

Smoke Management Review Committee Meeting
Oregon Department of Forestry
Tillamook Conference Room, Administration Bldg, Salem
0930-1600 December 17, 2003
Santiam Conference Room, Operations Bldg, Salem
0800-1400 December 18, 2003

In Attendance: Stephen Fitzgerald, Gary Stevens, Gregory McClarren, Jim Russell, Stan Benson, Brian Jennison, Erik Christiansen, Lee Miller, Mike Dykzeul, Mike Ziolkko and Cindy Smith (notetaker).

Visitors: Tim Reinhardt (URS Corporation), Mike White (Coos Forest Protection Association), Nick Yonker and Jim Trost.

December 17

1. Administrivia

Mike Ziolkko, ODF

The administrative rule change required before Smoke Management fees could be increased will be considered at the January Board of Forestry meeting.

2. Minutes

The following were corrections were noted:

- Page 2 – last paragraph, line 3, change PM 2.4 to PM 2.5
- Page 3 – under "email from Mark Wallberg.."
 - first paragraph, third line, change the year from 2003 to 2002.
 - second paragraph, line two, insert "while measured" after the word intrusion.
- Page 4 – under item 4. Fee based program, third bullet, first line, insert "the Forest Service" before would prefer..
- Page 5 – Last paragraph, line two, replace "enforcement" with "enforce the"

The minutes were accepted as amended.

3. **Burning PE Plastic on Piles**

- **URS Contractor's Report Presentation** - Presented by Tim Reinhardt, Senior Project Manager, URS. (See Attachment 1.)

URS Corporation had been tasked by this committee to perform an extensive literature review on the science of emissions resulting from utilizing polyethylene to cover burn piles. This work was funded by the USFS.

Tim Reinhardt utilized a PowerPoint presentation to emphasize the results of the research he and Chris Wrobel had completed regarding emissions from burning polyethylene (PE) covered silvicultural piles. Reinhardt is an industrial hygienist and Wrobel is a PC chemist for URS Corporation. They reviewed 76 publications on PE and pile emissions.

In essence, they reported that it could be concluded that there was no good evidence to disfavor the use of PE based on toxins emitted, PE covered piles are dry and ignite more easily, burn cleaner and burn more efficiently. PE covered piles emit fewer emissions than wet piles. More ignition material is required to ignite wet piles than to ignite a dry pile.

- Discussion
 - In reference to the table, *PE Pyrolysis and Combustion*, on page 11 of Tim's presentation, Greg McClarren asked for an explanation of the minimum and maximum mass emitted.
 - Tim Reinhardt explained that there would be a minimum emission factor of 400 milligrams per gram and a maximum of 1500 milligrams per gram of PE and assuming there was 314

grams of PE per pile. Multiplying 314 grams by 400 milligrams per gram is 126 grams of mass emitted.

- Greg asked if micrograms per liter or cubic meter were not more common units of measure when referring to air pollution emissions.
 - Tim responded that this is an emission factor in terms of how much mass per mass of fuel burned.
- Again referring to the table on page 11, Greg asked if the TSP was PM10 and below?
 - Tim responded affirmatively.
- Jim Russell asked Tim how from an industrial hygienists perspective based on products emitted, he would categorize the public health risk?
 - Tim replied that he could not answer that question - he would need the concentration information and it would depend on where the receptor was located, how close it is, duration of exposure, etc.
- Mike Ziolko asked how they differentiated between the kerosene emissions from those of the PE in the testing.
 - Tim did not know how that was done.
- Greg McClarren noted that Tim had indicated that most of the PAH opportunity probably would not occur because the temperatures would be less than optimum and asked what the temperature range you would really be looking at would be.
 - Tim replied that he thought it would be less than 500 C.
- David Collier asked what the report said about sheets on the pile – after the pile is lit, temperatures are increasing, some of the chemical constituents of that sheet are volatilizing at those low temperatures, the sheet is obviously changing shape and melting but just because it's melting something's volatilizing but something's remaining – it's changing shape and falling into the pile. Chemically it's still there. He asked how much raw material to create PAHs is still there when the pile actually gets to temperature?
 - Tim responded that the only data he could find was that 18-41 percent is volatilized right off so 60-82% might be left.
 - David interpreted that to mean that a substantial amount of the sheet would still be there when the pile reached the critical temperatures to create the peak PAHs.
 - Lee Miller further clarified the point noting that from his experience, the whole plastic does not melt down, only the portion directly above the ignition point where it melts through the plastic and the heat comes back up and no more melts down – it goes directly out as a gas.
 - Tim said he would expect the center to be very hot and burn out first.
 - Jim Russell noted that Tim had pointed out that as the materials were entrained and columned the farther away from the source of heat, the less active any kind of a chemical change would be. It would either react in the pile under heat or else it would be entrained and not react. As the materials are – farther away from the heat... the likelihood of toxic material being transported away is low.
 - Tim agreed
 - Stan Benson said asked if it was a reasonable assumption that the products formed at lower temperatures are different
 - Tim agreed and said that as it melts, some turns to a liquid that is going to drip through the pile, if it lands on something that's cooler, it will solidify. He suggested thinking of the degraded material as a wax that will drip down and is a pool of liquid that is combustible... like a candle on a much larger scale.
- Greg McClarren asked at what temperature the flaming type combustion occurs.

