# Title: Surface fuel characteristics, temporal dynamics, and fire behavior of masticated mixed-conifer fuelbeds of the western U.S.


## Principle Investigator: Robert E. Keane
**Written by: Pamela G. Sikkink**

USDA Forest Service Rocky Mountain Research Station Missoula Fire Sciences Laboratory, Missoula, MT 59808

**Contacts: rkeane@fs.fed.us, tjain@fs.fed.us, pamelagsikkink@fs.fed.us, jreardon@fs.fed.us**


## Study Number: RMRS-2014-4405-187

## I. Problem reference

With fuel mastication gaining popularity as a fuel treatment in fire-prone areas of the United States (Kane et al. 2006), managers need a better understanding of the characteristics of masticated fuels and how the particles change over time to fully evaluate the benefits and/or drawbacks of (1) burning the treated areas under controlled conditions to maintain the fire potential at a low level or to further reduce the fire potential; or (2) leaving materials on the ground until either the fire potential of these fuels is further reduced by decomposition or these areas are burned at some time by unplanned wildfires. Currently, there are few datasets on either the particle characteristics or the changes that occur in fuelbed properties over time that are applicable to the masticated fuels in mixed-conifer forests in the U.S. We have little information on how decomposition affects ignition and smoldering in these materials or at what point in the decomposition process the materials are no longer a fire risk. Also poorly understood is how moisture is retained in these novel fuelbeds or how it fluctuates in natural settings throughout the year to affect fire danger. Such information is crucial to managers to evaluate and implement fuel treatments and burning prescriptions effectively.

## II. Background

Fuel mastication, or the mechanical modification of live surface and canopy biomass to reduce the potential of extreme fire behavior, is becoming the preferred fuel treatment for many fire hazard reduction projects in areas where reducing fuels using prescribed fire is challenging (Berry and Hesseln 2004). For mixed-conifer ecosystems, abundant research has been done on the variety of ways to masticate live biomass (Jain et al. 2012), how fire in the fuelbeds affects soil (Busse et al. 2006), how compressed fuels affect fire behavior (Smith and Brewer 2011), and how these fuel treatments affect vegetation (Battaglia et al. 2006). However, little is known about fuelbed and fuel particle change over time. When masticated materials are freshly created, they consist of abundant fine materials (needles and 1-hr twigs) and chopped or crushed woody pieces. Initially, their moisture content is high but subsequent drying increases the short-term likelihood that these fuels will ignite easily and carry flames across a landscape. The effects of long-term masticated fuelbed changes have not been well documented. Little is known about how moisture is retained in these diverse fuelbeds throughout the summer and fall months when potential for burning is high, how in situ moisture content fluctuates in different parts of the U.S., what types of structural, physical, and chemical changes they undergo, or how these changes affect fire behavior when burned.

This project expands on research conducted on the particle characteristics of masticated material from mixed-conifer forests in Colorado by Battaglia et al. (2006) and on mixed-conifer particle characteristics and the effects of moisture on burning examined by Smith and Brewer (2011) (Table 3). It examines moisture characteristics and drying rates of forest fuels, and their fire behavior, in more natural settings and in different

(forest) materials, than were used by Knapp et al. (2008) for masticated shrub material from northern California and Oregon. We focus on filling knowledge gaps for how masticated fuel from mixed-conifer stands age and decompose in forests of the U.S southeast and Rocky Mountains.

## III. Project Objectives

The goal of this project is to determine how fuelbed properties (i.e., ignition, smoldering, and flaming) are affected by the shape and age of masticated fuels using a combined field and lab approach. The specific objectives are:

**Objective 1 (FIELD/LAB):** To describe the fuelbed characteristics for masticated fuels of different ages including (a) fuel bed structural properties (thickness, moisture with depth, mineral content), (b) physical characteristics (particle shape and size, bulk density, % rot), and (c) chemical composition (C:N ratio, cellulose content, lignin content).

**Objective 2(FIELD)**: To determine how moisture dynamics are affected by fuel loading/depth and time since treatment in masticated fuel beds.

**Objective 3 (LAB):** To determine the relationship between the characteristics of the masticated material and the probability of sustained smoldering combustion.

**Objective 4 (LAB):** To observe differences in fire behavior (ignition, flaming, and smoldering) among different ages of materials and then design custom fuel models for masticated fuels in mixed conifer forests that predict fire behavior.

**Objective 5 (WIND TUNNEL/FIELD):** To validate the fire behavior predicted by the custom fuel model (developed in objective 4) on large fuel beds under controlled wind and humidity.

Hypotheses that are being tested include the following:

(1) Physical and chemical characteristics of the fuel beds will change with masticated fuel age.
(2) Loading, fuel depth, and age of the particles within the fuelbed will determine moisture dynamics within masticated fuels.
(3) The proportion of smoldering and flaming during burning will correlate with the lignin and cellulose ratios of masticated particles and the moisture available in the fuel bed.
(4) Smoldering probability will increase with fuelbed age because of changes in physical and chemical structure (degraded or rotted); and
(5) Fuel characteristics of all aged masticated fuels exist outside the range of acceptable conditions to run current fire spread models (i.e., fine fuels present to carry fire, adequate pore space between fuel particles, and sound wood).

## IV. Methods –

### 1. Objective 1: Characterization of fuel bed and fuel particles

**Study Site(s):**

Study sites will include mixed coniferous forests in the Rocky Mountains. The sites include forests with a variety of structural types and that have been treated with one of three mastication methods (Table 1). Highest priority for this study is on sampling masticated materials from a wide variety of ages.

**Table 1: Study sites for field sampling based on tree composition, mastication method, and time since mastication.**

| | **Moist Mixed Conifer** | **Dry Mixed Conifer** |
|---|---|---|
| **Horizontal drum head** | | Valles Caldera National Preserve – 2007-2008 |
| | | Valles Caldera National Preserve - 2012 |
| | | Sante Fe National Forest Los Griegos - 2006 |
| | | Sante Fe National Forest Paliza – 2011-2012 |
| | | |
| **Rotating head** | Northern Idaho Priest River PR1C– 2001 | Boise Basin Amber - 2004 |

| | | |
|---|---|---|
| | Northern Idaho Priest River PR1CC- 2007 | Boise Basin Amber New - 2010 |
| | Northern Idaho Priest River PR3 - 2011 | Manitou Experimental Forest – 2004 chipped |
| | Northern Idaho Deception Creek - 2004 | Manitou Experimental Forest WS - 2005 |
| | | San Juan National Forest Skelton – 2010-2011 |
| | | |
| **Mowing** | | Black Hills Site 1- 2012 |
| | | Black Hills Site 2 – 2012 mixed method |

Characterization of particles from the different ages and mastication methods among study sites is done using field sampling and lab procedures that will be described in subsequent sections. These two types of characterization give the following information at varying scales of investigation:

Field characterization – **Macroplot** --------

(1) GPS location
(2) Depths of fuel layers along 6 lines (spatial distribution), scale 3 m apart and 10 m apart
(3) Surface variation from laser readings or DEM
(4) Moisture data
(5) Temperature data
(6) Reflectance data
(7) Measures of long logs and particles on the ground

Field characterization - **Microplot groups** --------

(1) Depths of fuels @ 0.5m apart
(2) GPS location
(3) Duff characterization
(4) Ignition and smoldering times
(5) Depth of soil heating

Lab characterization - **Microplot** ---------

(1) Digital photo
(2) Shape distributions
(3) Number of particles of each shape
(4) Total weights for each shape
(5) Total fuel load
(6) Cellulose %
(7) Lignin %
(8) Carbon %
(9) Nitrogen %
(10) Mineral Content

Lab characterization - **Particle** ----------

(1) Shape
(2) Length
(3) Width
(4) Volume
(5) Surface area

**Field Sampling:**
Sampling within each masticated area will occur within a 30 x 50 m grid (Fig. 1). Two strategies will be employed on the grid at each location. These strategies include 1) a geostatistical sampling protocol to assess variation in fuelbed characteristics at 3 and 10m intervals; and 2) a small-scale Hood and Wu (2006) protocol to assess fuelbed variation at 0.5 m intervals.

