\_\_ (ft<sup>3</sup>) X \_\_\_\_\_

Net wood volume (ft<sup>3</sup>) = gross pile volume (ft<sup>3</sup>) X packing ratio

### 4. Determine the cost of transporting your slash pile

4.a) First convert your volume from cubic feet to yards

(Yd<sup>3</sup>=ft<sup>3</sup>/27) -> (yd<sup>3</sup> to tons-> tons= yd<sup>3</sup> \* weight in lbs / 2000lbs) -> 1 yd<sup>3</sup> of wood= 169 lbs

Net wood volume = \_\_\_\_\_ (ft<sup>3</sup>) / 27 = \_\_\_\_\_ Yd<sup>3</sup> x 169lbs = \_\_\_\_\_ lbs / 2000 lbs = \_\_\_\_\_ tons

Gross volume = \_\_\_\_\_ (ft<sup>3</sup>) / 27 = \_\_\_\_\_ Yd<sup>3</sup> x 169lbs = \_\_\_\_\_ lbs / 2000 lbs = \_\_\_\_\_ tons

4. b) Then determine your haul rate (\$/ton)

Haul Distance	Net wood volume	Gross pile volume
45 miles (x \$5.40/ton)	_____ (ton) X 5.4 = \$_____ / ton	_____ (ton) X 5.4 = \$_____ / ton
75 miles (x \$9.00/ton)	_____ (ton) X 9 = \$_____ / ton	_____ (ton) X 9 = \$_____ / ton
100 miles (x \$12.00/ton)	_____ (ton) X 12 = \$_____ / ton	_____ (ton) X 12 = \$_____ / ton

### 5. How many trips would it take to transport your slash pile if the pile was left as is (gross volume) and compressed (net wood volume)?

Net wood volume = \_\_\_\_\_ (tons) x 1 = \_\_\_\_\_ # of trips

Gross volume = \_\_\_\_\_ (tons) x 1 = \_\_\_\_\_ # of trips