PROCEEDINGS OF THE NATIONAL FIRE EMISSIONS TECHNICAL WORKSHOP

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1 INTRODUCTION

1.1 Background

Wildland, prescribed, and agricultural fires are important sources of airborne fine particulate matter ($PM_{2.5}$) emissions across the United States (U.S.). Fires release $PM_{2.5}$ directly into the atmosphere, and also produce gaseous pollutants that can react in the atmosphere to form secondary $PM_{2.5}$. These precursor pollutants include nitrogen oxides (NO_X), volatile organic compounds (VOC), and ammonia (NH_3). Small amounts of sulfur dioxide (SO_2) are also released.

Emissions from fires contribute to elevated ambient concentrations of $PM_{2.5}$, and impairment of visibility. Section 169A of the Clean Air Act establishes a national goal to improve and protect visibility in mandatory Class I Federal areas where visibility is an important value. Section 169A also calls for regulations to ensure “reasonable progress” toward the national visibility goal.

1.2 Purpose of the Workshop

This workshop culminated from a need to improve communication between the different stakeholders. By providing an open forum, common needs and goals were identified and areas of divergence realized. New tools, technologies, and methodologies were presented with a focus on development of tools not yet available. Ultimately a suite of common tools will be identified for a broad spectrum of users in an effort to reduce the duplication of efforts between the Regional Planning Organizations and Federal agencies, and to increase transparency of use. As this workshop was open to not only air regulators, but also land managers, it will strive to balance the objectives of all stakeholders. Participants will assess current fire emission tools, identify ways to improve existing tools for current and future use, and strive to maintain strategies to accomplish workshop findings and recommendations.

1.3 Workshop Goals

The overall goals of the workshop were to identify the short-term and long-term solutions to many common problems in creating fire emissions inventories, specifically in activity, consumption and emission estimation topics. Specifically, the overarching goals were to:

1. Identify common ground on a national level and develop consistent technical approaches to produce tools that benefit all RPOs.
2. Identify the regional/state/tribal/local conditions that dictate the need for approaches specific to these conditions.
3. Identify methods to project future fire emissions for planning purposes (2018 and other milestones).

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4. Consider the needs of SIP/TIP planning and development in the assessment of technical approaches and needs.
5. Publish workshop findings and develop a strategy with milestones to ensure the implementation of a responsible entity to oversee the process.

Table 1-1 presents the workshop agenda. The workshop was divided into two tracks: Fire Activity Tracking, and Fuel Consumption and Emissions. The sessions within each track contained one or more presentations. In addition, five plenary sessions were held to present background information on the two tracks, highlights of current approaches to develop fire emissions inventories, information on efforts to develop fire emissions inventories in Canada and Mexico, and background information on Emission Reduction Techniques (ERTs).

Full presentations can be found on the National Fire Emissions Technical Workshop Interactive Agenda web page hosted on the WRAP Fire Emissions Joint Forum site.[1] The letter and number combinations in the agenda (e.g., T1/P1) link to the session title and corresponding presentations on the website. A list of presenters and contact information is available in Appendix A.

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Table 1-1. Workshop Agenda

[Workshop Agenda available in PDF version only]

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1.4 Report Format

This report presents the issues, presentations, discussions, and recommendations of the National Fire Emissions Technical Workshop. The report is structured in the following format:

- 1 Introduction
- 2 Fire Emissions and Air Quality Planning: Highlights of RPO Approaches
- 3 Fire Activity
    - 3.1 Overview
    - 3.2 Fire Activity Tracking
    - 3.3 IMPROVE, Tracers, & Source Apportionment
    - 3.4 Remote Sensing/Geographical Information Systems (GIS)
- 4 Fuel Consumption and Emissions
    - 4.1 Overview
    - 4.2 Fuel Characterizations
    - 4.3 Fuel Consumption and Fire Emissions Modeling Systems
    - 4.4 Emission Factors
    - 4.5 Other Air Quality Model Input Needs
    - 4.6 Quality Assurance of the Emissions Modeling Process
- 5 Agricultural Burning
- 6 Projections
    - 6.1 Overview
    - 6.2 Methods for Developing a Projection-Year Inventory
- 7 International Fire Emissions Inventory Development
    - 7.1 Overview
    - 7.2 Fire Emission Inventory Efforts in Canada and Mexico
- 8 Emission Reduction Techniques
    - 8.1 Overview
    - 8.2 Emission Reduction Techniques and Smoke Management Plans
    - 8.3 How to Reflect Emission Reduction Technologies (ERTs) and Alternatives to Burning
- 9 Conclusions and Recommendations
    - 9.1 Short Term Recommendations
    - 9.2 Long-Term Recommendations and Needs

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The workshop steering committee has agreed to continue with conference calls for some immediate remaining issues such as data elements, cross-boundary emission migration, emission modeling tools, short-term remote sensing opportunities, source apportionment, monitoring, and plume rise. As these topics continue and come to completion, they will be included in these proceedings.

2 FIRE EMISSIONS AND AIR QUALITY PLANNING: HIGHLIGHTS OF RPO APPROACHES

Highlights of the RPO Approaches to Fire Inventory Development (Mark Janssen)

Regional Planning Organizations (RPOs) are responsible for developing regional haze plans in accordance with the Regional Haze Rule. There are five RPOs in the nation: the Midwest RPO, the Central States Regional Air Partnership (CENRAP), the Visibility Improvement State and Tribal Association for the Southeast (VISTAS), the Mid-Atlantic/Northeast Visibility Union (MANE-VU), and the Western Regional Air Partnership (WRAP). Each region covers at a minimum five States (Midwest RPO), and a maximum 14 States (WRAP). In order to develop regional haze plans, RPOs are developing emissions inventories for all sources of visibility impairing pollutants, including wildfire, prescribed fire, and agricultural burning. Each RPO has different goals and methods for obtaining results based on stakeholder needs, available resources, and relative importance of the issues**.**

As part of the regional haze plan, fire emissions inventories are in development for each region. Fire emissions inventories may include wild, prescribed, and agricultural fires. These inventories compile data such as fire activity tracking, fuel characterization, fuel consumption, emission factors, weather data, and information for projections. Data for each section is detailed below concerning sources and methods of compilation in each region.

Fire tracking is compiled at various governmental levels across the U.S. At the Federal level, incident databases are compiled by the Bureau of Indian Affairs (BIA), the Forest Service (FS), the Fish and Wildlife Service (FWS), the Bureau of Land Management (BLM), and the National Park Service (NPS). At the State level, each State may track fires at different levels of detail depending on the relative importance of fire and smoke in the area. Some western States, for example, may track all data elements needed to produce a robust fire emissions inventory, while States in the northeast may not have a centralized data collection system in place for fire tracking. Table 2-1 summarizes the data sources used by each RPO and State in developing fire inventories.

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Table 2-1: Fire Tracking - Databases: Federal, State, and Local

Source: Janssen, 2004.

		Midwest RPO	**CENRAP**	**VISTAS**	**MANE-VU**	**WRAP**
Federal Incident Databases	ICS209	Compared to NIFC summary report & Agency-specific databases	Used databases (NIFMID, NFPORS) compiled from incident reports.	Obtained QA'd database from Bruce Bayle for WF and Rx burns and P. Lahm for WF in the SE for 2002 and specific months in 1999		Obtained QA'd data base from P. Lahm with WF records for all WRAP States.
	BIA, Parks, F&W, BLM, FS (1202)	Obtained QA'd dbase from DRI for 2001-2002, downloaded data from NWCG website for 2003	NIFMID - downloaded data from NWCG website for 2002.			Obtained QA'd database from P. Lahm with WF records for all WRAP States. QC work performed to avoid duplications with ICS209 data and to account for fire complexes.
State/Local Incident Databases		IL, IA (2003 only), IN, MI, MN, MO, OH, WI	AR, LA, MN, and OK	For wildfires, electronic data received from AL, FL, GA, KY, NC (hard copy only), SC, TN, VA and WV	MD, DE, PA	Rx fire data submitted electronically or in hard copy format. Augmented NFPORS data and DOI 1202 Rx fire
State Summary Databases		IA (2001-2002), MO (Rx), WI	TX, MO, and KS			
NIFC Summaries		Compared to incident databases		Not used	Local agencies - Rx burning permits (MD, DE), State fire marshals	Used for QA purposes and to assess reasonableness of State-specific data.
NFPORS for Rx fires			Obtained for Minnesota and Missouri only	Data was received from AL, FL, GA, MS, and SC from State permit records; from AL, FL, GA and SC for ag burning; and AL, FL, GA and SC for debris		Obtained from FS and integrated into database. Used as supplemental data to augment (as appropriate) State submittals for Rx fire.

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Fuel characterization is as important to the development of fire emissions inventories as tracking. Different fuel types will have different rates of burn and spread, different heat capacity, and different emissions. As fuel types change across the landscape, it is understandable that each region will have their own methods for characterization. Some regions use the National Fire Danger Rating System (NFDRS) developed by the FS, while others use the Biogenic Landcover Database version 3 (BELD3) developed by the EPA, and still others use a combination off the two augmented with other sources. Table 2-2 summarizes the approaches used by RPOs and States to characterize fuels.