*Geostatistical sampling protocol*
For the geostatistical sampling protocol, the grid will consist of five transect lines laid out parallel to each other at each sample location (lines A through E in Fig. 1). The lines will be run upslope to a maximum of 30 m and be placed 10 m apart within an area representative of the masticated unit. The ground surface variation along each transect will be measured with a laser equipment beam at three meter intervals to create an accurate map of the fuel surface, which will then assist in mapping the overall topography, fuel depth, and total fuel loads. If laser equipment is not available to each crew, topographic information will be obtained using DEM layers in ArcMAP.

After laser measurements, fuelbed measurements will be collected at three-meter intervals, starting at zero, along each of the six lines. At each sample point, a trowel should be used to dig a very small hole to fit a ruler and make a series of measurements. These measurements will include:

1) depth of new litter since the mastication process (leaves, fallen branches, needle accumulation, cones, seeds);
2) depth of total masticated material to the duff layer; and/or
3) depth of the duff layer to mineral soil; and/or
4) depth of soil intermixed with duff layer to the mineral soil.

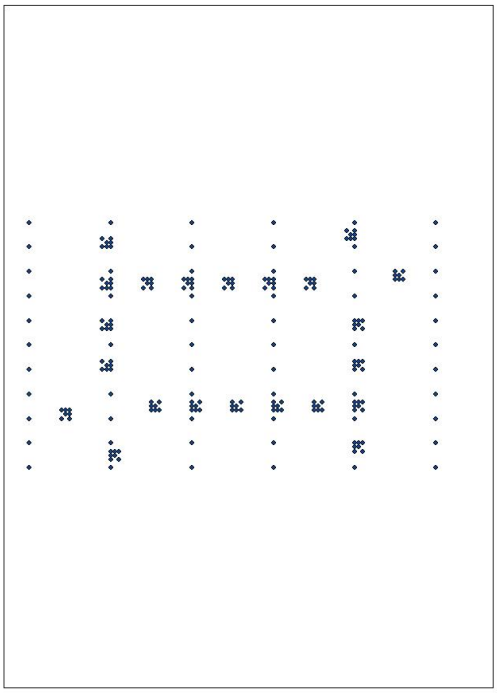

**Fig. 1.** Geospatial sampling design. Six lines are located at 0m, 10m, 20m, 30m, 40m and 50m from west to east. Each reading along a line starts at zero (base line) and is read at three-meter increments northward along each of the transect lines.

0-0 point is at lower left corner. Small-scale sampling using Hood and Wu transects is located at the closely spaced dots along lines 10 and 40 m that form the tightly arranged squares.

If 1000-hr fuels are encountered at a point of sampling on the 10 and 40-m transect lines, information on log diameter, log length, and sound or rotten designations should be recorded on the back of the sampling form to record information on how the large diameter materials are laid out on the geostatistical grid.

Vegetation characteristics at the surface of each sampling point should also be noted on the sample form. Percentage cover should be estimated, by lifeform, for a one-meter square area around the depth-description point. Height restrictions are set at 2 m above the surface of the masticated fuels. If known, species should be listed in the margin of the sampling form, but recording specific species names is not required.

Care should be taken during sampling procedures on the geostatistical grid to avoid trampling adjacent transect lines. Trampling could affect the depth-to-soil contact and laser measurements. Care should also be taken to avoid making large holes to check the depth characteristics because large holes may bias topographic analysis. They also may affect the Hood and Wu sample locations (depending on the random start location). Sampling should follow all safety procedures outlined in the Moscow job hazard analysis (JHA) constructed for soils field work (RMRS 4157-FWE 11/9/2012).

*Hood and Wu (2006) sampling protocol*

When the grid sampling described above is complete, two small-scale, crosswise transect lines should be laid out using the sampling protocol outlined by Hood and Wu (2006) (abbreviated hereafter as H-W). The transect lines for the H-W will start at a randomly selected meter mark along the 10- and 40- m lines of the geostatistical grid. Four 30-m transect lines will be laid out along the geostatistical transects at this random point as shown in Fig. 2. One set of four lines will be set at the random number from the bottom of the 10-m line; one will be set at the random number down from the top of the 40-m line. If a 30-m H-W transects extends beyond the limits of the 30 x

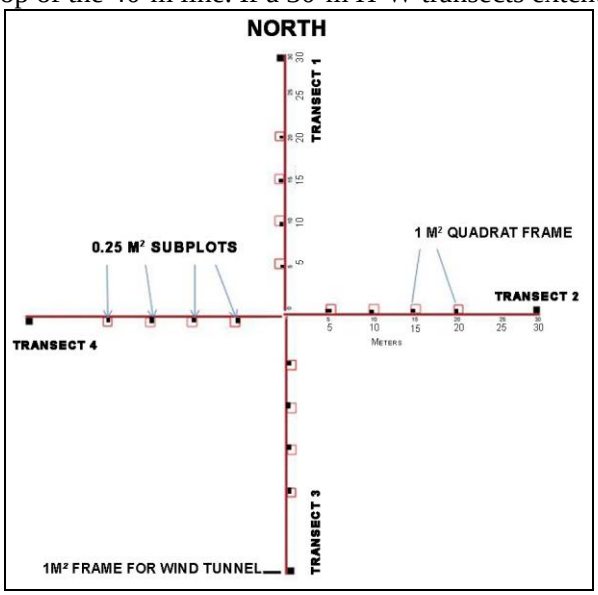


**Fig. 2. Layout of one set of four transects following protocols established by Hood and Wu (2006). The 30-m transects are arranged along the 10-m and 40-m geospatial grid lines with quadrats (red squares) and sub-plot (gray squares) at 5, 10, 15, and 20 meters along the line starting at a random meter mark. (NOTE: Plot arrangement on each transect rotates as shown in the diagram).**

50 m macroplot, the H-W will be truncated at the grid boundary line. This arrangement will add 1-m and 5-m intervals to the crosswise component of the grid for determining trends in the east-west (crosswise) direction. Every 5 meters along the H-W transects, a $1m^2$ frame will be aligned along each transect as shown in Fig. 3 (note that the direction of layout for this frame rotates for each of the four lines). Within each 1 $m^2$ frame, a 0.5 x 0.5 m quadrat will be laid out within the lower left corner of the larger frame as shown in Fig. 2. **Prior to collection, photograph the large and small quadrat plots.** Record the photo number in the proper column of the data form and then proceed with the data and material collections as described below.

At the corners of both the 1 $m^2$ and the smaller quadrat, the same the same depth measurements will be collected as were taken for geostatistical sampling above (see list above). When the depth measurements are complete, all materials within the 0.5 x 0.5 m quadrat should be collected in paper bags. Collection of the materials will be stratified into separate collection bags if fuel heterogeneity and the thickness of each layer warrant it. All material within the small quadrat will be collected down to the mineral soil layer. The materials should be separated into bags by 1) new litter; 2) masticated materials; 3) duff (containing a mixture of duff, soil, and unseparated materials from mastication). Label the samples with location, transect number, and meter location along the transect using H-W transect names, date collected, and material type. If any masticated materials to be collected extend beyond the boundary of the plot frame, they will be cut or sawed at the plot boundaries. An example of bag labeling would be as follows:

Date: **August 15, 2014**
Material Type: **New Litter/ Masticated/ or Duff**
Location Info: **PR3 Line 10 Transect 2 15m (or PR3 10.02.15)**
Associated Photos: **#15 and #16** (only needed on one of the set of bags)

*Optional lines to describe large-particle characteristics*
Reading of two extra 50 m lines is recommended in order to describe the characteristics of large logs and 1000-hr fuels within the macroplot. Using the same 10 m and 40 m lines as used for the H-W sampling, measure the lengths and widths of all logs greater than 3 inches (7.5 cm) in diameter that cross the transect lines but face to the center of the macroplot. Record the decomposition code with the length and width measurements. Stop all measurements of long logs at the macroplot edges.

*Miscellaneous samples required to describe mastication characteristics*
With the completion of the above sampling protocols, three more collections will be needed for lab analysis and burning test. These include duff samples, moisture samples, and samples that can be used for burn chamber work.

Duff should be collected from each location. These samples should have masticated materials on their surface and be collected from various locations within (or in close proximity to) the geostatistical grid. The samples should be approximately 0.2 x 0.2 meters and at least 0.08 m thick. Place each duff sample in a plastic box (such as those used for selling baked goods) and label each sample with the location name, date, and sample number. Collect 10-15 duff samples from each location.