- Tim replied that would be at about 300 C
- Greg asked if a pile is about 598 kg – about 1300 pounds – Tim confirmed.
- Tim recommended using translucent PE and thinner sheeting for best emission reduction technique.
 - Regarding the use of thinner sheeting – Lee Miller pointed out that the thinner material punctures too readily when applying it to the pile and recommended using the 4-mil type.
- Referring to earlier questions regarding how to evaluate this from a human health standpoint, Tim said he would model the emissions transport to receptors in this area. How close do you expect the nearest resident to be exposed to the pile for any given time? Concentrations for downwind receptors could be estimated and short and long-term health impacts could then be assessed. Once the health impacts have been determined it would then be possible to determine if the risks were significant enough to warrant actual emission measurements.
 - Stephen Fitzgerald commented that you can track emissions but have to compare that to the risk – if can burn that pile at a wetter time can burn when there is less risk of escape, etc...and it can be burned more completely without smoldering.
 - Tim added that the analysis could be done for waxed paper for comparison.
- An email from absent committee member, Jim Brown, in which he forwarded the information he had researched on the use of Kraft or wax paper, was distributed. (See Attachment 2). It included the following statements:
 1. *Kraft paper and the resins to make it weather resistant have the advantage of being derived from a renewable resource, wood. To consume a **wood product** for a **wood-producing** purpose seems appropriate and benignly self-serving for the wood product industry. My personal preference favors the use of paper.*
 2. *On the pollution side, I would be surprised to learn that a sheet of resin-coated Kraft paper produces less pollutants than an equal –area sheet of the polyethylene film we have been discussing – under identical slash-burning conditions. That said, compared to the quantity of pollutants emitted by the slash being burned, and considering that the whole purpose of smoke management is to get the smoke aloft, pollutants from either covering material are genuinely trivial.*
 3. *A 6-by-300-foot roll of Kraft (per Terra Tech) weighs 48 pounds. I do not know how that compares to the weight of polyethylene. I do not know how the durabilities of the Kraft and polyethylene compare.*
- Jim Russell asked, based on the amount of plastic being talked about and monitoring downwind concentrations, would current technology be able to differentiate between plastic and smoke?
 - Tim replied “No”.
 - Jim Russell noted that inefficient burning produces far more pollutants than what we expect to get from burning plastics.
- Stan Benson asked if polyethylene would change its integrity when its physical form changes?
 - Tim clarified that its chemical identity would remain the same.
 - Stan asked how soon would it settle out?
 - Tim replied that it would vary - the chemical chain will shorten.
- Lee Miller noted that a dry pile may need only a couple tablespoons of fuel to ignite it but a wet pile could use an extreme amount of fuel and the fuel being burned would produce many of the same products of combustion.
- Jim Russell asked if there was any evidence of toxic material bonding to the particulate matter.
 - Tim replied no, it would not create something new, but it could attach and it would be transported with the plume. Within about 300 feet of the fire one wouldn’t see much reaction.

- Stan Benson noted that the chemicals produced by fuels and by PEs have a lot of similarities - It appears we would reduce emissions by using plastic rather than starting fuels.
- Greg McClarren commented that there is no research that characterizes the combustion profile of piled organic material in forest setting but there is research that describes the combustion profile and asked if it was by species?
 - Tim replied that there is – to some degree – but not much on broadleaf species.
 - Greg then asked to what degree the research was relative to the emissions from those piles?
 - Tim responded that there was a good body of evidence for that.
- Erik Christiansen noted that there is a great deal of research on health effects to fire fighters – down wind... from burning clearcuts primarily.
- Jim Russell asked if Tim knew why New Mexico required that plastic covered piles to sit for six months before they were burned.
 - Tim responded that it could be to justify the use of the plastic.
- Greg McClarren noted that there is research on dry material combustion in a forest setting versus non-dry or relatively green material.
- The report will be made available on the website.

Response to Letter from David Collier

Copies of a letter from Dave Collier addressing his concerns with the issue of using plastic on slash piles were distributed. Stephen Fitzgerald asked that the bulleted items be numbered one through six for reference in discussing the issues David raised and added that he would like brief comments from each committee member on bullets 2, 3, and 4.

Bullet 2: “Discuss further the state of our knowledge about the use of plastic in Oregon and other states; as well as the potential impacts of polyethylene emissions (review URS report in detail).”

- Gregory McClarren said he saw an equity issue here – having to do with exemption – DEQ has a rule that says you won’t burn plastic. Any plastic burning would require an exemption. There are potential impacts (hazards). There is a lack of data of emissions from piles burned that were covered with clear PE, versus black PE versus no PE and a lack of data on what carbon black is.
- Gary Stevens said he agreed with much of what Greg said and added that if PE was used, he thought there was enough information to show that the total quality and quantity of these emissions is reduced. *If best management practices were developed, PE might be a good covering material.*
- David Collier said he appreciated the work that Tim Reinhardt did and added that there are a number of places where DEQ could agree – and a number of places where DEQ would like more information and a few areas where DEQ would have some concern – especially when talking about burning polyethylene in areas within proximity to the public as well as regulatory equity between forestry and the public. He had taken testimony the previous night in Medford about air quality and was concerned about the number of people who were adamant about doing nothing to jeopardize air quality in the Rogue Valley.
- Brian Finneran said he thought the impacts of using PE are nill, that they probably cause less smoke if the pile is dry than if it were wet. He understands that DEQ has to know about the use of plastic in Oregon and we need to answer that question added that carbon black is basically just carbon but would support the use of clear PE.
- Lee Miller noted that after listening to the presentation he thinks more that ever that we should use PE.

- Stan Benson said he would agree that there are not many alternatives – paper just doesn't do the job. He added that using black PE may be important in maintaining the integrity of the product over time and noted that the benefits far exceeded the risks in terms of reduced ignition fuels, reduced emissions from burning dry piles versus wet piles which far overshadow anything from burning PE.
- Erik Christiansen said that he couldn't say federal agencies don't use plastics – they have used plastic to cover hand piles for years and it is sometimes removed prior to ignition and sometimes not. Erik wanted to make it clear that what was being discussed was the use of PE on **hand piles**, not grapple piles, dozer piles etc. He agreed that the use of PE probably does not add to the toxic impact. We need to clearly articulate why we cover piles.
- Jim Russell expressed his concern over getting into the issue of equity. He said the issue is whether the use of PE should be allowed.
- Stephen Fitzgerald commented that it does not appear that the potential toxic effects are there in sufficient quantities to deny the use of pure PE and using carbon black is not an issue. When look at an exemption for PE, he would not like to see limitation in wild land interfaces because of the benefit is burning at time when wet and a reduction in overall emissions. He would not want to limit it to a specific distance away from homes because of the benefit of risk reduction.

Bullet 3: Discuss available alternative materials (pro and con). USFS and/or ODF would be asked to provide more specific information on the cost difference between polyethylene and wax coated Kraft paper (or other alternative material), as well as durability factors that limit the usefulness of non-plastic covering material. DEQ would like to understand these issues better.

- Lee Miller said that in his work he deals primarily with machine piles – about two to five tons of material in a sort of a hay stack formed pile. He has tried numerous alternatives but has not found any that work as well as plastic.
- Stan Benson said PE stands up better and said the Committee needs to be careful not to be paralyzed by the minutia.
- Erik Christiansen noted that there are basically three alternatives – PE, coated papers and asphalt impregnated paper (which may not even be available any more). He added that the trade-off for what is emitted is about the same for PE and paper but other criteria come into play (portability and cost..) and in practicality we have found PE to be our best option.
- Stephen Fitzgerald said that with emissions being the same - the practicality of using PE over paper comes down to the durability of the PE.
- Gregory expressed his concern that the alternatives from the past are all that we have discussed and asked about the future and innovation.
- Gary Stephens said issues of portability and effectiveness are important.
- David Collier said there are a number of areas where we agree and could come to a consensus rather quickly.
- Stan Benson commented on availability and added that it's possible to burn on both the coast and the snow zone with the use of plastic.
- Jim Russell added that he doesn't even think about burning on the west side until there has been at least a couple inches of rain - because of the risk

Bullet 4: Discuss possible situations under which the use of polyethylene could be: allowed without restriction, minimized and prohibited. This could include options such as: a commitment for additional chipping in areas with reasonable road access; the option for different covering materials based on geographic/climactic distinctions (wetter vs. dryer areas); prohibiting the use of any plastic within “X”

miles of populated areas (urban/wild land interface); minimal use approach (i.e. require covers for ignition areas only, not the entire pile; reuse (i.e. the use of tie downs so that plastic can be easily removed and reused); other ideas.