Fuel consumption and emission factors are estimated using several methods, including modeling software and studies developed by the FS, and EPA's AP-42. The modeling software currently available includes the First Order Fire Effects Model (FOFEM) version 5.11 and Consume version 2.1. Both models predict emissions based on data such as fuel type, region and/or location, fire size, and vegetation. The Midwest RPO and CENRAP both used FOFEM for their inventories for most of the criteria pollutants. VISTAS and MANE-VU used the AP-42 and other documentation, and the WRAP used the NFDRS fuel loading table. For pollutants such as NH_3, EC and OC other means of estimation are required as the models do not estimate these pollutants. Only the Midwest RPO, CENRAP and WRAP have estimated emissions for these pollutants. Table 2-2 summarizes methods used to compute fuel consumption and emission factors.

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Table 2-2: Fuel Characterization

Source: Janssen, 2004.

	Midwest RPO	CENRAP	VISTAS	MANE-VU	WRAP
Forest Service	NFDRS code from database, modified by Midwest FCCs, cross-check with BELD3	BELD3, database fuel codes	NFDRS code from database	Depends on data States can obtain from local agencies	Explicit fuel loading; NFDRS fuel model code; vegetation type description; no information. If no information, GIS application to link incident location with national + AK NFDRS cover map to assign fuel model code and crosswalk to NFDRS (modified) fuel load values table.
ICS-209	Correlated fuel model code to NFDRS		NFDRS code		
BIA, Parks, F&W, BLM	Linked to NFDRS map	BELD3, database fuel codes	State supplied value or NFDRS code assigned by vegetation type listed		
States with fuel codes	Same as FS/ICS-209	BELD3, database fuel codes	NFDRS code assigned by vegetation type listed or default State value used from EPA wildland fire resource document depending upon what State supplied	DE	
States without fuel codes	Same as DOI	BELD3	None. Fuel loading values were developed by NFDRS code based on a default value, compared with EPA values from "Data Needs and Availability for Wildland Fire Emission Inventories - Short-term Improvements to the Wildland Fire Component of the National Emissions Inventory" along with review by SE forestry experts for reality check.		

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Table 2-3: Fuel Consumption and Emission Factors

Source: Janssen, 2004.

	Midwest RPO	**CENRAP**	**VISTAS**	**MANE-VU**	**WRAP**
Fuel Combustion/Consumption Model	FOFEM	FOFEM	"Data Needs and Availability for Wildland Fire Emission Inventories - Short-term Improvements to the Wildland Fire Component of the National Emissions Inventory" values or AP-42 depending upon fire type. Wildland fire values were from EPA document	DE, WRAP emission factors; PA, AP-42	NFDRS fuel loading table modified by Emissions Task Team of the Fire Emissions Joint Forum to account for variability in fuel consumption rates for different fuel types (1h, 10 hr, duff, crown, etc.). Smoldering emissions added to events (WF and Rx) associated with heavier fuel loads.
NH3, EC, OC emission factors	EPA Wildland Fire Resource Document	NH3 emission factors derived from those for NOx, CO2, and CO.			NH3 - fraction of CO per OAQPS compilation report. EC & OC - fraction of PM2.5 per OAQPS compilation report.

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Agricultural fires present a more complicated challenge regarding emissions estimations. Activity data is not normally contained in central repositories, nor is it compiled by one agency. Also, not all crops burned have emission factors. The combination of sparse activity data combined with few emission factors make inventory development difficult, none-the-less agricultural burning must be included. Table 2-4 details the different sources of data each region has used.

Emissions inventory results are used as input into emission and photochemical models. These models are used to see impacts of emissions on visibility and air quality for either the entire region or portions of the region. These models take into account the local climatic events to estimate the dispersion of the pollutants both spatially and temporally. The results are allocated monthly and/or hourly depending upon the needs of the RPO. Emission models include Sparse Matrix Operator Kernal Emissions (SMOKE) modeling system used by all the RPOs except the Midwest, and the Emissions Modeling System (EMS-2003) used by the Midwest RPO. For the photochemical models the VISTAS and WRAP used the Community Multiscale Air Quality (CMAQ) modeling system, the Midwest RPO used the Comprehensive Air Quality Model with extensions (CAMX), and the MANE-VU used a combination of the Regulatory Modeling System for Aerosols and Deposition (REMSAD), the California Photochemical Grid Model (CALGRID), and CMAQ. Plume rise models are also used. However, at this time only three RPOs are calculating plume rise: the Midwest RPO, VISTAS, and WRAP. Both the Midwest RPO and VISTAS are using the WRAP/FS methodology for height distribution, and the WRAP developed a methodology to assign “hard coded” plume characteristics for each fire event.

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Table 2-4: Activity Data and Emission Factors

Source: Janssen, 2004.

	Midwest RPO	**CENRAP**	**VISTAS**	**MANE-VU**	**WRAP**
Activity Tracking					
Incident Reports	IA (2003 only), IN, MI, MN, WI		AL, FL, GA and SC only	DE, MD	Agricultural burning data from States and agricultural extension offices. Gap-filling using crop production & BELD data for areas with no data. Temporally aggregated data (monthly, annual) broken into daily, realistically sized events through stochastic modeling techniques.
Expert Input	MO, OH, IL	Surveyed Ag Extension Offices in each county (AR, IA, LA, KS, MN, MO, NE, OK, TX)	None		
By Crop Type		Survey questions were crop-specific.	Limited		
Prairie Restoration	Listed in incident report for Illinois		N/A		
Emission Factors					
Emission Factor Source	NFDRS for grasses, AP-42, Jenkins	AP-42, Jenkins	AP-42	AP-42 (Table 13.1-2, Table 13.1-1)	Crop specific emission factors for approximately 70 crops compiled by B. Jenkins, PhD, UC Davis. Source data from AP-42 and UC Davis emissions studies.
Emission Factor Model	FOFEM for grasses	FOFEM for grasses (rangeland)	AP-42		Crop specific emission factors for approximately 70 crops compiled by B. Jenkins, PhD, UC Davis. Source data from AP-42 and UC Davis emissions studies.

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Table 2-5: Modeling Issues

Source: Janssen, 2004.

	Midwest RPO	**CENRAP**	**VISTAS**	**MANE-VU**	**WRAP**
Monthly Allocation	Random assignment of incidents to days	Used fire incident dates and ag survey responses to generate monthly profiles.	Monthly profiles developed from fire by fire data for wildfires and prescribed burns	DE, date and duration of WF and Rx can be summed to obtain monthly emissions	No monthly allocation. Multiday wildfire events are converted to a series of daily events; daily acres estimated using *spreading oval* algorithm (modified FEPS method).
Hourly Allocation	Standardized diurnal profiles by NFDRS and Wild or Rx	Used SMOKE-formatted diurnal profiles recently distributed by Houyoux.	EPA/SMOKE Profiles		Diurnal profiles provided to WRAP's Regional Modeling Center for hourly allocation of daily emissions.
Repair Missing Coordinates	Aassign to wildland grid squares	Assign to forested land/grassland grid squares	Coordinates checked using GIS system prior to inclusion in inventory. Coordinates outside of appropriate boundaries (e.g. in ocean) deleted - resulted in <3% of acreage being lost		Several GIS-based QC techniques employed: T/R/S to lat/lon; county info to county centroid lat/lon (some Ag data); locations outside of modeling domain; water bodies; conflict with reported lat/long investigated & repaired
Plume Rise	WRAP/FS methodology modified for height distribution		WRAP/FS methodology modified for height distribution		Emissions Task Team developed methodology to assign *hard-coded* plume characteristics for each event. Plume characteristic assignments based on idealized estimates of heat release & buoyancy.
Emissions Model Used	EMS-2003/. Concept in late 2004	SMOKE version 1.5	SMOKE v.2	SMOKE	SMOKE

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Table 2-5: Modeling Issues

Source: Janssen, 2004.

	Midwest RPO	**CENRAP**	**VISTAS**	**MANE-VU**	**WRAP**
Photochemical Model Used	CAMX		CMAQ	CMAQ, REMSAD, CALGRID	CMAQ
File Format for files	NIF3.0 Point Sources.	Produced both NIF3.0 and IDA-format files.	IDA PTINV/PTDAY/PTHOUR; IDA ARINV	IDA, NIF 3.0(?)	PT files for SMOKE; all incidents represented as point sources.

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RPOs are also tasked with calculating projections of fire activity for their regions. For the Midwest RPO, CENRAP, and VISTAS, historical data by county and month was used. The WRAP has projected activity to 2018 by scaling 1996 activity with long term averages for wildfires. The Grand Canyon Visibility Transport Commission (GVCTC) 1995 Fire Emissions Project was used to estimate prescribed fire activity for 2018. MANE-VU has no calculated projections at this time.

Table 2-6: Projections

Source: Janssen, 2004.

Midwest RPO	**CENRAP**	**VISTAS**	**MANE-VU**	**WRAP**
Historic data by county/month	Historic data by county/month.	Historic data on a fire by fire basis where possible converted to county annual data with monthly profiles based on actual fire by fire data		2018 developed for WF (typical wildfire year), Rx fire, and agricultural burning. Typical WF estimates based on scaling 1996 WF activity by long term WF averages in the Western US. Rx fire based on Grand Canyon Visibility Transport Commission (GCVTC) 1995 Fire Emissions Project .