Collections of materials to study moisture loss from the masticated materials and to use in burn chamber fires also need to be collected. The collections should include a range of sizes and shapes from each sample location and be placed in very large sample bags (1 x 1 x 1.5 m). Collect materials from within the entire geostatistical sampling grid for both of these collections. Collecting from small areas within the grid is also acceptable as long as a variety of sizes and shapes are collected that reflect the variety of materials existing within the sample location.

**Field instrumentation:**
If a weather station already exists near each sample site, date will be collected from the weather station to analyze field and weather conditions that may affect seasonal patterns of fuel drying and energy transfer. If there is no weather station located near the sample location, several instruments will be installed to collect weather data and other relevant information. The instruments and the expected benefit of each are shown in Table 1. Each instrument station will be set up outside of, but near to, the geostatistical sample grid (Figure 3). They will have solar panels for power and be equipped, if possible, to send text data over cellular phone lines if sample sites are located more than 500 miles from Missoula. Wires will be contained to minimize disruption of service due to animal activities.

The data collected from the instrument stations will be combined with weather station data to describe physical conditions at the mastication sites and to use in creation of the fuel loading model criteria.

**Table 1:** Instrumentation installed on sample location and its resulting data

| Instrument | Products | Interval | Use for project |
|---|---|---|---|
| Raws Fire or Javelin weather station OR existing weather station on site ( measures for general area) | Wind speed and direction<br>Peak winds<br>Air temperature<br>Fuel temperature<br>Fuel moisture<br>Relative humidity<br><br>Solar radiation | Hourly (sent to web collection site) | Accelerate drying process<br>Unknown<br>General temp. measure<br>Not applicable<br>Not applicable<br>Humidity flux during growth<br>Amt of sunlight reaching plants<br>Not applicable |
| Infrared Temperature sensor | Surface temperature | Hourly | Fuel surface temperature |
| Evapotranspiration gauge (for 2014) | Evapotranspiration | Daily | Moisture loss from control area |
| Net Radiometer | Reflectance of light from control site | Hourly | NDVI value for control area |
| Soil temperature gauge | Soil temp | Hourly | Soil temp of control site during green up and curing |
| Soil moisture gauge | Soil moisture | Hourly | Soil moisture |
| Fuel moisture gauge | Fuel moisture | Hourly | Fuel moisture |
| Fuel temperature gauge | Fuel temperature | Hourly | Fuel temperature |

**Fig. 3:** Instrumentation platform established in Priest River Experimental Forest for mastication project in 2013

**Laboratory work:**

*Sorting and measuring masticated materials:*

The sample bags from each site will be divided into two groups. First, 10 of the samples from each location will be separated into masticated material, new litter, and materials <1/4 inch (3.5 mm) in diameter. These three bags will then be used to compute a fuel load for each fuel type at the sample location. Second, the remaining samples will have the masticated materials sorted into shapes and sizes as described below and the new litter and fines will be sorted into two separate bags. 10 samples will be processed as described below, time permitting.

The bags for particle analysis will be sorted, measured, and dried in the following order:

(1) **Check the "new litter**" bag to make sure that the materials all are either green or freshly dropped from trees or shrubs since the mastication process occurred. This will also require knowing how old the mastication material is and the process by which it was ground up in the field. The materials in this bag should include any green or brown leafy material, pine cones, catkins, pine needles, branches with fresh buds, roots, seed pods, and moss/lichen material. Rocks and bugs may be discarded. If branches look marred by a chipper or have been well decomposed, they should be moved to either the masticated material bag or the duff bag.

(2) **Sort the duff bag**. Because of the collection process and the difficulty in sorting particles quickly in the field, this bag will contain a substantial amount of material that really belongs in the bag with the masticated material (described below). As this bag is sorted, several piles should be created. These piles will be defined below and include:

a. cylinders – 1h;
b. cylinders – 10h;
c. cylinders – 100 h;
d. wood ribbons;
e. bark ribbons;
f. bark chunks – 1 and 10h;
g. bark chunks (100h);
h. litter (all slivers <3mm thick and fairly small)

i. all other particles that don't fall in categories a-h; and
j. duff

First, run the duff materials through a set of soil sieves a handful or two at a time. The most efficient arrangement of sieve stacking is #4, #6, #8, #10, and #16 with a closed pan at the base. The sieving process efficiently removes dirt and small litter particles less than 2 mm in diameter. It does not separate into the piles listed above but does make discerning each of the classes much easier. Sieving also does not separate new litter from the masticated materials so attention needs to be focused on getting each particle into either the new litter bag or into the piles of classified materials listed above.

(3) **Sort the masticated fuel's bag.** Sort the particles into the following shapes as defined:

a. Cylinders – round shape; twigs from branches
b. Semi-cylinder – cylinder that has been cut in half lengthwise
c. Triangle – shape with three distinct sides;
d. Rectangle – shape with four sides and corner angles that are essentially $90^o$
e. Parallelogram – shape with four sides, corner angles different than $90^o$, and sides of different lengths
f. Ellipse – oval shape with two ends tapered
g. Parabola – pointed tip, other end flat
h. Neiloid – angled shape like the base of a tree trunk (mark as half or whole)
i. Cone – rounded tip, other end flat

Combine all masticated materials sorted here with the materials sorted from the duff bag listed in a-j above. This should result in pans of wood particles, bark particles, and duff that will be divided into size classes in the next step.

(4) **Divide each of the shapes into size classes**, if present. Size classes should be evaluated from the widest portion of the particle. Size classes include **1h**, which are less than 6.34 mm (1/4 in) in diameter; **10h**, which are between 6.35 mm (1/4 in ) and 2.64 cm (1 in) in diameter; and **100h**, which are greater than 2.64 cm (1 in) in diameter. These size classes effectively divide each shape class into three sizes within the class (e.g., Rectangle 1h, Rectangle 10h, and Rectangle 100h). Do not divide litter (previously sorted from the duff bag), duff, or new litter into size classes.

(5) **Place each shape and size class in its own pan**. All members of the group should be placed in the pan so that a total weight for each shape encountered in the H-W plots can be obtained. Record the total wet weight and the pan tare for each pan.

(6) **Count the total number of pieces in each shape/size class**. If the number of particles is too abundant to count, record as TNTC (too numerous to count). Litter, bark, and cylinder 1h often are too abundant to count. Record the total number of pieces of each group on the sample form on the total fuel load page.

(7) **Create a subsample of each pan**. Decide on the percentage of the total number of pieces that you want to use as the subsample and fill out the individual data forms with this information. Percentages will be determined by the total number of samples available. Sometimes there is only one particle in a shape/size class. If this is the case, the particle is weighed for the total fuel load calculation, but it is saved for the smolder tests and it is not dried. A subsample of the litter is usually based on a percentage of the total weight, not the total number of pieces, because a percentage of the total particles would be TNTC. Subsamples of duff and fresh litter are also based on a percentage of the total weight, not a percentage of the number of particles. The subsample should be placed in a pan that will sustain drying in a $90^oC$ oven and arranged so that the particles can be distinguished individually when they need to be weighed after drying. Arranging particles from shortest to longest in length generally can be used for this distinction, but they could also be marked with a number if desired.

(8) **Measure each particle piece selected for the subsample**. If arranged in order by length, start with the smallest and take the measurements required in the individual data forms (Appendix A). Particles can be measured with either a metric ruler or, in the case of the Firelab, with a digital caliper that sends measurements straight to a text file in the computer. Either way will work. Because each shape has

different measures that are needed to calculate volume and surface area, the measures collected are unique to the shape. Particles are measured at the start, middle, and end of 10 cm and then every 10 cm thereafter. For cylinders, the particle was measured in the initial manner then turned 90$^{o}$ and measured again. This gave a good representation of the variation in diameters along an individual twig.

(9) **Dry the subsample particles**. Place the subsample pans in the oven at 90$^{o}$C. Dry for at least two weeks to remove all moisture from the particles. If the particle is especially large, drying will take longer.

(10) **When particles are dry**, first weigh the pan with the entire subsample in it to determine moisture loss for the entire subsample. Second, weigh each individual particle in the subsample. This second weight gives a dry weight to use as the mass value for the particle. Keep the subsamples dried in the oven until ready to do the chemical work described below.