- Erik Christiansen suggested focusing on the use of PE on piles for this discussion and said it may include using thinner film when practical, removing it under certain circumstances, the use of clear PE as a best management practice and maximum size of PE allowable in order to keep emissions to a minimum. He suggested using only what's needed to get the job done.
- Mike Dykzeul noted that in many cases these considerations have been going on for years and added that it's an on going process and his commitment is to shareholders in operations. Mike also pointed out that the amount of fuels has continued to decrease.
- Stan Benson said he would still go with best management practices – what's appropriate in one circumstance may not work in all circumstances – need guidance but with flexibility - fit to the circumstances (weather conditions, size of fuel, etc.).
- Lee Miller commented that chipping has failed every time for one of his foresters and she has tried many times over a twenty-year period. Regarding the use of clear versus black plastic, Lee added that sometimes a pile sits for two years and a good quality product is important to him. He commented that since the use of plastic to cover the pile lowers emissions, maybe all piles should be covered.
- Mike Dykzeul said these are all negotiable policy or procedure type issues and if a rule change is needed, the rule should just refer to best management practices the same as is done with agricultural exemptions.
- David Collier said he wanted to focus on practices in areas within close proximity to the public - he still has questions and would like to have the opportunity have that dialogue.
- Gary Stevens said would concur. His goal is supportive of what is in the best interest.
- Gregory McClarren concurred with David and Gary and said he has seen the unintended consequence of too prescriptive of a regulation. He pointed out that the notion that piles must be covered for a specific time frame (like New Mexico requires) could be too prescriptive and pointed out that the objective should be to achieve the fuel objective, forestry objective and the air quality objective.
- Stan Benson noted that looking the New Mexico six month and looking at our reforestation requirements – may put you out of the one-year window and it would be a conflict in law.
 - Gregory McClarren agreed that you come into conflict with the one year reforestation goal – in that circumstance maybe another alternative is best...that's where innovation comes in...maybe you don't burn it but remove it...
- Stephen Fitzgerald agreed that development of Best Management Practices (BMPs) is the way to go. He suggested the following BMPs: removing the plastic when possible; use of thinner material if it works; using pure PE – and certify that it is pure PE; minimize the size of the plastic used to avoid public backlash – maybe a percentage of the pile to get enough of a dry area for efficient combustion without giving the impression of burning a lot of plastic. He asked Tim Reinhardt how long pure plastic could be expected to last on a pile. Tim replied that he did not have that information but Jim Russell said he has seen it last on piles for 2-3 years.
- Jim Russell said he has seen many practices over the years – everything from using tires and napalm to burn piles – over the years burning has been innovative and now we have PE, which allows burning under better circumstances - it's an emission reduction technique and it works. It's a best management practice.
- Stephen Fitzgerald asked about the issue of geographic climate variation. He sees no geographic differences because even a few inches of rain reduces combustion.

- Erik Christiansen replied that there is difference in his opinion.
- Jim Russell added that it's a factor of cost.
- Stephen Fitzgerald said it could become a BMP and he sees the need for PE.

Bullet 1: Review important issues facing USFS, ODF, and DEQ regarding the use of polyethylene, including the role of plastic in fuels treatment and regulatory equity issues. Each agency will be asked to summarize its needs and concerns.

- Stephen Fitzgerald commented that when look at equity issue, it is an emission reduction technique and the benefits to the public and air quality are important. Through the BMPs and through ODF under the oversight of DEQ, the stewardship foresters are the ones who could really control this. Not all plastics are the same and there would be penalties for not using the right one under this exemption.
- Gary Stevens asked what about covering small piles in the back yard that could not be burned in the fall.
 - Stephen Fitzgerald pointed out that back yard burning would not be a forestry exemption...
- Lee Miller, regarding innovation, said there is one company in Oregon that had gone away from not burning – they have gone back to piles and burning because of the animal damage etc. They are a progressive company that tried removing the material, chipping it, etc., but it just didn't work and they have had to replant some areas as many as three times.

Stephen Fitzgerald then suggested that the committee make a recommendation and move it on to the next level.

- Greg McClarren said he saw no reason for it to come back to this committee once the recommendation has been made.
- Stephen Fitzgerald said he would draft a letter asking the state forester to take the committee's recommendation to DEQ.
- Brian Jennison recommended asking DEQ to consider adding an exemption and how that might be done.
- Stan Benson asked if USFS spoke for all fed agencies
 - Jim Russell responded that they (USFS) do not wish to be participants because they are not in the position to negotiate.. and asked that ODF take this to DEQ.
- It was suggested that DEQ might respond by establishing an advisory committee.
 - Mike Ziolkko said he did not what purpose would be served by going to another advisory committee to create the rule
- Greg McClarren said it would depend on what comes out of this group.
- Stephen Fitzgerald thanked Dave for putting this paper together to help focus the issue.
- Greg McClarren also expressed his appreciation for Jim writing the check that paid for the research done by URS.
- Jim Russell thanked URS and Tim Reinhardt for their work.

4. Break

5. Public Comment

Mike White, Coos Forest Patrol, noted the biggest thing foresters face is education of the public and stated that serious education is needed. He noted that the public needs to understand that PE is being used as a burning aid, not for disposal of the PE. The hazard of not burning when it's in or near the urban interface also needs to be communicated to the public. Regarding BMP, Mike thought industry

would probably be open to it - if it fit their goals etc. Most importantly he saw the need to get someone to explain why we do what we do.

6. Working Lunch (continuation of plastics discussion)

A motion was made by Greg McClarren and seconded by Jim Russell that the committee move forward with a recommendation of the Smoke Management Committee to the Board of Forestry.

It was suggested that the Smoke Management Review Committee “Request that State Forester Marvin Brown ask DEQ to consider adding a limited exemption to the open burning rule (OAR 340-264-0060-General prohibitions Statewide, Item #3) to allow PE as an emission reduction technique for the purpose of forest land burning as administered by the Oregon Department of Forestry only, to meet requirements of the SMP.”