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Within the scope of this workshop, RPOs are interested in sharing ideas and methodologies regarding fire tracking, fuel characterization, consumption, agricultural, modeling issues, project specifics, and projections. There are new tools and data systems available, or in development, which should ease the inconsistencies and through transparent means, aid land and air regulators at all levels. Also in development is a means of compiling data in a manner that will be transparent for all parties.

3 FIRE ACTIVITY

3.1 Overview

National Fire Activity Tracking (Sheldon Wimmer)

There are many methods of collecting fire activity data. Data are collected at varying degrees of spatial and temporal resolution, and often data elements required to develop a fire emissions inventory are not collected at all (e.g., fuel characteristics, burn duration). Many State and local agencies only collect fire data for the purposes of resource accounting as opposed to emissions inventory development, and do not collect data elements such as fuel type, fuel loading, blackened acres, or start and stop times and dates of fires. In addition, many agencies do not have resources dedicated to collecting fire activity data, especially in regions where fire activity is sparse. However, with the introduction of new particulate matter National Ambient Air Quality Standards (NAAQS) and the Regional Haze Rule, fire activity data collection has become important for all areas of the United States, as well as Canada and Mexico.

Figure 3-1 shows the aspects involved in fire activity data collection. As mentioned above, data quality objectives will vary widely among different regions of the country, and affect the data elements required to produce a fire emissions inventory. However, even if data elements are defined, it is difficult to obtain the data needed to develop an inventory. Data collection systems are decentralized and inconsistent. Double-counting and overlap of fire incidents often occurs. Fire activity data often needs to be augmented due to incomplete reporting. This may include the use of summary data, remote sensing tools, and fuel characterization maps. Finally, data must be quality-assured for completeness and correctness (e.g., correct fire locations, reasonable start and stop times and dates, reasonable fuel characterization).

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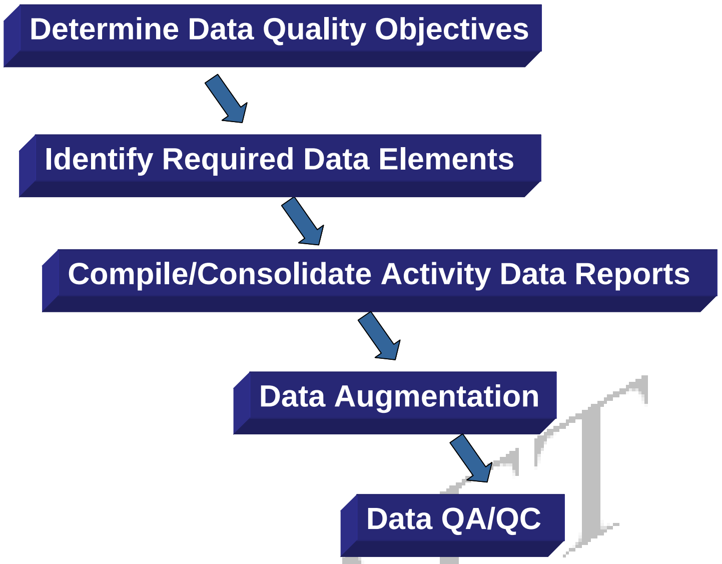
Figure 3-1. Fire Activity Overview



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The following sections discuss the issues surrounding collecting fire activity data, required data elements, and data augmentation.

3.2 Fire Activity Tracking

3.2.1 Purpose

Fire activity tracking is the first step in creating an accurate fire emissions inventory. Unfortunately, there is no standard for collecting fire activity data on a National, regional, State, or local level. Lack of resources contributes significantly to this problem, especially in attainment areas or where fire activity is not prevalent. The *Required Data Elements* and *National Fire Activity Database & Options* sessions encouraged discussion of the issues surrounding the development of a consistent fire activity reporting system and the data elements needed to create a robust fire emissions inventory.

3.2.2 Presentation Summaries

Required Data Elements (Sue Ferguson)

An introductory presentation outlined issues in gathering required data elements, including the following:

- Spatial, temporal, and *de minimus* scale issues

- Data elements, including time and location, fuel type and condition, and Burn information
- Data formats
- Data quality objectives

The presentation laid the groundwork for discussions on fire activity data, as well as short- and long-term needs. It discussed how spatial scales can vary widely with each measurement tool. Fire reporting systems may have *de minimus* cutoffs; for example, the ICS-209 reporting system does not include forest fires below 100 acres and grass fires below 300 acres. Different satellite systems also cover a broad range of resolutions. A typical satellite generally picks up fires greater than 250 acres, but the MODIS satellite has a *de minimus* cutoff of 15 acres.

Temporal scale issues include air quality observations, which can take anywhere from minutes to several days to process depending on the observation; remote sensing, which can produce a wide range of temporal observations; and fire reports, which can vary anywhere from the exact start time of the fire to annual summary reports. *De minimus* scale issues focused on the question of how small fires can be without affecting air quality and/or visibility. A small fire less than 10 acres can cause plume blights over Class I areas, for example.

Time and location, fuel type and condition, and burn information were proposed as minimum required data elements. “Lessons learned” from collecting each of these data elements were also discussed. Some required data elements can be approximated from known information. For example, time of ignition can be approximated by burn type, and burn scenarios can sometimes approximate location. If regulations for a particular county specify that all prescribed burns must occur between 9:00 a.m. and 5:00 p.m. in March, much of the needed fire data can be extrapolated from this information.

Data formats and data quality objectives were also mentioned. Data formats for wild and prescribed fires are varied and inconsistent. For example, different reporting requirements can cause double counting of acres, especially when individual fires merge to become fire complexes. Data quality objectives vary depending on the user; one user may require specific scientific information, while another may only want to know if the fire was extinguished in a timely manner.

National Fire Activity Databases & Options (Sheldon Wimmer, Dennis Haddow)

Seven national fire occurrence databases currently exist, and different agencies report to different databases. For example, the National Interagency Fire Management Integrated Database (NIFMID) is used solely by the Forest Service, and includes historical incidents for all fire types to 1970. The National Fire Information Reporting System is used only by some State forestry agencies and municipalities, and not all States have the wildland fire module incorporated into the system. Further, not all State agencies are required to report to this system.

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Other systems, like the Incident Status Summary Reports (ICS-209), only capture timber fires more than 100 acres and grass fires more than 300 acres.

Different reporting systems present the problems in collecting consistent fire activity information. While all existing databases report location, start and end dates, fire type, and fuel information at some level, a host of reporting issues has surfaced regarding the basis of acres reported (e.g., blackened vs. perimeter acres), spatial and temporal data (e.g., duration of burn, lat/lon vs. county resolution), and accurate fuel loading (e.g., regional defaults vs. stand-specific information). In addition, many of these databases are not available to the public.

3.2.3 Discussion

Required Data Elements

In the presentation on required data elements, the following questions were used as a guideline for discussion:

- What elements are needed to estimate emissions?
- What default assumptions should be used when data is unavailable (e.g., how should fires be allocated)?
- What format is most effective for creating emission inventories?
- What Data Quality Objectives should be obtained?

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Participants discussed the need to define spatial and temporal scales up front. This approach would be a sensible way to organize outcomes and discussions for fire tracking in the future because people could be talking about different scales without realizing it. This approach would be especially useful in discussing regional haze.

Measurement of secondary organic aerosols (SOA) was mentioned as a data element needed to estimate emissions. Secondary organics are more important than primary organics, and they are also less understood. The data elements needed to model SOA are currently available, but there is inadequate communication between regional haze/chemical transport modelers and foresters.

National Fire Activity Databases & Options

Different agencies are using different systems. In fact, 34 different systems currently exist. The reason for the number of different systems is a combination of different needs and the unwillingness of agencies to coordinate a standardized system. Any common reporting system will need to be flexible and accessible to everyone.

From a State agency’s standpoint, the main problem is a lack of protocol or guidelines. Most States have their own system of emissions reporting, and they have not been compatible in the past. However, now that EPA has established the National Emissions Inventory (NEI) Input Format (NIF), some standard has been established for emissions reporting in general. Protocol does not currently exist for fires, but it could be developed if data elements and data quality objectives were defined. Fire emissions reporting could plausibly be converted to NIF.

Participants debated two methods of reporting fire activity: 1) developing a transparent protocol, and 2) developing a standardized reporting system. Concerns arose that a standardized reporting system with language indicating required information would discourage agencies from reporting anything. Transparent protocol lends a more open attitude of accepting whatever data is available. The Inter-RPO protocols were referenced as examples. This type of protocol would avert the issue of different definitions of data elements. If a reporting system were to demand consistency, many agencies would only report the minimum requirements, thus creating an incentive to report less. However, other participants argued that creating a standardized system was feasible. The National Fire Air Issues Coordinating Group (NFAICG) would have the authority to enforce the standards and require agencies to report consistently while recognizing the need for flexibility.

One suggestion to encourage reporting was to create incentives for agencies. A similar situation succeeded with EPA’s AirNow program, in which initial resistance was overcome by providing stakeholders with useful services that they could not produce themselves.