Fig. 4. Divisions of fuels from one sample bag by shape and size.

*Testing Bulk Density and Chemical Contents:*

*Bulk density*

Bulk density was measured on oven-dried particles of known weights. It is a two-fluid displacement process that has been used in the past for soils or duff (**, 19** ). Because bulk density is defined as mass/volume, this procedure provides a comparison of volume obtained using bulk density with volume determined using the shape formulas. The steps to obtain bulk densities of each masticated particle are as follows:

(1) Mix up a solution of 50% water and 50% glycerin. Place the solution in the bottom of a large cylinder tube (we found one at a floral supply store). The depth should be around 20 cm. Over the glycerin solution, pour 1-K kerosene to a depth of at least 15 cm. Mount an analytic balance equipped with a bottom hook over the cylinder; put the cylinder on a stand that will raise and lower it below (Figure 4). Construct several weights mounted on ends of fishline that will accommodate light, medium, and heavy samples. These are used to guarantee each particle will sink into the glycerin.

(2) Using an oven-dried sample, clean off the dirt and any extraneous litter fibers. Cut the piece to a maximum of 7.62 cm, if required (this is needed only if the piece is too long for the immersion cylinder). Lengths of the pieces will vary but can be made to fit by cutting because length is not important to the bulk density measure. Only mass (weight) is critical.

(3) Find the dry weight of the particle to be tested.

(4) Tie a weight on the particle using a sheep-shank knot. Choose a weight that is appropriate to the size and weight of the particle to be tested. The weight must be heavy enough to sink the particle in both fluids.

(5) Hook the weight and its tied particle to the hook on the base of the balance. Record the size of the weight being used for testing. Record any notes on the particle's characteristics on the data sheet. **Tare the balance to zero.**

(6) Place the particle and weight into the kerosene. Lower the weight to within about 1.25 cm of the kerosene-glycerine boundary. Using a timer, leave the particle to coat with kerosene for 3 minutes at that location. Record the weight of the kerosene-coated particle.

(7) Lower the particle into the glycerin. Place the top of the particle 1.25 cm from the boundary of the two fluids. Set timer for 3 minutes so the particle equilibrates and displaces the glycerin. When 3 minutes is up, record the weight of the particle in glycerine. Watch for bubbles and remove them. Watch for stray fibers lost. Shake the weight gently (if required) or gently move the fishline to just above fluid interface to remove major bubbles.

(8) Remove sample. Dry the fishline and weight with a paper towel. Return to step 3 to continue with another particle.

(9) To clean the fluid interface of loose dirt, barks, or fibers at the end of a session of testing, use an aquarium net with very small pores. It will take the loose pieces off the surface of the glycerin and leave the fluids relatively clean for the next session of testing.

(10) Use the following equation to find the bulk density of the tested particle:

$$\text{Bulk Density of particle} = \frac{\text{Particle dry weight} * (\text{viscosity of kerosene} - \text{viscosity of glycerin})}{(\text{Weight in kerosene} - \text{weight in glycerin})}$$

(11) When working with the particles, errors are generated from bubbles on the particle, bubbles on the weight, the fishline not long or short enough (wrap to shorten), waste material caught on weight (from dirty interface), moving stand to tare, weight not high enough (particle floats), and adding paper clip to extend length only on extension to glycerin.

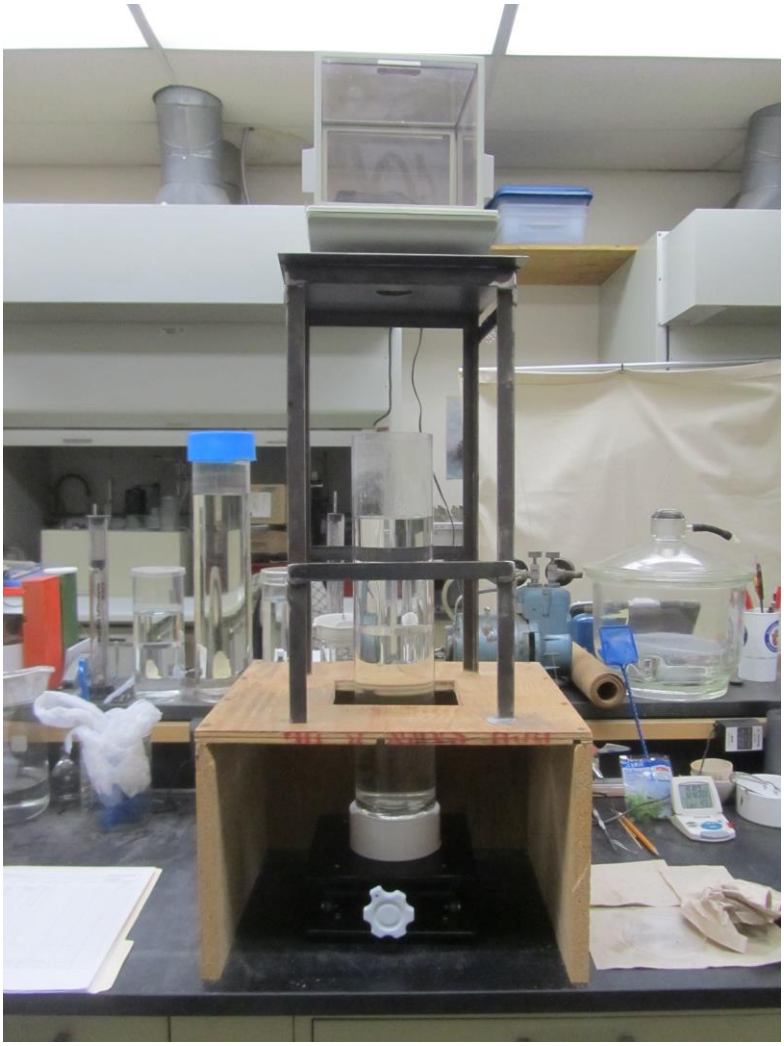

**Fig. 5:** Bulk density apparatus for mastication project showing stand, cylinder, and particle submerged in liquid

Data collected from the bulk density process includes pan name, test date, shape/size designation, sample number, size of weight on end of line, weight in kerosene, weight in glycerin, and a full description of particle characteristics (notes).

*Surface area tests*

Initial tests for surface area are being conducted using the Brunauer-Emmett-Teller (BET) method (Brunauer, Emmett and Teller, 1938). Because this test has not been used for fuels, it is being conducted on 10h fuel sticks of known surface area and weight to see if the technique can be used on the masticated fuels. The fuel sticks are put in sealed containers with various concentrations of lithium chloride to see how they absorb moisture (fig. 6). If the fuel sticks work out reasonably well, the masticated fuels will be subjected to the treatment. The goal is to get independently derived surface area measurements to compare with the surface area volumes derived from the shape equations. Data taken are weights of each stick at regular, short-spaced intervals.

Fig. 6. Surface areas tests on 1h and 10h fuel sticks using BET method of various absorptions of lithium chloride.

*Mineral content*

The mineral content of each H-W site is taken from the duff samples. The sorted bag of duff is first shaken and mixed well to combine the fine duff/litter particles and the mineral soil particles. Three small crucibles are half filled with materials from the duff bag. Weights of the filled crucibles are taken and then the samples are put in the drying oven for several days. Once dried, they are again weighed and finally moved to a muffle set at 450$^{o}$C. After 24 hours, the muffle furnace removes all organic material and only minerals remain. The final weight as a percentage (minus the weight of the crucible) is the mineral content for the H-W plot.

*Carbon and Nitrogen content*

Carbon and nitrogen ratios will be tested using the Missoula Fire Sciences Lab LECO Carbon Nitrogen Analyzer. Particles will be measured and weighed, then crushed into fine-grained powder to use in the carbon nitrogen analyzer. Less than 10 g will be required for each test. These analyses will be run before any other type of chemical analyses is attempted.

The carbon and nitrogen tests will be run on the ground and dried particle samples by trained LECO operators at the Missoula Fire Sciences Lab. An excel spreadsheet will be produced for three trials of each sample giving the carbon and nitrogen values for each.