Discussion:

- Jim Russell said he thought an exemption would be difficult to get and he would propose that it would be better to recommend ODF identify the effective and efficient use of PE as an emission reduction technique and incorporate that in the Smoke Management Plan in ODF’s OAR as opposed to looking for an exemption to the open burning regulations.
 - It was noted that conflicting rules would result.
 - Mike Ziolkko suggested a way around that would be to change the wording in DEQ’s regulation to state that “the requirements in this division are exempt from any regulation that comes under ODF regulation – or only to forestry type burning.”
 - David Collier said he could not answer the question right now but would work at finding the best place to put it in the rules.
- Gregory McClarren said it would require being able to monitor tonnage and emissions across the state in order to meet our responsibilities under Air Quality, Smoke Management and Regional Haze direction – both statutory and OAR. How we wrestle with it is important.
 - Stephen Fitzgerald suggested that if start here, ODF could work out the details and we could provide some ideas/examples of how this could be done.
- Jim Russell expressed his concern that the focus is the illegal burning of plastic and not the forest management technique and why we need the exemption.
 - Mike Ziolkko added that the justification would be part of the recommendations.
- Greg McClarren asked about forest fire risk reduction.
 - Mike Ziolkko responded that if it’s not on forested land, ODF has no authority under the Smoke Management Plan.
- Gary Stevens asked if it could it be done with an interagency agreement rather than a rule change?
 - Mike Ziolkko responded that it would need a rule change.
- Greg McClarren referred back to wildfire risk reduction and said there are thousands of acres in Oregon that are defensible space and need wildfire risk reduction.
 - Stephen Fitzgerald answered that if it’s forestland, it’s on forestland and it doesn’t matter if they’re managing it for timber or wildlife or whatever. Rangeland could present an issue.
- Mike Dykzeul suggested putting it all under the responsibility of ODF.
- Stan Benson suggested the exemption should be kept simple.
- Erik Dykzeul said he found some language in the Smoke Management Plan which states that “the Smoke Management directive is applicable to prescribed burning of forest land in Oregon within ODF Forest Protective Districts or National Forest boundaries where the intent is to

maintain the land in use for forest management purposes or as a commercial forest operation.” And the next section goes on to state that “burning on private land at anytime outside of a protection district is not part of the Smoke Management Plan.” Erik went on to say that much of the land in EO with trees on it is not in a forest protection district and is therefore not included in it.

- Mike Ziolkowski responded that the EO land is within protection districts. We may not provide protection but it’s within our protection district boundaries.
- Jim Russell asked how long this process will take.
 - David Collier said he did not have an answer – it depends on what kind of discussion can be held regarding the options for minimizing the use of plastic in areas close to populations. He did understand desire to resolve the issue as soon as possible. It would be to the benefit of all involved.
- Brian Jennison suggested a simplified request to the Board of Forestry.
- Greg McClarren suggested adding explanation/background in the letter... a key point in the recommendation is that we recommend this as an emissions reduction technique.
- Gregory McClarren said that he would argue that there is a conflict in the regulations. The conflict being that the covering is specifically provided for with no reference made to removal or the combustion thereof in the purposes of section 3 or 6. Yet in section ... it says that no plastic be burned..
- Gary Stevens suggested deferring to ODF and DEQ to work out the details.

MOTION – the following motion was made by Brian Jennison and seconded by Erik Christiansen:

Recommendation of the Smoke Management Committee to Marvin Brown:

“The SMP review committee recommends that PE be allowed for “forest practices burning”. Currently it is prohibited, as are petroleum products for ignition device under OAR Section 340-264-0060(3). We further recommend that petroleum products used solely to ignite prescribed burns (including piles) be specifically allowed. These recommendations are consistent with OAR sections 340-264-0050(4)(a) and 340-264-0040(3)(6). The reason for making this recommendation is the long-standing inconsistency in OAR and the desire to reduce emissions and improve air quality.

The vote was unanimous and a letter to include the following background and suggestions for Best Management Practices as well as findings will be drafted by Stephen Fitzgerald for final review at the January meeting.

BACKGROUND

1. Dry piles produce far fewer emissions than wet (Consume model)
2. PE emissions are negligible (URS report findings)
3. Treated paper emissions are about equal to PE emissions. Treated paper is more difficult to handle and less durable than PE.
4. PE is more durable and effective.
5. Provides a wider window of opportunity for burning piles.
6. Does not apply to backyard and other open burning.
7. Petroleum products are used to ignite prescribed burns.

SUGGESTIONS FOR BMP

1. Removal of plastic prior to burning recommended if/where/when practical.

2. Use only PE as opposed to other plastics. – certification required and administered through the stewardship forester. (and enforced on federal land through the SMP)
3. Limit quantity of PE to the amount of material needed to ensure efficient ignition.
4. Use the minimum thickness of PE to achieve efficient combustion.

FINDINGS

Proven emission reduction technique – conditions – BMP – Enforcement – stewardship forester

7. Develop Matrix Results

Stephen Fitzgerald suggested that the committee members break into three groups to facilitate completion of the Matrix results by developing a draft recommendation for each item by adding detail and suggested grouping items a and k together.

Each group would develop a report (2-5 pages) and that report would then be brought back to the committee.

Committee members chose to work through Matrix Item B together as an example.

Matrix Item “B”

Are burning objectives being met?

Context /Background

1. Burning objectives are not always being met, particularly by large industrial owners, i.e. tonnage limitations on optimal days, added cost of burning on non-optimal days.
2. Fuel objective may be met on burning on non-optimal days but silvicultural objectives may not be met.
3. Federal lands have been able to achieve their objectives because sites are more intensely prepared and this allows them to meet the objectives.
4. Industrial lands are in the Coast Range (in close proximity to DA’s) and the Willamette Valley whereas federal lands are more distant (as in SW Oregon)
5. Targets for burning on NF Land have increased east of Cascades but targets have not been met due to seasonal severity (i.e. Extended fire season) and availability of staff to do the work - get NF data
6. Regional Haze Rule, HAPS and revisions of the PM standards could further restrict burning to achieve burning objectives.
7. Changing demographics – i.e. people moving into WUII or influx of folks adverse to smoke.
8. More competition with other burning sources for (i.e. ag, range)

Options for Dealing with the Problem

1. Strategy of maximizing burning on the best days. (i.e. No tonnage limit)
2. Take advantage of and integrate current technology on a statewide basis. (Better micro - forecasting, predictive models (Blue Sky), Sodar)
3. Evaluate new technologies
4. Decentralization of Smoke Management decision-making to put the responsibility on the field.
5. Take advantage of AQ monitoring data.
6. Prioritization of burning based on site needs (reforestation) – develop protocol for prioritization.
7. Review criteria for tonnage, distance, etc. –
 - Plan based on reforestation, AQ objectives, visibility impact, risk of intrusion and micro-forecasting

8. Proactive training – burners must pass course (S360, RX410) – Education.

8. Break

9. Public Comments

There were no public comments at this time.