The main goal of creating a common reporting system is to eliminate redundancy. It may not be possible to create one standard reporting form, especially since each agency will want to use the system they have developed. However, it may be possible to create an interim system to consolidate all the information into an optimum format to distribute to land managers. Before this can happen, end users need to agree on what data elements are needed.

The discussion turned toward data elements needed for the 2002 National Fire Emissions Inventory. Participants discussed a matrix entitled “Framework for Discussing Data Quality Objectives.” The matrix was created during conference calls leading up to the workshop, and was suggested as a way to report fire activity for different scales of modeling (i.e., regional haze and highly resolved modeling). The following parameters were discussed:

- Acreage cutoff
- Active fire centroid
- Start/stop time and date

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Wildfire Acreage Cutoff: Participants discussed the importance of including “small” fires; e.g., fires less than 100 acres. In some regions such as the West, fires less than 100 acres may not be as important for regional modeling. Other regions may place more importance on smaller fires.

It was suggested that for the upcoming 2002 national wildfire emissions inventory, only fires greater than 100 acres should be actively pursued, but if reporting agencies included smaller fires, those would also be accepted. However, it was pointed out that even small fires could significantly impact the air quality in Class I areas. Acreage cutoffs would eliminate many potentially important fires.

It was pointed out that if acreage cutoffs were imposed, different report forms would have to be utilized. For example, the ICS-209 report form only captures forest fires more than 300 acres.

Active Wildfire Centroid: It would be preferable to get an active fire centroid for fires more than 1,000 acres. That goal is feasible in the final report, after the fire has been extinguished, but getting a daily active centroid will require the use of a Global Positioning System (GPS). Most fire fighters have this type of equipment, but daily centroid is rarely reported.

Start/Stop Time & Date: Wildfire start and stop times are difficult to determine. Often, discovery time is used as a surrogate for start time.

3.2.4 Short-term Recommendations

The following short-term recommendations arose from the presentations and discussions in the fire activity session:

Required Data Elements

1. Time of ignition should be recorded in order to determine more accurate fuel consumption.
2. Fuel moisture should be recorded, as total consumption is highly sensitive to moisture conditions.
3. All fires need unique names.
4. Methodology is needed to consistently convert Township/Range/Section into latitude and longitude location.

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National Fire Activity Database–2002 Inventory Development: Wildfire Reporting

1. *De minimus* acreage cutoffs should be determined by either area burned or fuel load. For example, a piled half-acre fire may have a high fuel loading, and may significantly affect a Class I area.
2. Less than 100 acres, need county ID and acres burned (not mandatory for 2002 but desired).
3. Greater than 100 acres, must have specific location (all RPOs, 2002).
4. Type I IMT incidents need a fire centroid or an actual perimeter burned, in lieu of 1,000 acres.

National Fire Activity Database–2002 Inventory Development: Prescribed/Agricultural Fire Reporting

1. Whatever data is available with location and date.

3.2.5 Long-term Recommendations and Needs

The following long-term recommendations and needs arose from the presentations and discussions in the fire activity session:

Required Data Elements

1. Group needs to be assembled (RPO's, Private, Federal, etc.) to create a protocol for required data elements of future tracking/reporting systems.
2. Temporal and spatial scales, geographical location, and data application (e.g., regional haze modeling vs. high resolution modeling) should be considered in developing a list of required data elements.
3. Data elements needed to calculate SOA should be incorporated into the data-gathering process. SOA is an important constituent of monitored ambient $PM_{2.5}$ concentrations. The contribution of fire to SOA cannot be definitively determined with current methods. Some data elements needed to model SOA are being collected in some areas, but this effort needs to be expanded.
4. Reporting formats should be in ASCII text or NetCDF files, and be accessible via ftp or the web.
5. Methodology of reporting complexes needs to be standardized to avoid double counting.

National Fire Activity Database

1. Consistent reporting among fire agencies.
2. A consolidated fire occurrence reporting system for all fire types.
3. Accessibility to the system.
4. A consistent definition for reporting acreage (i.e., burned vs. blackened).
5. Improved fuel loading data.
6. Improved spatial data.

3.3 IMPROVE, Tracers, & Source Apportionment

3.3.1 Purpose

With current measurement techniques, there is difficulty in discerning smoke from other organic aerosols in the atmosphere. The session included one presentation, by Dr. Bill Malm, illustrating this problem and introducing the concept of molecular marker measurement, which would enable this distinction to be made. Making such differentiations will be important for the regional haze rule and $PM_{2.5}$ standard, where organic aerosol source apportionment will be necessary.

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3.3.2 Presentation Summary

Is it (blank) or is it smoke? (Bill Malm)

The presentation began with an overview of the current inability to attribute organic aerosols, which contribute to hazy conditions in the atmosphere, to sources such as fires. Next, data was presented showing quantities and trends in organic aerosols in the U.S. Current conditions show that the southeast U.S. has the highest concentrations of organic fine mass, with large areas having concentrations more than $3\mu g/m^3$. As a percentage of all PM, organic fine mass makes up only 20-30% in the southeast, whereas the percentages the northwest are higher, in the 40-50% range. Of this fine mass, the major constituents are organics and soil in the western U.S. In the east, a much larger portion of the PM is from sulfate, and a much smaller portion is from soil compared to the western U.S. The overall trends that are seen from 1988 to 1999 are a decrease in sulfate concentrations, particularly in the west and northeast, and an increase in organic carbon, especially in the west. In addition, visibility in those areas decreases with increased organic carbon concentrations, which may be a result of increased fire activity. In some areas of the country (e.g., Montana, Idaho), almost all (>90%) of the elemental carbon (EC) and organic carbon (OC) is from fire or trees (secondary organic aerosol formation). The IMPROVE monitors provide EC and OC concentrations and the EC/OC ratio; however, that ratio does not distinguish whether either the EC or the OC is from smoke or biogenic sources.

Information was presented on techniques that can be used to determine the sources of the organic aerosols. One technique that can be used to help determine whether the carbon is biogenic or from smoke is to use the C^{14}:C^{12} ratio, where C^{14} represents biogenic carbon and C^{12} represents fossil carbon. Another technique to help distinguish the source of the carbon is the use of molecular markers. To be useful as a marker, a chemical must have several properties, including a uniqueness to a specified material, stability in the atmosphere, and it must appear in measurable quantities. Some markers have been developed for several combustion sources, such as levoglucosan for wood burning, cholesterol for meat cooking, and trisnorneohopane for vehicle exhaust. In addition, potassium could be a potential marker for smoke, as organic carbon is highly correlated with water soluble potassium.

However, even with these techniques, it is difficult to quantitatively determine the sources of of monitored primary and secondary organic aerosols. Of the total monitored organic aerosols, 35% are primary organics and 65% are secondary. It has been estimated that fossil fuel combustion sources account for 15% of primary organics. Other non-fossil fuel sources, including wildland and agricultural fires, account for the other 20% of primary organics. A number of sources contribute to secondary organics, including biogenic emissions from trees and fires. However, there is no definitive information available regarding source contributions to SOA formation.

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3.3.3 Discussion

One participant commented that with current monitoring techniques, the source of carbonaceous aerosols cannot be determined. Dr. Malm pointed out that by looking at the EC/OC ratio, which is stable over time, it is possible to determine what portion is smoke and the portion that is secondary organic carbon. In addition, data on the season could help determine whether an event was related to fire, using judgment.

Cheap and easy ways to monitor specific molecular markers are needed to help solve this problem. The first step in this monitoring would be to differentiate smoke from other sources of the aerosol, and the second step would be to determine what type of vegetation had been burning. It may be possible to make a cheap and easy measuring tool for levoglucosan, but there is a time variance problem with levoglucosan. Levoglucosan can vary depending on whether the fire was hot or smoldering and can change depending on the stage of the fire. Mr. Malm felt an effort is needed to identify which markers should be studied more thoroughly, and then methods to measure those markers could be investigated.

A question was asked about whether the IMPROVE network could analyze any identified markers with existing samplers. Mr. Malm suspected that another sampling train would be needed for most markers. However, water soluble potassium, such as potassium sulfate or potassium nitrate, could be measured pretty easily with existing equipment and the use of a different filter. However, after two to three days, potassium is not a good marker due to depletion. Mr. Malm also stated that a goal for monitoring programs in the future is to be able to attribute haze to a fire or other sources using markers.

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One participant asked whether the weight of evidence approach with back-trajectories should be used in identifying sources. Trajectory analyses have provided important information on the transport of air pollutants, and on emission source regions that make important contributions to various air pollution problems. These analyses involve uses meteorological conditions such as wind direction and velocity to calculate airflow trajectories associated with high pollutant concentrations, and the comparison of these with airflow trajectories associated with low pollutant concentrations. Mr. Malm answered that it could be used for large, regional scales, since this approach gives only average values.

In the plenary session, participants discussed the need to use both models and monitors for SOA. A hybrid approach needs to be developed in order to capture anthropogenic and natural sources completely. Participants also indicated that integrated tracking and a solid activity database are needed in order to pinpoint sources of pollution in a Class I area.