Data collected for each of the three replicates include: Plot number, location, shape, fuel size class, lab id, notes, average nitrogen % and average carbon %.

*Lignin and cellulose content*

Lignin and cellulose correlate with decomposition of a particle. Particles with less decomposition have high proportions of cellulose and will usually flame and burn out quickly. Particle with abundant decomposition have high proportions of lignin and are more likely to smolder. Chemical changes that woody fuel particles undergo as they decompose over time are closely related to the physical changes that occur in the fuel bed. Loss of cellulose and lignin within the wood cells results in a loss of structural integrity. As cellulose and lignin in the wood particles degrade, fuelbed characteristics (such as bulk density, particle packing, porosity, particle shape, moisture retention, and mass) change and carbon and nitrogen are released to the forest floor (Duryea et al. 1999). The state of decomposition at each of our study sites will be assessed by chemically analyzing the ratios of carbon-to-nitrogen and cellulose-to-lignin of the masticated fuels.

All samples to be tested for lignin and cellulose need to be measured for length, width, and weight before being crushed and tested. The Wylie mill will be used to crush the samples. Less than 10 grams will be required for each test.

The tests for the lignin-to-cellulose ratios are done using an adiabatic calorimeter. Using pure lignin and pure cellulose powdered samples to start, limits are established for the fuels samples. Additional samples are tested for additional proportions of lignin and cellulose, such as 50:50, 75:25, etc. The result forms a correlation line showing values for pure cellulose, pure lignin, and various known proportions of cellulose and lignin. Using these limits and proportions, a value of the lignin: cellulose ratio in each individually ground fuel sample from the study sites can be estimated. It's location on the correlation line should reflect the amount of cellulose and lignin in the particle.

Samples run with calorimeter proceed as per instructions in Appendix 1 of this study plan.

## 2. Objective 2: Characterization of moisture properties of masticated fuels in mixed-conifer beds

Moisture studies on the masticated fuels still need to be completely developed. At this time, particles in various stages of decay will be selected for analysis. These particles must not have been previously dried in the ovens. The particles will be put into an environmental chamber with controlled humidity and temperature to equilibrate at various humidity levels. They will start at 10% humidity and allowed to sit for the time necessary to equilibrate. Once equilibrated, the particles will be pulled out of the chamber and weighed. They will then be returned to the environmental chamber at 20, 30, and 40% humidity, respectively, and the equilibration process will be repeated for each humidity level. The techniques will go through some adjustments as needed to assess the movement of moisture into the particles.

## 3. Objectives 3-5: Characterization of burn properties of masticated fuels in mixed-conifer beds

**Duff field samples:**
The duff samples collected at each site will be used to create the base of each test burn. Combined with a slow ignition system being developed for this project, they will provide a realistic surface to conduct the smoldering tests. The duff field samples will be described for particles, vegetation present and general moisture condition before being used for the smoldering tests.

**Smoldering tests:**
Conditions that promote smoldering combustion in mixed-conifer masticated materials will be tested using reconstructed fuelbeds confined in insulated burn boxes. During sustained smoldering, subsurface temperature data will be collected from thermocouples installed in the fuelbeds. Fuelbeds will be constructed from the stratified materials collected from the 0.25 $m^2$ subplots.

Test burns for smoldering potential will be conducted following a multi-step design using several combinations of the conditions listed in Table 2. Because not all tests will have replicates and the burn conditions will not be exactly the same for each test, a true factorial design is problematic, but we will explore the range of possibilities for getting masticated fuels to smolder with this design.

**Table 2:** Factors used in experimental smoldering tests on material from each of the 10 study sites.

| | Age | Fuelbed Depth | Particle size | Moisture |
|---|---|---|---|---|
| Site | <2 yrs | < 5 cm | Small <x | Wet[1] |
| | <2 yrs | >5m | Large >y | Wet |
| | >2 yrs | < 5 cm | Small <x | Dry |
| Site | >2 yrs | >5 cm | Large >y | Dry[1] |

[1] *These values will be determined when more data is available from on-site moisture gauges. Wet and dry conditions will vary among sites. The range of values for each site will be indicated by the moisture probes and the general moisture values obtained from the collected materials.*

The smoldering tests will be conducted as follows:

1) Moisture will be added to the particles for the "wet" condition and stabilized in a moisture chamber
2) Duff from the field samples will be used as a base for the particle bed
3) Particles will be used for each test based on the proportion they have within the H-W microsite
4) Thermocouples will be inserted into the duff base to retrieve the heat effect.
5) Tests will use a standard source of ignition for all fuel beds. The fuel bed will be ignited with a standard ignition source that gradually elevates temperature until ignition. The heat influx will be recorded by connections to a computer. Registers from the thermocouples will also be recorded via computer connections.
6) Time to ignition, total smolder time, and duff temperatures 1, 5, and 10mm below surface will be recorded.

**Burn-chamber tests:**

Fuel beds will be built for the burn-chamber tests using materials from the study sites. Fuel loads for each site will be computed from the sorting processes. These fuel loads will be used to construct fuel beds with similar proportions of masticated fuels, new litter, duff, and total loads. The fuel bed will be at least 10 ft long to accommodate the fire start and be able to measure a fire spread for the materials. We may also test lumber in some of the fuel beds if on-site materials are inadequate in quantity or size. The methods used for the burn-chamber tests will be standard burn chamber procedures developed by Rothermel (1972) for fire behavior tests.

The experimental burns will be instrumented and videotaped as individual fires. During burning, fire behavior measurements will be collected from various sensor types and video recordings in the MFSL burn chamber. If the constructed fuel beds burn as BehavePlus predicts using low wind conditions, the custom fuel model will be also be validated using a higher wind speed. If the custom fuel model burns differently than predicted, variables will be adjusted to match the actual fire behavior characteristics. An additional burn will be conducted to validate the new model as needed. Tentatively, the two wind scenarios are planned as 2 mph and 6 mph. Six miles per hour in the wind tunnel will be considered "high" wind using a fuel bed that is restricted in size, but we may alter this value to simulate expected wind conditions. Fuel beds will be built to 1m wide **x** 2 m long and to a specified depth (averaged from the on-site fuels). They will be instrumented to collect data on fire intensity, flame length and angle, rate of spread, moisture loss during burning, and burn duration. Instrumentation will include a radiometer, thermocouples, video camera, and +/- an infrared gas analyzer for the moisture loss measurements. Dead fuel heat content and fireline intensity will be calculated from these measurements. Actual measurements of burn characteristics and fireline intensity will be compared with the predictions from BehavePlus using the custom fuel models (designed above).

## 4. Data Analysis

With the randomized complete block design, each block (=site) contains all levels of each treatment combination exactly once using the blocks as the replicates. The analysis therefore follows the standard statistical format to fit a

$2^4$ factorial ANOVA (Lawson 2010). We realize that by using this design we will inevitably have some degree of correlation in the variables we describe at each site, which will need to be addressed in all analyses. This may be particularly true for correlations between main effects and interactions. The degree of correlation will be assessed with pairwise correlations and variance inflation factors. We will adjust the predictor sets in our analyses using Akaike's Information Criteria (AIC) model selection methods combined with verification from a contemporary variable selection method such as elastic net (Zou and Hastie 2005). Area Under Curve (AUC) will be reported for final models. AUC is the area under the Receiver Operator Curve (ROC) and is a common metric for classification models (Hosmer and Lemeshow 2000).

The binary response of the smolder/no smolder tests lends itself to a conditional binomial distribution. Therefore, smolder tests will be assessed using logistic regression analysis. Levels of treatments will be dichotomized into low and high. Odds ratio estimates obtained from the analyses will compare whether smoldering is more prevalent in deep vs. not deep material or wet vs. dry materials, etc. These ratio estimates can be generated to evaluate risk factors for smoldering using all of the variables of the $4^2$ predictor combinations (Table 2).

To visually explore whether the data from the field sampling and smoldering tests fall into natural groups that might require the same custom fuel models, we propose to use non-metric multidimensional scaling (NMDS). This technique uses a distance function to group data and it does not require normally distributed data or non-correlated variables. It simply plots groups with similar characteristics together in two-dimensional space and is an effective method of distilling large quantities of data from various sources into a visual representation of the variation in samples.