10. Adjourn

The Committee adjourned for the day at 1630 and will continue at 0800 on December 18, 2003, in the Operations Building, Santiam Room.

December 18

The original agenda is included but committee members preferred to continue to work as one unit rather than break into sub-groups to work on the Matrix issues.

Following a brief review of the previous days work, committee discussion of **Matrix Item B** continued.

Matrix Item B

Discussion (continued)

Will it require changes in Rule, Statute or Directive?

1. Optimizing best burn days would require a change in Administrative Rule – 629-43-043-(6)

- Need to be specific with recommendations and may need to redefine the directive in order to maximize best burn days – Erik
 - What would the changes be? Where would they go?
 - Greg McClarren – by amending section **(1)(a) – objective section**. It is the intent of the SMP to meet Forestry and AQ objectives through the use of technology, intense forecasting and strategy utilizing and maximizing “best day”. David Collier– To manage emissions to meet air quality standards and prevent/minimize impacts... and provide maximum opportunity ...

Need further information on the following:

- Check last clause “and to encourage the reduction of emissions”. Is this consistent with the suggested addition (above) to the Objective paragraph and to the Regional haze Rule.
- What do we mean by “Best Day”? The best day for minimizing intrusions in the designated area (DA)? Or does it mean the best day to ignite a burn in the coast? Or meet your objectives (which may mean meeting both).
- Where do the numbers A, B, C, come from and do they still make sense?
- Consider changing Objective Statement to Goal Statement in Administrative Rule.

(Break)

- **Directive Changes –**
 - Erik Christiansen noted that the Directive is 1-4-601 – page 4 and references the Rule - it would require change be congruent with the rule change.
 - Mike Ziolkko referred members to page 5 “smoke Management instructions” – relative to instructions to add emphasis on “risk taking” issue.
 - Jim Russell – page 4 – 1st paragraph after Weather Center, would insert “when burning is taking place within the state”.
 - Mike Ziolkko suggested that in Program Elements - 4th Paragraph – the risk-taking issue should be addressed.
 - 1st sentence – Greg McClarren suggested changing “limitations” to “criteria” and add why (which is air quality) such as “for the purpose of minimizing emissions and meeting air quality objectives.” To insure conformation with the SMP Administrative Rule (629-43-043).
 - Erik Christiansen said he was confused on what an Administrative Rule means in the State of Oregon and what a Directive is.

- Mike Ziolko explained that a Directive is policy of the State Forester, and is how the Rule will be implemented, the rule sets the limits.
- Mike Dykzeul said he thought the current directive has served us well...and really needs only some small changes (like acreage/tonnage restrictions) and proposes that money for technology is the way to go.
- 2nd sentence – Consider other criteria and that the acreage (150,000) is irrelevant.
- Consider the notion of forecasting zones.
- Mike Ziolko - Page 9, number 3, - was put in at the request of DEQ – ties in with risk-taking and tonnage figure. Is it still relevant? Consider deleting it dependent on discussion with DEQ.

(Lunch)

2. Take advantage of Technology ...

- No rule change required
- In-house - seek funding/positions to do this.
- Continue to keep Oregon SMP in leadership position.
- Part of recommendation package to State Forester
- Directive Change –
 - Page 5, Program Elements, #3, add that “Want localized (site specific) forecasting as much as reasonably feasible.”
 - Page 6, Item 7, add “and appropriate agencies” to the end of the first sentence.
 - Page 7, Item 7, ODF staff should evaluate 1 % review - is the audit needed? What’s the cost/benefit? This was included initially upon DEQ’s recommendation.
 - Brian Jennison suggested using “may” conduct a review ... rather than “shall” conduct a review... (Mike D suggested that it could be a good tool for educating the public.)
 - David Collier to check with Brian Finneran about the need for audits.
 - Stephen suggested taking a look at the standards.(Page 7)

Erik Christiansen pointed out that a possible place for directive change is on page 5. No details were provided.

3. Enhanced communication between field staff and Salem Central staff.

- May be an internal staff issue
- Improvements in micro forecasting may take care of this problem.
- Recommend to the State Forester that field managers will be educated in the consistent application and administration of the SMP.
- Constant communication between the field offices and Central Staff. - Field staff cannot override a "no burn" call central staff.

4. Develop Protocol for Prioritization

- **Rule Change** – new section in rule – Under 4 – Administration - added as c.
 - Identify criteria for identifying high priority units i.e. reforestation that have a constrained prescription window including but not limited to: proximity to DA(higher priority than Class 1., high risk units (for

escape or a lot of people), 2 – years old and brush encroachment, WUI, proximity to Class 1 area.

- **Directive Change** – Page 10, Special Guidance, subsection 2, then renumber the other subsections.

Stephen Fitzgerald suggested changing Objective Statement to a Goal Statement in the Administrative Rule.

Jim Russell – Would like to see how the program is operated reflected in the Rule and he would like to see the zonal forecasting aligned with the districts for easier management.

Public Comment:

A brief discussion was held regarding intrusions.

- Jim Trost, ODF, was present to explain intrusions. He noted that first there would be a preliminary report which basically informed field and staff that the intrusion had occurred and an intrusion report would be coming. Jim provided a sample report of an actual intrusion and explained the information included in the report. He also included a copy of the forecast and instructions for the same day. Mike Ziolk pointed out that on the day of the intrusion, the burn instructions were for 500 tons or less, spaced 15 miles apart and 15 miles from downwind DAs. The burns were 560 and 240 tons, not much over the instruction and an intrusion resulted. ODF took a chance in this situation to allow the burns. Jim Trost added that the mixing height was even better than anticipated. It was noted that the intrusion shows that the tonnage limit and spacing were exceeded and an intrusion resulted.
- David Collier asked if the forecast is normally for 24 hours out to cover residual smoke?
 - Jim Trost said the forecast is for well beyond the 24 hours.
- Nick noted that it was a light intrusion.
- Jim Trost commented that even though they really don't want intrusions, this is the kind of intrusion that helps define the limits.
- Greg McClarren asked if anyone called in and Nick said that no one called in to Salem.
 - Greg McClarren inquired what happens then? Are there consequences?
One positive thing is that the forecasters use it to tune up the science.
- Lee Miller responded that they take it very seriously. Generally he would get a call from the local regulator (district) and know they would not burn the next day. Generally they get shut down. That's how it's self-regulating.