Participants also discussed the lack of speciation data needed to fully identify sources of SOA. Researchers acknowledge that emission factors need to be developed for VOC species, but no one has determined which species to measure in order to develop a profile. It is suspected that 80% of light-scattering VOC is in the form of alpha-pinenes. Speciation of this compound can vary by orders of magnitude in wild fires depending on combustion stage. Speciation of alpha-pinenes also varies by vegetation type.

When asked if any speciation data existed for SOA precursors, Dr. Malm replied that some information was available, and the list of available data needs to be examined to determine what compounds to focus on. The data may not give different information for different fires at this time, but comparisons could be run with existing profiles.

3.3.4 Short-term Recommendations

The following short-term recommendations arose from the presentations and discussions in this session:

1. Markers for source apportionment need to be identified.
2. Cheap and easy methods to measure those markers need to be developed.
3. Weight of evidence approach can be used with current assessment tools.

3.3.5 Long-term Recommendations and Needs

The following long-term recommendations and needs arose from the presentations and discussions in this session:

1. The identified, cheap and easy measurement methods should be integrated in monitoring networks where appropriate.
2. An emission inventory of hydrocarbon gases that are precursors to secondary aerosols should be developed.
3. A hybrid approach is needed to integrate emissions modeling, dispersion modeling, and monitoring of SOA.

3.4 Remote Sensing and GIS

3.4.1 Purpose

With satellites and remote sensing technology, it is possible to detect fires or areas that have been scarred by burns, create maps of the areas, and use the maps in conjunction with other satellite data and other information sources to estimate emissions from those fires. The presentations in this session informed the audience of current efforts in fire monitoring, mapping, and emissions estimation using satellite data. The limitations and availability of the data were also discussed.

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3.4.2 Presentation Summaries

Fire Monitoring and Air Quality Forecasting Using NASA Terra and Aqua Satellite Data (Wei Min Hao)

The first presentation of the session provided an overview of a U.S. Forest Service Fire Sciences Laboratory project to use two satellites to make maps of burned areas in the U.S. These satellites make four overpasses every day, which detect fire hot spots and transmit images of the fires and the hot spots. Several satellite images of fires in North America were shown during the presentation. The hot spots detected by the satellite have been compared to the perimeter of fires measured and drawn by the forest service and have shown very good matches. The satellite hot spots and fire perimeters drawn by the forest service for the Hayman Fire in Colorado were shown to demonstrate a nearly identical matching of data from the different sources. In addition, a comparison between the number of fires detected by satellite measurements and the numbers in the national fire database based on size showed strong correlation, especially for the larger fires of six square kilometers or more. Satellites can be very useful in detecting burned areas, as approximately 90% of the total burned area in North America is due to fires of six square kilometers or larger, and a large percentage is from very large fires (approximately 40% of areas burned are from fires more than 300 km^2). Using the satellite data in conjunction with the NFDRS fuel map, and combustion efficiency data for the fuel types, the amounts of carbon monoxide and particulate matter can be estimated. Current efforts are underway to estimate daily emissions with this process. Challenges for the future include developing real-time emissions estimates from fires and incorporation of emission rates into the FARSITE and the National Oceanographic and Atmospheric Administration (NOAA) HYbrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) models.

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Remote Sensing of Fire with AVHRR and Landsat (Peng Gong)

The objective of the effort described in this presentation is to use data from the Advanced Very High Resolution Radiometer (AVHRR) satellites to map burn scars in boreal and temperate forests in Canada and the U.S. between 1985 and 2000, and to estimate the corresponding emissions from those fires. In this effort, the data need to be processed to the one-kilometer level, which is the level of the historical AVHRR data. A fire detection algorithm was developed to identify individual fires from the satellite data and then modified to eliminate false fires. Another algorithm was developed to combine each individual fire into an annual map of the areas burned. A map showing the fires detected using the first and then the modified algorithm was shown to display the number of false fires that were eliminated. Additional maps comparing satellite-based maps and ground-based maps of fires in several States showed that the satellite was a little more likely to underestimate the size of a fire than ground-based mapping. The satellite maps show good correlation with the USGS maps for total burned area. To estimate emissions from these fires, a software tool developed by U.C. Berkeley and funded by the California Air Resources Board is available. This program incorporates a formula that is used for each pixel on the burned area map, which include variables for fuel data, humidity, and burned area. The satellites are also able to measure temperature, but are limited in the upper range because saturation of the instrument is reached between 322 and 332 K, depending on the particular satellite. In addition, the satellite detects fires when there is a large difference between the currently measured temperature or reflectance and the background temperature or reflectance. When the differences between background and fire measurements are small, as in the case of desert areas and grasslands, detecting actual fires is more difficult. Future work is planned to improve the algorithm for fire detection in these vegetation types.

3.4.3 Discussion

Fire Monitoring and Air Quality Forecasting Using NASA Terra and Aqua Satellite Data

In response to a question regarding the equivalent measurement in acres for the detection limit of the satellite (noted as six square kilometers), an area of 200 acres was mentioned. The true conversion of six square kilometers to acres is 1482.6.

It was noted that the carbon monoxide from the Hayman fire was five times the amount of carbon monoxide released from all industrial sources in the State, and that particulate matter was two to three times the amount of industrial source releases. The Hayman fire was a large fire, and while it may seem unusual, more of these types of mega-fires are occurring.

It was clarified that MOPIT, which was noted in several of the presentation slides is a Terra satellite. In addition, several additional satellites will be launched this or next year by NASA and some others will be launched in Europe.

In response to a question about the impact of clouds on the satellite measurements, it was noted that four passes are made each day, so at least one clear picture per day can usually be obtained. If clouds interfere with a pass, there will be no data for the period.

Remote Sensing of Fire with AVHRR and Landsat

It was pointed out that agricultural burns are not typically picked up by the satellite because they are usually less than one square kilometer in size, which is at sub-pixel resolution for the satellites. They do not burn long and do not burn hot enough to be detected thermally.

In response to a question about Landsat 7 satellites and the problem it has had in getting pictures of parts of the U.S., Mr. Gong noted that there is a good archive of data until the satellite failed in March of 2003. It is still not operating correctly, so the lack of data since March 2003 may affect the efforts of some studies.

There were several questions regarding LANDFIRE software. This software is being used to try to create a consistent database at 30 meter resolution which will project growth for 100 years. It was clarified that the LANDFIRE database is mostly going to be fuel data rather than actual fire data. One area in Montana and one area in Utah have been completed.

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Key issues for the short term are detecting the fire, correctly detecting the size of a fire, identifying the fire perimeter, and detecting the intensity of the fire. There are many ways that intensity can be defined. One way to define fire intensity is by the amount of energy released, but Another is to measure radiative energy, which could probably be done for 2002 in the U.S. in two to three weeks and could be available late next year. It was pointed out that the RPOs need to have some estimate of fires for 2002 this year, so it is important to understand what can be done in the next four to six months. One suggestion was to compare the national fire database with satellite data, which agree 90 percent of the time at the two hundred acre detection limit. Prescribed fires may cause the 10 percent uncertainty since the national fire database only contains wildfires. The AVHRR could be ready in three months for fire area on a daily basis. However, while it would be possible to perform these activities, there is no money in the current budget to perform these tasks.

This discussion led to questions regarding the detection limits and accuracy of the satellite data. This information is shown in Table 3-1 below.

Table 3-1. Satellite Data Limits of Detection and Accuracy

Data Source	Detection Capability	Size Accuracy*
AVHRR	2 km^2, 500 acres	>25,000 acres/event, 250 acres/day
MODIS	0.8 km^2, 200 acres	1500 acres/event, 50 acres/day
LANDSAT	0.009 km^2, 2 acres	2 acres/event

* MODIS and AVHRR size accuracy represent the area (not perimeter) accuracy for forest and shrubland; perimeter cannot be determined from LANDSAT

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In addition to the data presented in the table, it was noted that MODIS is better able to measure intensity than AVHRR, since AVHRR has a saturation point for temperature. In addition to these data, another source of data to be aware of is GEOMAC, which is an incident specific archive center of the USGS, which can give the user Type 1 fire perimeters for 2002.

A paper detailing the burn scar mapping efforts with AVHRR will be available in late 2004/early 2005.

3.4.4 Short-term Recommendations

Finding funding to get some of the efforts done in time for the RPOs to use the information this fall would be optimal. This includes the AVHRR daily basis fire area data and the 2002 intensity data for the U.S.

3.4.5 Long-term Recommendations and Needs

As these satellite-based data collection efforts are ongoing, more and better data will be available over the next few years. In the future, efforts will focus on getting better accuracy of fires in non-forested area, such as grass and shrub land. Other efforts will work to move toward real-time fire and fire emissions data.

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4 FUEL CONSUMPTION AND EMISSIONS

4.1 Overview

Background presented by Sam Sandberg and Roger Ottmar

As seen in Figure 4-1, developing a fire emissions inventory is a stepwise process involving complex data elements and large areas of uncertainty. For example, there are currently limited methods available to report black, brown, and green areas in a fire event. Fuel loading and fuel consumption introduce large errors, as they can vary widely at the regional and State level. Fuels and types of fires may vary widely, ranging from deep duff fires that can smolder for a month or more in Alaska, to grassland fires that last less than a few hours. Further variability is introduced when more than one fuel bed burns in a fire event. While emission factors introduce smaller errors, many pollutant emission factors are outdated, and emission factors for other pollutants, such as some air toxics, have not yet been developed.