We will use analysis techniques from geospatial analysis to explore the fuel-bed relationships in the field. Contour maps, point pattern analysis, and directional analyses showing the variation in fuel depth, duff, and mineral soil interactions will characterize parts of spatial variability characteristics in the masticated materials.

### 5. Materials

The major materials required for this project are (1) collection bags for the field samples; (2) fuel moisture sensors and batteries or solar panels to run the data loggers so we can collect real-time data on variations in moisture throughout the summer and fall; (3) supplies to conduct smoldering combustion tests; and (4) supplies to conduct wind tunnel tests (insulation, ignition materials, calibration materials, thermocouples).

- Measurements of live and dead fuels to 0.1 gm.
- Measurement of carbon and nitrogen to 0.01 gm.
- Measurement of wind speeds to 1 mph.

Training for field sampling by two field assistants will be given in May 2013. Training will include instruction on the grid setup, H-W layout and sampling, duff collection, and materials that need to be collected for moisture study, burn and wind chamber experiments, and chemical analysis.

Data will reside with principle investigator and on the USDA FS "O" drive. Data validation is not applicable, although there are several repeat measures being taken with different types of instrumentation to validate or verify that equipment is working properly.

## V. Quality assurance/quality control procedures.

The following measures have been taken for data accuracy:

- The RAWS weather station has recently undergone repairs and been recalibrated by the company. Normal company standards will be applicable.
- The net radiometer has also returned from factory repair, has been recalibrated by the company, and checked by Jim Reardon. Normal company standards will be applicable.

- The data logger will be checked for functionality by Jim.

For data quality, the following accuracies will be acceptable:

- Data recorded on an hourly basis.
- Measurements of temperature will be calibrated for accuracy to $1^{o}$C.
- Measurements of moisture will be acceptable to 1 mm.
- Measurements of live and dead fuels to 0.1 gm.
- Measurement of carbon and nitrogen to 0.01 gm.
- Measurement of wind speeds to 1 mph.

Training for field sampling by two field assistants will be given in May 2013. Training will include instruction on the grid setup, H-W layout and sampling, duff collection, and materials that need to be collected for moisture study, burn and wind chamber experiments, and chemical analysis.

Data will reside with principle investigator and on the USDA FS "O" drive. Data validation is not applicable, although there are several repeat measures being taken with different types of instrumentation to validate or verify that equipment is working properly.

## VI. Application of research results.

**Table 2. Type, Description, and Delivery Dates for deliverables planned for this project**

| Deliverable Type (see proposal instructions) | Description | Delivery Dates |
|---|---|---|
| Non-refereed publication | Effects of time on masticated fuels (Ecology and Environment, Nature, Science, or equivalent) | 12/2015 |
| Non-refereed publication | Technical Note: Designing and validating custom fuel models for the BehavePlus fire modeling program | 12/2015 |
| Non-refereed publication | Jain: General Technical Report on parameters for implementation and prescription burning of masticated fuels; | 5/2016 |
| Training session | Heinsch: Workshop: *Predicting fire behavior in masticated fuels using BehavePlus* at MFSL | 1/2016 |
| Training session | Heinsch/Sikkink: Workshop on BehavePlus at national AFE conference highlighting custom fuel models created for masticated mixed-conifer fuels | 12/2015 or 1/2016 |
| Tech transfer | Sikkink: On-line presentation at Landscape Conservation Cooperative (focused on appropriate LCC's in Rocky Mountains and southeast US) or equivalent webinar series | 6/2015 |
| Tech transfer | Jain: Plan field trip to PREF through Fire Science Consortium | 8/2015 |
| Refereed publication | The moisture properties of degraded masticated fuels | 6/2016 |
| Refereed publication | Controls on fire behavior in aged masticated fuels | 6/2016 |
| Refereed publication | Mixed-conifer masticated fuel particles: their changing physical and chemical properties with time | 6/2016 |
| Web site: (MASTIDON) MASTIcation Decompos- ition Operations Network | Sikkink: revamp and rename existing I-MAST web site to refocus on mixed-conifer mastication materials, publications, and issues that are pertinent to fuels treatment and prescriptions for managers | 12/2013 |

## VII. Safety and health.

Safety considerations for the field portions of this study are covered in the Moscow Job Hazard Analysis on file at both the Moscow Lab the Fire Sciences Lab.

Standard safety procedures designated by RMRS will be followed during the sorting and lab work for this project, including proper use of chemicals, required clothing and safety equipment for burn tests, and designated break times during the sorting process.

## VIII. Environmental analysis considerations (see FSM 1950 and FSM 2150).

No NEPA studies or other clearances are needed for this study.

There are no threatened or endangered species known within the proposed study areas for the study areas. Checks will be made as field sampling is conducted to verify this is the case. No chemicals will be applied to the site.

## IX. Personnel assignment, time of completion, and cost

**Table 3. Roles and Responsibilities of Associated Personnel**

| Personnel | Role | Responsibility |
|---|---|---|
| Robert Keane | Principle Investigator | Keep project on schedule and within budget; submit annual reports; coordinate publication development and product delivery; troubleshoot; supervise field crews; perform data analysis; prepare manuscripts |
| Pamela Sikkink | Co-Principle Investigator | Coordinate field techs in sampling and material collection from Montana, South Dakota, and North Carolina; build fuel beds, conduct smoldering tests; perform statistical analyses; coordinate website information; prepare manuscripts |
| Theresa Jain | Co-Principle Investigator | Field sampling and material collection in Idaho, New Mexico, and Colorado; Coordinate prescribed burns on masticated materials, if required; develop fuel bed characteristic parameters for implementation of mastication and prescribed burning of masticated material; prepare manuscripts |
| Jim Reardon | Co-Principle Investigator | Oversee and conduct ignition and smoldering tests; install field moisture sensors; perform upkeep and maintenance on field and lab equipment; adapt technology to field requirements; assist with southeast sampling; assist with wind tunnel burns; prepare manuscripts |
| Brett Butler | Cooperator | Oversee burns in burn chamber and wind tunnel; prepare manuscripts |
| Faith Ann Heinsch | Cooperator | Oversee custom fuel model design and BehavePlus 5.0 runs; present BehavePlus workshop for managers spotlighting custom fuel models developed for masticated fuels; prepare manuscripts |

**Table 4. Main tasks associated with this project and assignments of responsibility for completion**

| Project Milestone | Description | Delivery Dates |
|---|---|---|
| Field sampling (1/2 in 2013; ½ 2014) | Identify specific locations for sampling within each site; collect masticated fuels for description and laboratory burns; install all moisture instrumentation in 2013 | Fall 2013, Fall 2014 |
| Fuelbed and particle characterization | Dry fuels for moisture contents, sort fuels for particle size classes, burn fuels for mineral content | Spring 2014; Spring 2015 |
| Chemical analyses | Test for carbon, nitrogen, cellulose and lignin | Spring 2015 |
| Smolder tests | Construct and burn fuelbeds for ignition and smoldering (minimum 160 burns) | Spring-Summer 2015 |
| Data analysis | Analyze data and begin manuscripts | Spr-Sum 2015 |
| BehavePlus runs | Design custom fuel models; Run Behave for predicted behavior | Fall 2015 |
| Validate models | Wind tunnel burns at two wind speeds; video tape and connect instrumentation to collect data on fire behavior | Winter 2015 |
| Present to managers and scientists | Present preliminary results at professional meetings (talk or workshop) | Winter 2015 |
| Present to managers and scientists | Training session: Behave workshop<br>Training session: On-line tech transfer | Spring 2016 |
| Manuscript reviews | Complete and submit articles for in-house or peer review | 2015-May, 2016 |
| Submit progress reports | Annual reports on progress each year | 2013, 14, 15 |
| Submit report | Final report to JFSP | June 1, 2016 |