Nick Yonker added that the intrusion report reflects on the program.

In response to questions, Mike Ziolk said that it is within the purview of the Committee to look at the following points:

1. Field administration of the program
 2. Consistency between districts and forests
- The issues would be discussed under Item K.

Future Meeting Dates:

January 22, 2004 - 0830

Wednesday - February 18, 2004 - 0830

March 18, 2004 –0830

April 15, 2004 – 0830

May 27, 2004 – 0830

June 24, 2004 – 0830

Actions:

Copies of rules and directives, one current and one with committee change recommendations will be sent via email to committee members.

Stephen Fitzgerald will have the draft recommendation regarding PE for the State Forester ready for the January meeting – it will reflect the motion, etc as agreed upon at the December 17, 2003, meeting of the Smoke Management Review Committee meeting.

The meeting adjourned at 1400.

The original agenda for December 18, 2003, had been:

1. Sub-Committees Meet	All	0800
2. Sub-Committee Reports	All	1100
3. Working Lunch Continue Sub-Committee Reports	All	1130
4. Future Meeting Dates	All	1350
5. Adjourn		

Next Meeting January 22, 2004

Committee information may be found on the web at:

http://www.odf.state.or.us/DIVISIONS/protection/fire_protection/smp/SMR/SM_Review.asp

Emissions from Burning Polyethylene-covered Silvicultural Piles

12/17/03, Salem, Oregon

Tim Reinhardt, CIH
Chris Wrobel, Ph.D.
URS Corporation

Background

- Polyethylene (PE) plastic sheeting used to keep silvicultural piles dry until burned.
- Piles burn more cleanly than broadcast burns
- Dry piles ignite easily (need less slash mix to start) and burn efficiently
- But what air toxics does burning PE create?

Background (cont.)

- URS tasked to review literature and report what the science shows
- URS performed comprehensive literature search and reviewed over 76 publications about PE and pile emissions

Background (cont.)

- PE is a plastic created from polymerization of ethylene, 1-propene, 1-butene, 1-hexene, or 1-octene (all straight hydro-carbons with a double bond)
 - Only C and H atoms in pure PE (translucent)
 - Carbon black added to color it—may include contaminants (including PAHs) in small amounts
 - High-density (HD) and low-density (LD) PE.
 - HDPE no branches—LDPE ~50 branches per 1000 carbon atoms

Background (cont.)

- Some other additives can be in formulation of some PE products, PE pellets are 98.9-100% carbon & hydrogen
- PE density ranges from 0.91 to 0.925 g/cc
- So, a 6 x 6 sheet of 4-mil LDPE weighs ~ 314 g (11.1 ounces)

PE Pyrolysis & Combustion

- PE melts at ~ 110 °C, forming a waxlike liquid. At higher temperatures, liquid and gases are formed by:
 - Pyrolysis (heat-induced breakdown into smaller alkene and alkanes @ ~180 °C)
 - Combustion (breakdown of hydrocarbons by heat & oxygen)

PE Pyrolysis & Combustion (cont.)

- PE pyrolysis forms aromatic rings at high temperatures (>730 °C)
- At temperatures below ~750 °C, 18-41% of the PE is volatilized before ignition occurs
- Pile surface temperature rises from ambient to ~ 1000 °C in ~1-5 minutes

PE Pyrolysis & Combustion (cont.)

- In a pile, most PE should melt and volatilize as temps increase from 250 to 600 °C
 - Emissions mainly aliphatic hydrocarbons and radicals (characteristic of combustion), with low percentage of aromatic hydrocarbons and PAHs
 - At higher temperatures later in burn, combustion dominates, and a higher percentage of aromatics via Diels-alder reaction
 - Once emissions are in the plume, there is insufficient heat to create more aromatics by Diels-Alder reaction

PE Pyrolysis & Combustion (cont.)

- Most studies of PE emissions were done in temp/O₂-controlled reactors at 500-1000 °C.
 - Major products are CO & CO₂, H₂O, and hydrocarbons (alkanes, alkenes and aromatics; >140 chemical species)
 - CO₂ emissions max at 600-700 °C, min at 1000 °C
 - CO emissions peak at 800 °C
 - CO and PM emissions relatively constant in such reactors—unlikely in a pile burn
 - 70-97% of PM was PM_{2.0}

PE Pyrolysis & Combustion (cont.)

- Hydrocarbon emissions peak at ~700 °C, ethylene dominates
- HCs like methane, ethane & ethylene decrease above 700 °C
- Benzene emissions peak at ~750 °C
- PAHs increase at temps > 900 °C

PE Pyrolysis & Combustion (cont.)

Chemical	Emission Factor			Mass Emitted (314 g per pile)		
	Minimum	Maximum	Units	Minimum	Maximum	Units
CO	100	175	mg/g	31	55	g
CO ₂	400	1500	mg/g	126	471	g
Acetylene	ND	2.9	mg/g	ND	0.9	g
Methane	0.2	7	mg/g	0.1	2.2	g
Ethane	0.175	0.6	mg/g	0.1	0.2	g
Ethylene	1.5	12	mg/g	0.5	3.8	g
Propylene	0.4	1.5	mg/g	0.1	0.5	g
Benzene	1.23E-02	4.78E-02	µg/g	3.86E-03	1.50E-02	mg
Toluene	3.30E-03	4.60E-03	µg/g	1.04E-03	1.44E-03	mg
Ethylbenzene	6.00E-04	1.20E-03	µg/g	1.88E-04	3.77E-04	mg
1-Hexene	1.00E-03	4.30E-03	µg/g	3.14E-04	1.35E-03	mg
TSP (soot)	8	36	mg/g	2.5	11.3	g
PAHs				0.77	39	g

PE Pyrolysis & Combustion (cont.)

- PE an efficient PAH emitter, but only at high temperatures; PE unlikely to remain in burn piles by the time they reach 900 °C
- Most of the emissions studies were controlled bench-scale reactors, with controlled oxygen supply, at constant, relatively high temps
- AP-42 EFs for air toxics were lower than these reactor experiments, but these obtained by burning bundles of PE refuse, doused with kerosene
- No studies from the diverse temps and combustion conditions found in pile burns, let alone with the PE starting only on the top of a pile

Wood Pyrolysis & Combustion

- Woody biomass mainly cellulose, hemicellulose and lignin, but still a polymer.
- Wood pyrolysis & combustion first requires preheating of fuel to drive off water
- Then at 150-190 °C:
 - Decomposition by bond scission into smaller subunits (important below 300 °C)—liberates CO₂, CO, H₂O, VOCs and oxygenated VOCs, creates reactive char
 - Above 300 °C, tar-forming reactions more important

Wood Pyrolysis & Combustion (cont.)