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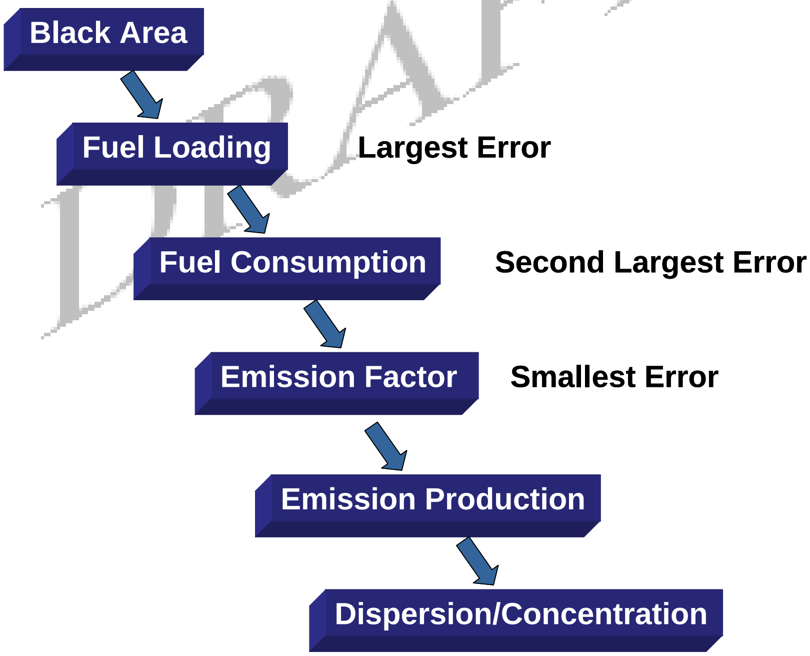
Figure 4-1. Emissions and Consumption Overview



A number of sessions at the National Fire Emissions Technical Workshop addressed the calculation of fuel consumption, emissions, and other inputs to air quality models. Separate sessions were then held to address fuel characterization, modeling of fuel consumption and emissions, emission factors used in these models, and the development of other inputs required by air quality models. Another session addressed data quality objectives (DQO) for the process.

4.2 Fuel Characterization

4.2.1 Purpose

Characterization of fuels for tracking emissions from wildland and prescribed fires is a difficult process. There are no national standards for characterization and there are few resources available to specify characterization. The purpose of this session was to discuss the current tools available, to introduce tools in development, and to identify the needs of the community to satisfy short and long term goals regarding fuel characterization.

4.2.2 Presentation Summaries

Fuel Characteristics (Roger Ottmar)

The natural fuels photo series is currently available.[2] This series is a collection of six volumes, each representing a region in the United States. There are two to four series in each volume containing between 4 and 17 sites. Each site includes photographs; standard, wide-angel and stereo-pair, augmented with information regarding the fuels and vegetation within the site, and sometimes stand structure and composition (Figure 4-2). The sites represented in each volume provide a basis for appraising and describing woody material, vegetation, and stand conditions for areas within that region, quickly and inexpensively. The series is primarily a land management tool which allows an ecological assessment leading to treatment options such as prescribed burning or harvesting where appropriate. The data are also useful for predicting fuel consumption, smoke production, fire behavior, and fire effects during fires. Care must be taken when assessing an area to ensure that appropriate matches of fuel and vegetation exist. This system is optimally used when making site observations and comparing them to the photos in the series. However, it can be used to make general assumptions regarding dominant species types across regions when necessary.

Mapping Fuels using the FCCS System (Don McKenzie)

The Fuel Characteristic Classification System (FCCS) is in development.[3] This system is an electronic database that dynamically captures the structural complexity and geographical diversity of fuel beds. This system contains 265 default fuel bed prototypes, and is fully customizable as well. This tool calculates quantitative fuel characteristics (physical, chemical, and structural properties) and probable fire parameters using either default information or modified information detailing vegetation structure and fuel biomass. This system is not limited to a specific region, and fuel beds can be applied at any scale. Figure 4-2 gives an example of a fuel bed prototype and associated fuel loadings.

The FCCS system will be used to create a map for use with modeling systems (Figure 4-3) and also to aid in predicting fire hazards. The FCCS system uses three indices for determining fire hazards; surface fire potential, extreme fire potential, and fire effects potential. This system is being developed to work with remote sensed vegetation data as well. Fuel beds

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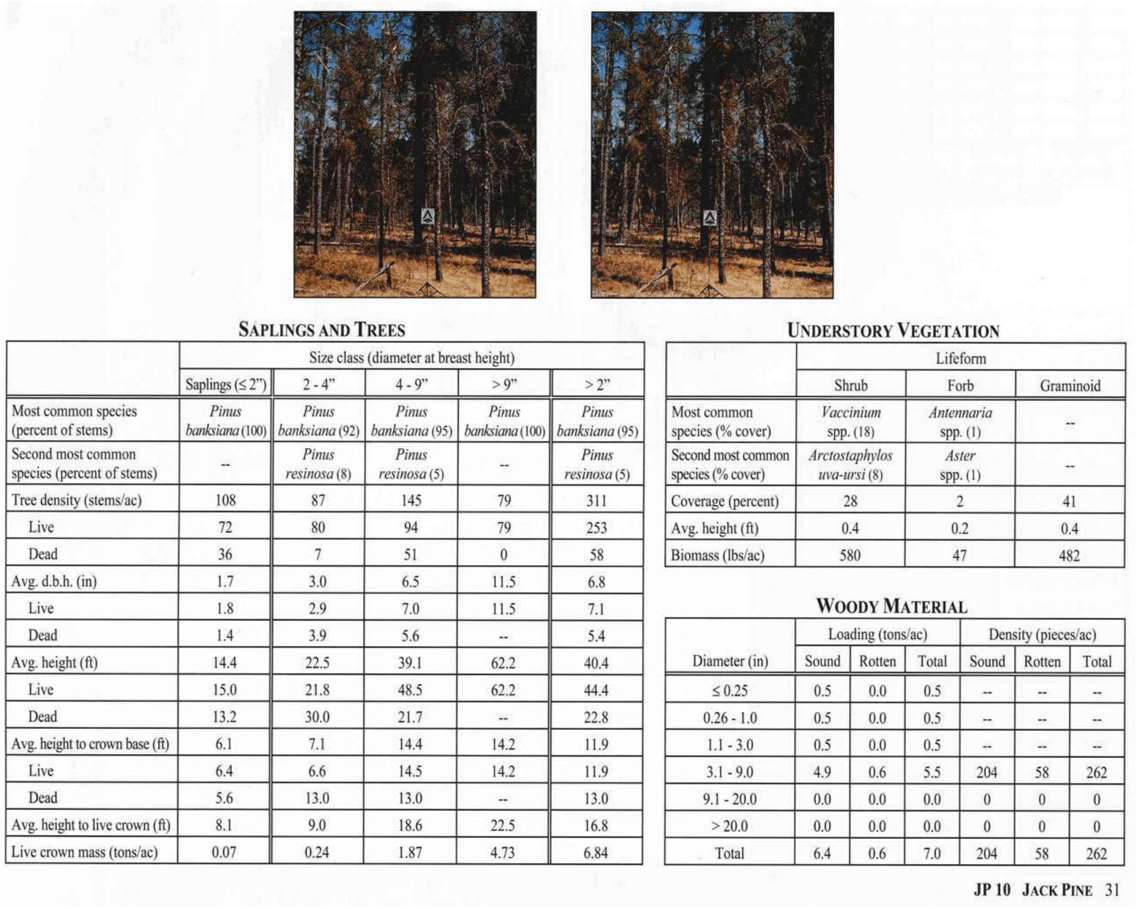
have been developed for the western portion of the United States. The beta test version is scheduled for release on May 30, 2004 with the final release in October 2004.

Figure 4-2. Example of the Photo Series. Source: Ottmar, 2004.