## Table 5: Costs for study

| | 2013 | | 2014 | | 2015 | | 2016 | | |
|---|---|---|---|---|---|---|---|---|---|
| Budget item | Requested | Contributed | Requested | Contributed | Requested | Contributed | Requested | Contributed | Total all years |
| LABOR | $19,655 | $65,594 | $143,320 | $68,838 | $115,450 | $78,386 | $43,103 | $68,668 | $603,014 |
| TRAVEL | $10,000 | $16,000 | $10,000 | $16,000 | $3,000 | $0 | $3,000 | $0 | $58,000 |
| EQUIPMENT | $200 | $18,000 | $0 | $43,000 | $5,000 | $27,000 | $0 | $2,000 | $95,200 |
| MATERIALS AND SUPPLIES | $8,482 | $3,500 | $0 | $3,000 | $3,000 | $0 | $0 | $0 | $17,982 |
| OTHER/ Science Delivery | $3,080 | $720 | $2,000 | $0 | $0 | $0 | $500 | $4,000 | $10,300 |
| TOTAL DIRECT COSTS | $41,417 | $103,814 | $155,320 | $130,838 | $126,450 | $105,386 | $46,603 | $74,668 | $784,496 |
| TOTAL INDIRECT COSTS | $3,313 | $0 | $12,426 | $0 | $10,116 | $0 | $3,728 | $0 | $29,583 |
| TOTAL REQUESTED FUNDING | $44,730 | | $167,745 | | $136,566 | | $50,331 | | $399,373 |
| TOTAL CONTRIB-UTED FUNDING | | $103,814 | | $130,838 | | $105,386 | | $74,668 | $414,706 |

## X. Data Management

**Data types**

---To study the characteristics and temporal dynamics of masticated fuelbeds that are in various states of decomposition, we will collect masticated fuels, fuelbed depths, and moisture data from 10 sites in the Rocky Mountains and North Carolina using a complete randomized block design. Plot-scale data will consist of fuelbed depths (cm); and the total weight ($kg/m^2$) of material from a 0.25 $m^2$ subplot from each site. Instrumentation of the masticated fuelbeds at each site will provide new data on hourly moisture readings (%) from the two layers within the fuelbed (base and surface) from March/April to November for two years.

---Each of the samples for fuel and fuelbed characterization will provide new data on weights and moisture content of 1-, 10-, and 100-hr particles (%) separated to size classes. Each will also provide new data on fuel bulk density ( $kg/m^3$), rot (%), and fuel loads by size class and total fuel bed (kg/m2).

---To determine the state of decomposition, subsamples of aged and freshly masticated material from each of the 10 locations will be analyzed for pH; nitrogen (%), total carbon (%), total lignin (%), total cellulose (%); + or - total hemicellulose (%); and mineral content (%). This will be new data for the 10 sites, although not new data for mixed-conifer masticated materials.

---Burn tests in the laboratory and wind tunnel will provide new data on the ability of the materials to sustain smoldering (Yes/No), and information on fire behavior if smoldering can be maintained. New fire behavior data for mixed-conifer materials under controlled wind tunnel experiments will include: fire intensity (kW/m), flame length (m), flame height (m), rate of spread (m/sec), depth of burn (cm), radiant heat (kJ/kg), and more.

---All field and laboratory data will be stored in Access database files and Excel workbooks.

---Photographs and video recordings: Photographs of vegetation growth in masticated material at each subplot will provide data on plant cover (%) and height (cm) that are available to carry fire into the canopy during prescription burning. Photographs will be in digital format (lossless JPEG format). Fire behavior from test burns will be video recorded. Only video recordings with notable fire behavior will be saved from each of the wind-tunnel tests. Video will be in digital format (mp4).

**Quality Assurance**

---Data for all parts of the project is collected on paper data sheets that can be referred to if needed for checks on data input. Checks for outliers, missing entries, and data entry errors will be conducted by running summary statistics on all data during the data exploration phase of statistical analysis in SAS.

---The LECO carbon-nitrogen analyzer at the Missoula Fire Sciences Lab is maintained according to the manufacturer's specifications and regularly recalibrated. Operators are well trained by Fire Sciences Lab chemists on its operation. Quality assurance for chemical analysis of cellulose and lignin will be provided by the laboratory paid to conduct the tests.

---Quality for wind tunnel burns is assured by calibration of the equipment according to manufacture guidelines by operators who have been trained in wind-tunnel calibration and its safe operation.

---Quality of moisture data from on-site instrumentation is guaranteed by the manufacturers of the probes. They will be calibrated as suggested in operating instructions.

**Data Access**

---Edit access to the data will be limited to the co-PIs via shared hard drive; each change to the data will be noted in a log, along with the reason for the change.

---There are no sensitive data associated with the project.

**Storage and Backup**

Data will be stored in an Access database with security enabled. Data for statistical analyses will be output to Excel workbooks, and .txt files for ease of use. Backups will be stored on the RMRS "O" drive and on external USB drives that can be taken off-site for additional protection from catastrophic events.

**Long-Term Data Management**

1. ***Metadata***

   Currently we would use the FGDC Biological Data Profile (BDP) metadata standard for archiving data as stipulated by the Rocky Mountain Research Station (RMRS). All spatial data will use the Content Standard for Digital Geospatial Metadata (CSDGM). We will create documentation of the field data and statistical results using Metavist software. However, by the time the project is completed, RMRS requirements may have changed to the ISO 19115 metadata standard with its version of the Biological Data Profile and FGDC spatial metadata; if change is required, we will transition to the new formats. As required by JFSP policy, a copy of our metadata document(s) will be deposited with the FS Research Data Archive (FSRDA) to provide a complete JFSP metadata catalog.

2. ***Data Repository***

   We plan to use the JFSP-recommended repository, the FSRDA (http://www.fs.usda.gov/rds/archive).

3. ***Data Access***

   ---Upon completion of the project, all data will be deposited with documentation at the Forest Service's Research Data Archive, which has standard procedures for data access by the public. We will work with the archivist to get the data in useable format for reference by our scientific articles and for public use. No data will be released from the Research Data Archive before journal articles have been published, but afterwards, all data will be documented and made publicly available with "open access" as per RMRS policy.

   ---We will include a citation and link to the data in our journal articles.

   ---If any errors are discovered in the data after publication, we will notify the FSRDA archive so that it can update the data and metadata accordingly.

## XI. Literature

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# How to use the Adiabatic Calorimeter

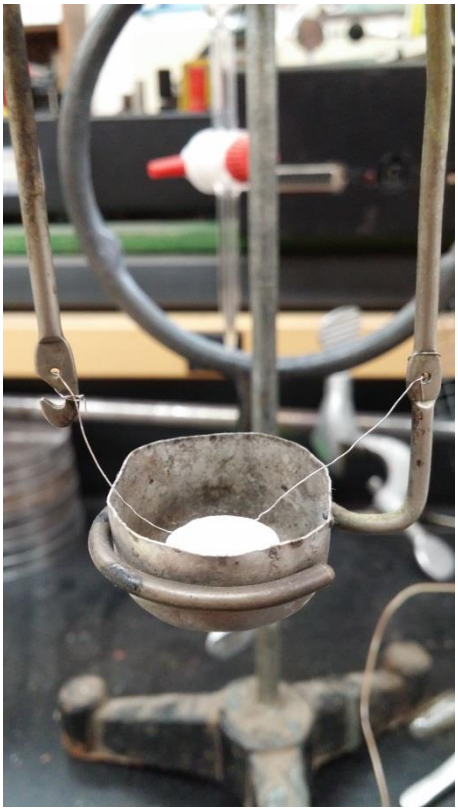

Methods (Adiabatic Calorimeter)

The Adiabatic Calorimeter is a piece of equipment used to mesure the amount of energy stored in a substance. First the energy is measured in calories per gram and is then converted Into btu's per pound. The prosess in which this data is collected and measured will be outlined in the following document.

1) First the sample substance must be in a physical can be processed by the calorimeter. example we are using benzoic acid pellets, the correct physical state.


2) Wiring the apparatus for combustion. Platinum wire is used as an ignition fuse. The wire needs to be placed as seen in the photo to the right, being wrapped carefully around the eyelets on either side and dipping down into the sample dish. For the example 0.0176g of wire was used .

3) Placing of the sample in the sample dish.
The sample must be placed so that the wire is in contact with the sample but not in contact with the sample dish.



4) Filling the inner water jacket.
The inner water jacket must be filled with 2000g of de-ionized water.
Make sure to compensate for the weight of the jacket itself.