- Smoldering, glowing & flaming combustion
 - Smoldering: low-temp pyrolysis, oxidation of reactive char, requires little oxygen
 - Produces CO & CO₂, and more char
 - Produces many incompletely oxidized VOCs and PM
 - Glowing: higher-temp, incandescent oxidation of char, needs more oxygen
 - Produces similar products to smoldering, but at a higher rate
 - Flaming: oxidation of gaseous VOCs
 - High rate of heat release
 - More completely oxidized emission products because gas-phase combustion has more available oxygen than solid-phase

Wood Pyrolysis & Combustion (cont.)

- Rate of combustion—fuel-specific factors
 - Fuel moisture: heat used to drive off water
 - Fuel bed arrangement: optimum for a given bulk density, mass and fuel size. Need just enough, not too much space between fuel pieces
 - Fines burn more rapidly than large fuel elements

Wood Pyrolysis & Combustion (cont.)

- Emissions dominated by carbon. Flaming combustion more complete (cleaner) than smoldering/glowing combustion

Emission species	Carbon contribution (% by weight)	
	Flaming phase	Smoldering phase
Carbon dioxide	95.8	86.6
Carbon monoxide	3.0	10.1
Organic carbon particulate	0.7	2.3
Elemental carbon particulate	0.2	0.1
Methane	0.2	0.5
Nonmethane hydrocarbons	0.1	0.4

Compound	Emission Rate (g/kg)		Mass Emitted ¹ (g)	
	Minimum	Maximum	Minimum	Maximum
Acetic Acid	1.6	4.4	963	2631
Ethylene	1.1	3.3	661	1961
Methane	1.2	19.4	739	11601
Carbon monoxide	28.2	359.0	16834	214682
Carbon dioxide	1146	1771	685308	1059058
Formaldehyde	ND	2.4	ND	1423
Formic acid	0.7	1.6	425	939
Hydrogen cyanide	0.6	0.6	365	365
Methanol	0.8	4.3	493	2571
Ammonia	0.3	1.5	169	891
Nitric oxide	0.9	2.3	526	1357
Nitrogen dioxide	0.6	0.6	360	360
Sulfur dioxide	1.2	1.2	705	705
PM	6.0	34.2	3588	20452
PM2.5	2.8	17.6	1674	10525
PAHs (total)			15.3	20.7

Discussion

- Combustion chemistry complex, but some general conclusions can be made
 - PE is nearly pure hydrocarbon, melts easily
 - Pyrolyzed PE rapidly breaks into waxlike hydrocarbons that should:
 - Volatilize
 - Drip to lower levels in the pile, then volatilize or burn analogous to a candlewax supporting a flame on a wick
 - Reactor studies indicate PAHs efficiently formed at high temperatures
 - These unlikely to represent pile burn conditions
 - AP-42 EFs were lower, for example

Discussion (cont.)

- Wood is also a polymer, but more heterogenous (contains O, N, some S)
 - Supports solid-phase combustion (dirty)
 - Produces typical combustion products, and similar VOCs to PE
 - Produces more oxygenated VOCs (aldehydes, ketones, etc.) than PE
 - Silvicultural burn emission factors for PAHs are orders of magnitude lower than wood stoves—more oxygen likely key reason

Discussion (cont.)

- Using ranges of emission factors for PE and wood, and amounts of each in an 8-foot diameter pile (314 g/598 kg), PE emissions appear insignificant, except for PAHs, but only if:
 - 1) the upper estimate EFs from reactor studies are used
 - 2) no assumption is made that up to half the PE will volatilize before temperatures reach 900 °C

Discussion (cont.)

- Pure PE is available, black sheeting contains additives. Visual inspection, MSDS review could lead to list of “approved” products
- MSDS sheets won’t provide details on potential combustion products
- Using smaller pieces of PE would produce less emissions from the PE, but this is likely to be offset by dirtier emissions from damp-edged piles
- Using 1-mil or 2-mil sheeting would produce ¼ to ½ the emissions compared to 4-mil sheets of PE

Discussion (cont.)

- No benefit to weathering PE
- Alternatives include wax-coated kraft paper
 - Wax (paraffin) will burn like PE pyrolysate
 - Paper may contain traces of residual sulfur, but will otherwise burn like the wood

Conclusions

- No good evidence to disfavor PE based on toxics emitted
- No measurable impact likely, except for PAHs using assumptions considered conservative and inappropriate to pile combustion environment (worst-case)
- Using thinner sheeting, if only causes a few holes/pile, probably best emission control method at least cost

Conclusions (cont.)

- Could perform further analysis:
 - Emissions/transport modeling for piles to estimate concentrations at downwind receptors
 - Assess short-term/long-term health impacts via screening risk assessment for each potential pollutant
 - Determine whether risks are significant enough to warrant actual emissions measurements

Conclusions (cont.)

- Comparative emissions study possible, but difficult & costly to assess all pollutants from operational pile burns with much accuracy (~\$150k+)
- If emissions study critical, better to greatly narrow the measured pollutants to chemicals of concern, via risk assessment ranking (~\$15k)

ZIOLKO Mike E

From: Jim Brown [jimbrownorch@msn.com]
Sent: Thursday, December 18, 2003 7:20 AM
To: SMITH Cindy
Cc: ZIOLKO Mike E
Subject: Fw: Clean Burn

Cindy -

Unfortunately, I will be unable to attend the meeting today (Thursday), due to continued - but thankfully decreasing - illness. I will call, or Cindy please telephone me at 503-284-6455 to confirm receipt of this e-mail. I do want my comments conveyed to the committee.

I have forwarded the e-mailed material which I received yesterday. It looks like a scan of a copy of aetc., but the figures are readable at least to an order of magnitude. There is more info on the way to me. I will forward it as soon as I get it. Sorry the info is so late. I began re-rattling cages two weeks ago!

Please have someone on the committee read the following comments (my own) at the meeting for the record:

1. *Kraft paper and the resins to make it weather-resistant have the advantages of being derived from a renewable resource, wood. To consume a **wood product** for a **wood-producing** purposes seems appropriate and benignly self-serving for the **wood-product** industry. My personal preference favors the use of paper.*

2. *On the pollution side, I would be surprised to learn that a sheet of resin-containing kraft paper produces less pollutants than an equal-area sheet of the polyethylene film we have been discussing - under identical slash - burning conditions. That said, compared to the quantity of pollutants emitted by the slash being burned, and considering that the whole purpose of smoke management is to get the smoke aloft, pollutants from either covering material are genuinely trivial.*

3. *A 6-by-300-foot roll of treated kraft (per Terra Tech) weighs 48 pounds. I do not know how that compares to the weight of the polyethylene. I do not know how durabilities of the kraft and polyethylene compare.*

I have the names of companies which produce and vend kraft. I have not included them here because I do not know whether that information should be a part of the record. It was interesting to hear from one company rep that his company very recently shipped a single order of 400 rolls of kraft paper to Oregon.