SAPLINGS AND TREES

	Size class (diameter at breast height)				
	Saplings (≤ 2")	2 - 4"	4 - 9"	> 9"	> 2"
Most common species (percent of stems)	*Pinus banksiana* (100)	*Pinus banksiana* (92)	*Pinus banksiana* (95)	*Pinus banksiana* (100)	*Pinus banksiana* (95)
Second most common species (percent of stems)	--	*Pinus resinosa* (8)	*Pinus resinosa* (5)	--	*Pinus resinosa* (5)
Tree density (stems/ac)	108	87	145	79	311
Live	72	80	94	79	253
Dead	36	7	51	0	58
Avg. d.b.h. (in)	1.7	3.0	6.5	11.5	6.8
Live	1.8	2.9	7.0	11.5	7.1
Dead	1.4	3.9	5.6	--	5.4
Avg. height (ft)	14.4	22.5	39.1	62.2	40.4
Live	15.0	21.8	48.5	62.2	44.4
Dead	13.2	30.0	21.7	--	22.8
Avg. height to crown base (ft)	6.1	7.1	14.4	14.2	11.9
Live	6.4	6.6	14.5	14.2	11.9
Dead	5.6	13.0	13.0	--	13.0
Avg. height to live crown (ft)	8.1	9.0	18.6	22.5	16.8
Live crown mass (tons/ac)	0.07	0.24	1.87	4.73	6.84

UNDERSTORY VEGETATION

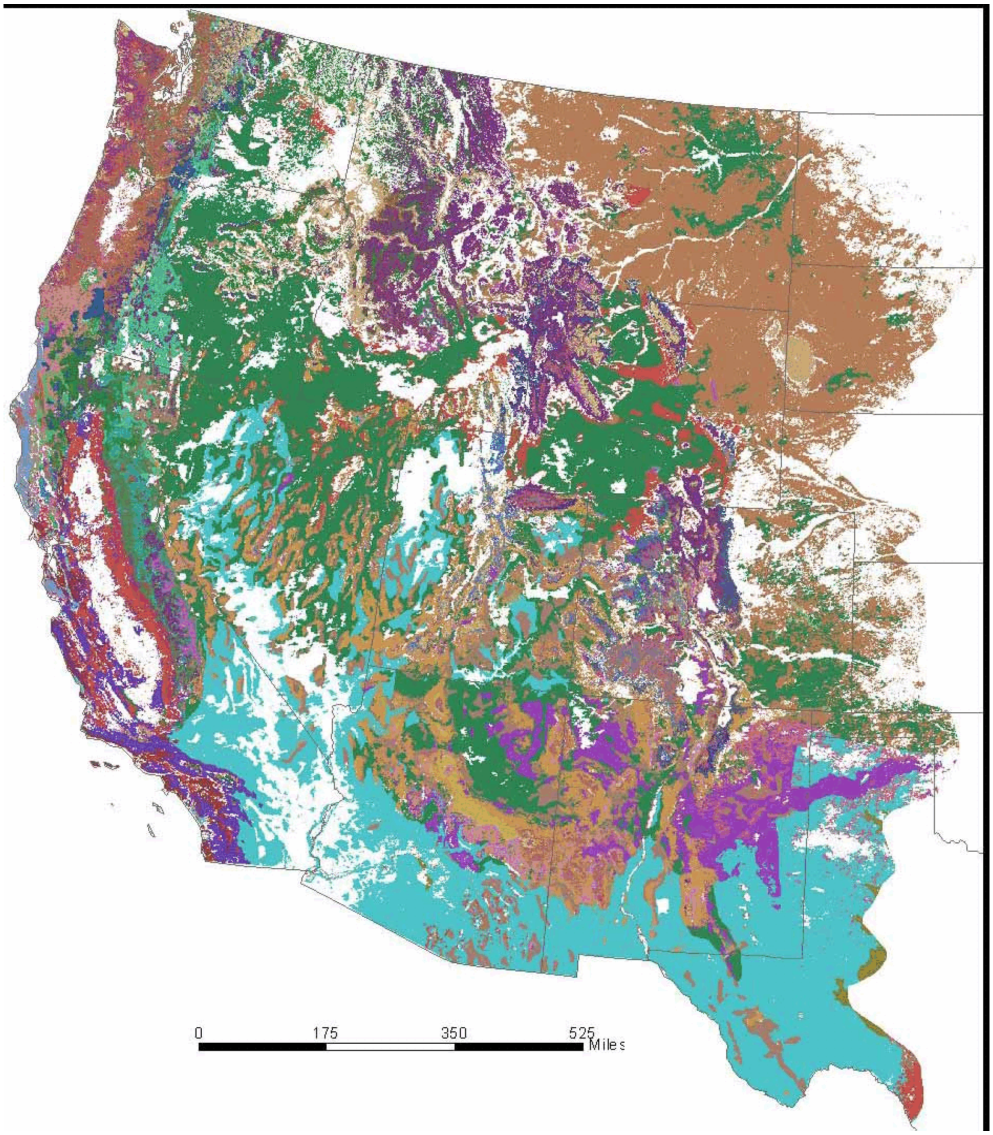
	Lifeform		
	Shrub	Forb	Graminoid
Most common species (% cover)	*Vaccinium* spp. (18)	*Antennaria* spp. (1)	--
Second most common species (% cover)	*Arctostaphylos uva-ursi* (8)	*Aster* spp. (1)	--
Coverage (percent)	28	2	41
Avg. height (ft)	0.4	0.2	0.4
Biomass (lbs/ac)	580	47	482

WOODY MATERIAL

	Loading (tons/ac)			Density (pieces/ac)		
Diameter (in)	Sound	Rotten	Total	Sound	Rotten	Total
≤ 0.25	0.5	0.0	0.5	--	--	--
0.26 - 1.0	0.5	0.0	0.5	--	--	--
1.1 - 3.0	0.5	0.0	0.5	--	--	--
3.1 - 9.0	4.9	0.6	5.5	204	58	262
9.1 - 20.0	0.0	0.0	0.0	0	0	0
> 20.0	0.0	0.0	0.0	0	0	0
Total	6.4	0.6	7.0	204	58	262

JP 10 JACK PINE 31

Figure 4-3. FCCS Fuel bed Map
Source: McKenzie 2004



Landscape Fire and Resource Management Planning Tools (LANDFIRE) Project (Jennifer Key-Long)

LANDFIRE[4] was created to provide fire and fuel information to support the implementation of the National Fire Plan by predicting fire potential at a national level due to changes in landscapes over time. LANDFIRE is multi-functional, containing both a reference database and mapping capabilities. Plot data such as existing vegetation, potential vegetation, fuels and structure are contained within the database.

The mapping capabilities include topographic and soil characteristics, climate, and ecogeophysical attributes (Figure 4-4). LANDFIRE will create maps of vegetation and ecological characteristics from field data, satellite imagery, and ecosystem simulations. The output has several layers including fuel model, canopy cover, crown height, crown base height, crown bulk density, elevation, slope, and aspect. This tool is proposed for use at the national scale at 30-meter pixel resolution. This system uses FCCS data to describe the fuel complex and determine fire potential. Presently two prototype areas are being developed to demonstrate the capability of the program to predict fire. These are in the Central Utah area and the Northern Rocky Mountain area, and are scheduled to be completed by Fall 2004.

Land managers were asked what they presently use to characterize fuels for use in tracking wildland fire emissions in order to identify possible needs. Although there were many responses, the following list captures the general consensus:

- A modified NFDRS table
- The photo series
- Explicit data from State/local agencies
- GIS
- Expert opinion

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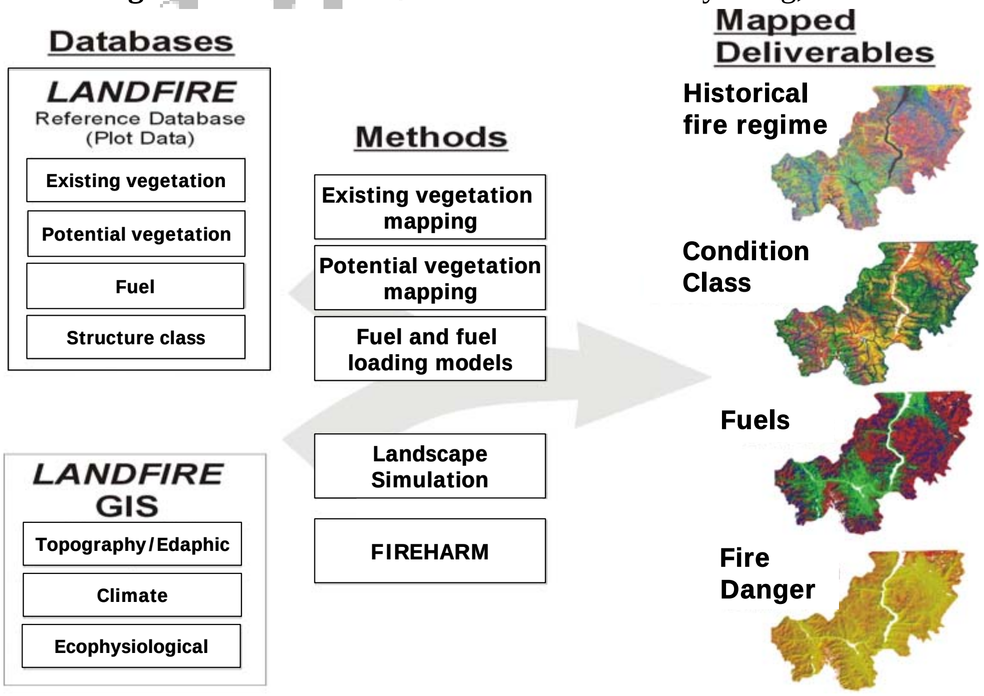
Figure 4-4: LANDFIRE overview. Source: Key-Long, 2004.



4.2.3 Discussion

The levels of accuracy afforded with these methods do not allow for the prediction of emissions at a scale that’s acceptable for most land managers; therefore, appropriate levels of resolution need to be developed for different scales of application. The fuels characterized as important for determining fire effects are not the same as those characterized for fire behavior. For example, the canopy needs to be known to predict fire spread, however for total consumption and emissions all the fuels need to be characterized accurately, which includes the understory vegetation and duff. There also seems to be a dichotomy between regional and stand level requirements, and the relevant importance of emissions from each.