5) Placement of the inner water jacket. The inner water jacket must be placed inside the calorimeter in the middle of the large opening at the top of the apparatus

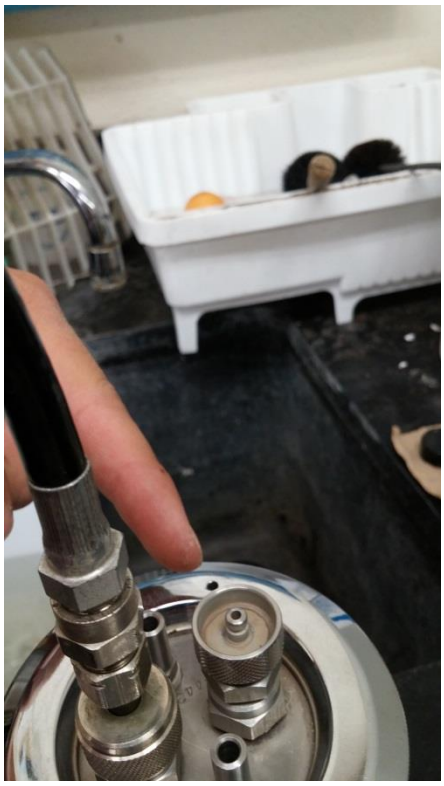
6) Assembling the oxygen bomb. Carefully lower the top half of the bomb assembly into the lower receiver . Then secure the bomb by screwing on the coupling ring.

Completely assembled oxygen bomb.

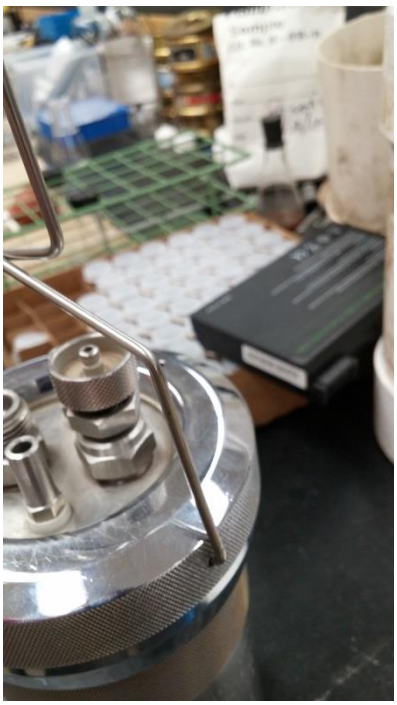
7) Filling the oxygen bomb. First attach the bomb to the oxygen tank using the hose provided.

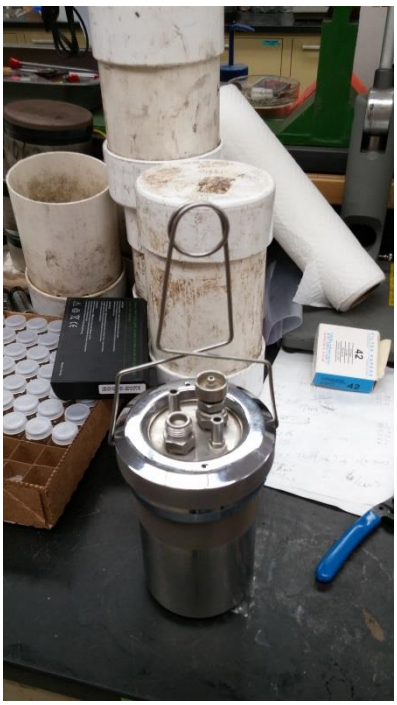
Next fill the bomb with between 20 to 25 psi of 100% oxygen


Purge the system by loosening the release valve on the top of the bomb (make sure to turn off the oxygen first). Then refill bomb up to between 20 -25 psi

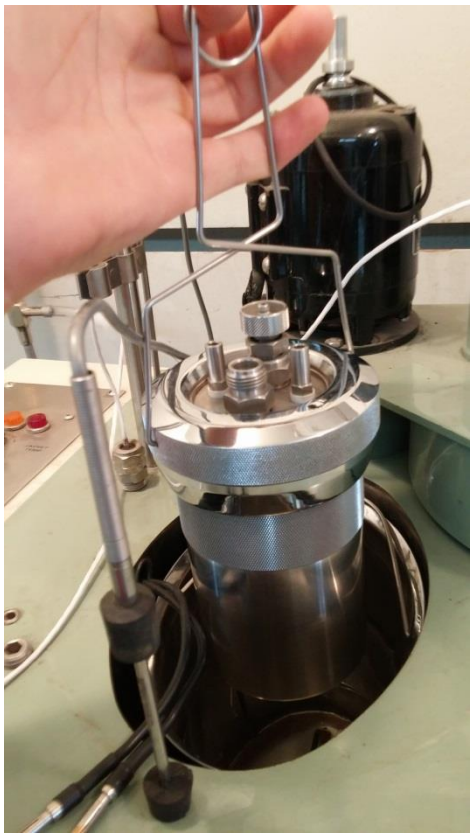


8) Insertion of the bomb in the detonation chamber. Attach the tongs to the bomb for secure placement into detonation chamber





Using the tongs carefully lower the bomb into the combustion chamber (inner water jacket).

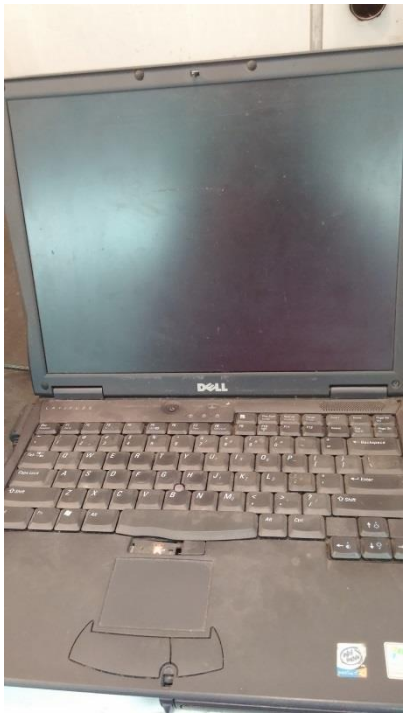


9) Attaching the leads to the bomb for detonation. Stick the two electrical leads from the calorimeter into the receivers located at the top of the oxygen bomb

10) Ignition procedure.
Slide over the colorimeter hood, drop the set rod into set hole. Then lower the hood using the lever located at the back of the hood. Be sure to make sure that the thermometers are placed in the right locations, see picture for reference.

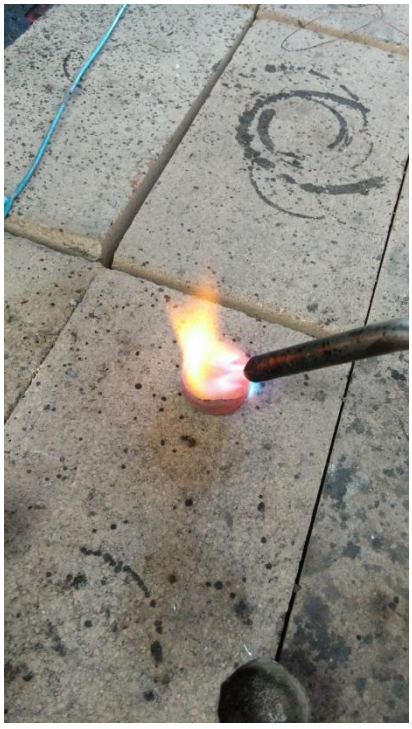
Turn on the warm and cold water supply . Now turn the machine on using the toggle  located on the control panel.


Use the readout to match the temperatures on the inner and outer water jackets . Use the controls located on the calorimeter to fine tune the temperatures.




One the temperatures have reached equilibrium ignite the sample by pressing the ignition button. The red light will flash if ignition has occurred.


11) Dissembling the bomb.
Once the rising temperature has flattened out it is safe to turn off the calorimeter. Remover the bomb, release the pressure by loosening the valve in step 7. Then take off the coupling ring and pull apart the upper assembly. Remove the sample dish and, using a blow torch remove and impurities from the dish.



Sample of data form for bomb calorimeter:

| Unit | Sample Plot | Class | Hour type | rep | sample wt | wire lost | temp change | capsule wt | ht of capsule | correction | cal/g | Percent Cellulose |
|---|---|---|---|---|---|---|---|---|---|---|---|---|