I hope this information is helpful to the committee's decision-making process.

Jim Brown

p.s. **IMPORTANT.** Due to reliability issues at my previous ISP, I have made a change. **New e-mail** is jimbrownorch@msn.com

----- Original Message -----

From: Barbara Nelson
To: jimbrownorch@msn.com
Sent: Wednesday, December 17, 2003 1:22 PM
Subject: FW: Clean Burn

-----Original Message-----

From: Barbara Nelson [mailto:barbara@svwpc.com]

12/18/2003

SALINAS VALLEY WAX PAPER CO., INC.

POST OFFICE BOX 68 • SALINAS, CA 93902
1111 ABBOTT STREET • SALINAS, CA 93901
(831) 424-2747 • FAX (831) 424-5883

MESSAGE

DATE 12/15/03

TO: Jim Brown
Portland

FROM: Charlie Nelson
Add'l Pages _____

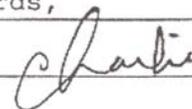
Re: Info on wet strength additives and Rosin Sizing used in making
paper for "CLEAN BURN" Slash Pile Cover
Smoke Management review Committee/Oregon Dept. of Forestry

Following is copy of letter we received when similar questions came
up in conversations with USDA/Forest Service back in 1999. This letter
seems to address some of the questions we discussed.

In addition, I expect to have in a few days, some information from the
Hurcules Co. regarding the rosin sizing used in the paper manufacturing.
Gentlemen at Hurcules told me the rosin sizing was pitch that has been
refined into a micro colloidal form to be used in making various
types of paper. He was going to run it past his tech people and try
to provide us with some sort of statement we can pass along to you.
He was not aware of any sort of testing that had been done regarding
what would be produced when rosin sizing burned-he agreed that since
pitch came from a tree, the products of combustion should be no different
than burning trees(trimminqs).

If any question, please call-I am not a chemist, but I'll try to help
you get answers.

Best regards,





Georgia-Pacific Resins, Inc.

a wholly owned subsidiary of
Georgia-Pacific Corporation
2683 Miller Road
Decatur, Georgia 30035-4088
Telephone (770) 653-6300

October 8, 1999

Lee Jenkerson has asked me if we have any information on combustion products of our polyamide wet strength resins. I'm afraid we don't, but in trying to help you, we have done a literature search, and we would like to share what little information we found with you.

We have not found any published studies on comparison of combustion products of paper treated with polyamide wet strength resins to those of untreated paper, which is probably what would be most helpful to you. We did find some data on combustion products of glossy paper, nonglossy paper, cardboard, and some other fuels. I have attached a copy of page 116 from the 4th edition of Kirk-Othmer's "Encyclopedia of Chemical Technology".

I have also attached an abstract of an article that was published in the Organohalogen Compounds Journal in 1994. The authors analyzed emissions from the burning of packaging materials and compared them with emissions from the burning of biofuel. They were looking for certain toxic chlorinated compounds. They reported comparable emissions for the packaging materials and for the biofuel.

The only data we have that I think might be useful to you is heavy metal analyses. We have analyzed a number of our polyamide wet strength resins for heavy metals with all of them being below the minimum detection limit. Antimony and mercury were < 0.3ppm, arsenic and lead < 0.2ppm, barium < 0.5ppm, cadmium and chromium < 1.0ppm, and selenium < 0.25ppm. As you can see in the Kirk & Othmer table, these values are much lower than the published levels of metals in wood, paper, and the other fuels listed.

Sincerely,

Ralph B. Sorstokke
Product Information Scientist

12/15/03

"Clean Burn" Paper for covering slash piles would be close to the cardboard heading below, but without any of the adhesives used to produce the cardboard (corrugated); might consider this product in non-glossy category, but there are so many types of paper that could fit this generality would be just a reasonable guess.

Table 10. Analysis of Re-use-Derived Fuel^a

Parameter	Glossy paper	Nonglossy paper	Cardboard	Film plastics	Rubber, leather, and hard plastics	Wood and textiles	Other organics	Total RDF ^b
	<i>Trace metals, mg/kg fuel</i>							
arsenic	3.1	3.3	3.5	2.7	2.5	5.2	4.6	4.0
barium	285.1	78.9	48.7	186.5	724.3	96.7	210.0	172.2
beryllium	1.1	1.3	1.2	0.5	0.4	1.5	1.5	1.3
cadmium	1.1	1.3	3.8	7.7	17.3	3.0	9.1	3.4
chromium	23.8	37.3	23.2	69.4	95.9	34.8	44.5	42.7
copper	74.6	49.3	27.0	2740.7	12.1	202.3	61.4	220.1
lead	88.4	621.2	66.2	836.6	688.1	747.6	475.1	495.5
manganese	61.2	187.6	101.1	311.8	83.1	163.9	367.3	250.4
mercury	0.3	0.7	0.4	1.0	0.4	0.9	1.2	0.9
nickel	10.4	16.5	25.5	45.6	170.4	27.4	17.7	24.4
selenium	3.1	2.9	3.3	2.1	2.0	3.5	3.8	2.9
strontium	62.4	73.2	47.8	86.5	88.6	198.9	474.8	283.2
zinc	164.5	227.5	161.4	482.2	2494.5	449.4	360.0	380.2
	<i>Ultimate analysis, wt %</i>							
carbon	43.4	47.3	49.6	59.8	59.5	50.1	34.6	41.1
hydrogen	5.3	6.1	6.4	8.2	8.9	6.0	4.3	5.3
oxygen	27.5	32.0	35.7	13.8	23.3	31.5	41.1	35.2
nitrogen	0.62	1.58	0.72	1.01	0.83	1.07	1.87	1.12
sulfur	0.35	0.25	0.24	0.56	0.67	0.28	0.38	0.34
chlorine	0.04	0.04	0.05	0.10	0.05	0.05	0.01	0.07
ash	23.0	12.7	7.4	16.8	12.5	11.0	18.3	16.5
higher heating value, MJ/kg ^b	14.7	19.7	18.5	31.0	25.4	21.0	16.5	18.7

^aFuel produced in Tacoma, Wash. Values on oven-dry (OD) fuel basis, Ref. 12. ^bTo convert MJ/kg to Btu/lb, multiply by 430.3.