The methods currently available for fuel characterization are the NFDRS map, the defaults in FOFEM, LANDFIRE protocols to make maps, the photo series, and knowledge of fuel condition. The FCC fuel bed map is not applicable to the whole country, neither is LANDFIRE. This reference makes characterization difficult at a regional scale and nearly impossible at the national scale. Fuel characterization will become easier with the implementation of the FCC map and the LANDFIRE information.

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4.2.4 Short-term Recommendations

RPOs are using various methods to characterize fuel loading and other fuel conditions, relying mainly on expert judgement and on maps produced using National Fire Danger Rating System (NFDRS) fuel classification system. Participants generally agreed that the FCCS system will be much better than the NFDRS system when it becomes available. In the interim, however, the NFDRS-based system provides a viable method for producing large-scale regional inventories.

A follow-up conference call was held to discuss methods available in the short term for developing fire emissions inventories. In this call, a method of refining the NFDRS system was discussed. The starting point for default fuel information is the NFDRS national vegetation map. The NFDRS map is converted to a Geographical Information System (GIS) database, which is then used to assign each fire incident to a NFDRS fuel class. However, the default NFDRS fuel loadings are not used, since these are not believed to reflect regional variations in fuel categories appropriate for the appropriate regions.

4.2.5 Long-term Recommendations and Needs

The long-term solutions for fuel characterization will be the use of the FCCS and LANDFIRE tools. Implementing these tools should give greater accuracy to emissions from wildland and prescribed fires across the country due to the increased detail in fuel characterization. [5,6] The Photo Series documents give detailed loadings, in tons per acre, for different fuel types and size ranges. In general, a number of possible Photo Series fuel models are identified for each NFDRS fuel class. In order to select among the possible Photo Series fuel models, expert judgement is elicited from foresters knowledgeable of the region. For large fires, the forest classes identified in EPA's Biogenic Emissions Landcover Database (BELD) are also used in selecting fuel models.

4.3 Fuel Consumption and Fire Emissions Modeling Systems

4.3.1 Purpose

The fire emissions modeling systems group met to: 1) develop a vision of how best to estimate fuel consumption and emissions production from wildland fires; and 2) list the key steps that can be used today and in the future to estimate fuel consumption and emissions production for wildland fire.

4.3.2 Presentation Summaries

Fuel Consumption and Emissions (Roger Ottmar)

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Several fire emissions models have been developed by the Forest Service to estimate fuel consumption and fire emissions. These models are in the process of being updated for fuel types where there is:

- Limited knowledge
- Increased wildland fire expected
- Emphasis on shrubs
- Emphasis on combustion by fuel stratum/categories
- Emphasis on smoldering phases

Six fuel bed types have been recently developed or improved for inclusion in the new models: boreal forest, grass, chaparral, sage, ponderosa pine mixed conifers, and Southern pine. Fuel consumption measurement projects are currently active in the West, Midwest, and Southeast. Fuel consumption studies are underway for rotten logs, snags, stumps, organic layer, piles, and basal accumulation. Table 4-1 summarizes the variables of selected fuel types.

Table 4-1. Fuel Types and Consumption/Flammability Threshold Variables

Fuel Type	Consumption Variables
Ponderosa Pine	• Preburn Loading • Preburn Diameter • Woody Moisture • Duff Moisture • Wind Speed

Table 4-1. Fuel Types and Consumption/Flammability Threshold Variables

Fuel Type	Consumption Variables
Southern Pine	• Preburn Fuel Loading • Woody Moisture • Duff Moisture
Shrub	• Days since rain • Fuel moisture content • Relative humidity • Wind speed • Topography • Shrub cover/density • Live/dead ratio • Lighting pattern

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In ponderosa pine and Southern pine forests, basal accumulation of litter forms a "duff donut." This donut greatly impacts tree mortality due to deep residual smoldering. When fires occur repeatedly in one area, there is no tree mortality. If the duff layer is allowed to accumulate, tree mortality could occur as the result of one fire. This is especially true in the Southeast, because the organic layer is not deep except around pines.

Despite the prevalence of basal duff burning, fuel moisture was determined to be more important from a fuel consumption and emissions point of view. Roger Ottmar presented results of fuel consumption experiments on downed cottonwood logs and cottonwood stumps. Percent consumed was determined by measuring tree circumference for woody materia and metal rods for litter. As seen in the presentation, results show that the maximum burn time after ignition time was 50 hours for logs and 75 hours for stumps. Most samples reached a plateau after approximately 25 hours.

Residual smoldering experiments determined that wind, fuel moisture, and woody diameter are all factors in residual smoldering consumption. Tests sites with high percentages of dry rotten material resulted in 100 percent consumption. Organic layers and stumps can smolder for up to a month. Basal accumulation around pine trees can also smolder for great lengths of time as well.

Methods for determining fuel moisture were discussed. The Keetch-Byram Drought Index (KBDI) was used in the Southeast to determine fuel moisture for duff, and large fuels to a lesser extent. KBDI can be calculated for the entire Southeast. This has been done successfully for the past four years in Florida. A 4-kilometer grid has been created with radar estimates for moisture and rainfall coupled with weather station information to normalize the radar estimates. Other areas in the Southeast, such as Alabama, do not have adequate data collection to produce such a map, but estimates have been extrapolated to these areas.

Sue Ferguson mentioned that she is looking at moisture probes that go into organic material or mineral soil to use as a surrogate for drying and wetting trends. The probes output a signal that shows drying and wetting, and users can calibrate that to how much organic material will be consumed. It incorporates a diurnal phase and rainfall.

Consume 2.1 and 3.0 (Roger Ottmar)

Roger Ottmar presented information on Consume versions 2.1 and 3.0. Version 2.1 includes the following attributes:

- Estimates consumption for activity, natural, and piled fuels (most fuel beds)
- Variables: loading, weather, woody/duff FM, pile information (size, species, cleanliness)
- Accounts for emission reduction
- First version of FCCS
- Consumption and emissions by flaming and smoldering combustion phase
- Output reports can be linked
- FASTRACS module
- Simple shrub model, no canopy or fuel category consumption/emissions

Consume 3.0 builds on version 2.1, and will be able to estimate flaming, smoldering, and residual combustion emissions for single or multiple fuel bed categories. It can also be run for single fires or in batch mode. It will incorporate the new FCCS fuel categories as they become available, so it can be used in any region of the country. To date, all fuel bed and fuel consumption data has been collected, and models have been developed for fuel beds and fuel bed categories. The software design document was developed in April 2002. Final release of version 3.0 is expected in April 2005.

FOFEM 5.0 (Elizabeth Reinhardt)

FOFEM was developed primarily for field workers with very little information. It is a comprehensive first-order fire effects model, meaning it can predict all immediate direct and indirect effects of fire. These include fuel consumption, smoke production, tree mortality, and soil heating. Users may select from a menu of defaults for all inputs, or manually input data elements.

FOFEM can be used to predict effects from one fire, or it can be used in batch mode. It also can be linked to GIS or other software. However, it does not model the temporal or spatial spread of a fire or changing meteorological conditions. It also does not model residual smoldering.

<u>Fuel Consumption</u>: Users can describe fuels in detail. If, however, they do not have fuel data, they can describe the vegetation type to use default fuel data using the following three

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keys: 1) The Society of American Foresters (SAF), 2) The National Vegetation Classification System (NVCS), and 3) The FCCS. The FCCS system currently available is outdated, but it will be linked to the new FCCS system as it becomes available.

Required inputs include fuel loads by size class and fuel moisture. Default loadings are provided for litter, duff, woody fuel by size class, herbs, shrubs and canopy fuels. Loadings can be adjusted to light, typical, or heavy. Outputs generated are fuel consumption by size class, and post-burn fuel loads. Consumption is predicted for duff and litter; surface woody fuels by size class, sound and rotten; live fuels; and canopy.

FOFEM 5 uses BURNUP, a theoretical model for predicting woody fuel consumption. Duff and live fuel consumption are predicted using rules and regression equations based on cover type, region, moisture, and season. BURNUP predicts woody fuel consumption by simulating heat transfer between fuel particles, combustion rate, and resulting fire intensity.

Smoke Production: Smoke production is estimated by multiplying fuel consumption by emissions factors. FOFEM predicts emission production rate and fire intensity over time for both surface and crown fires. Emission factors vary with fuels and moisture. FOFEM estimates production of PM_{10}, $PM_{2.5}$, CO, CO_2, CH_4, NO_X, SO_X. Emission production is estimated in time intervals from ignition until combustion ceases.

FOFEM uses separate emissions factors for flaming and smoldering combustion. Flaming and smoldering combustion can occur simultaneously in relative amounts depending on fuel moisture, fuel particle size class, and fire intensity.

Like fuel consumption, required inputs for smoke production include fuel load by size class, fuel moisture. Outputs generated include smoke production over time for each emission species, combustion efficiency, and emission factors. Emissions and intensity history can be saved for use in smoke dispersion models (e.g., NFS-PUFF, SASEM, SIS).

The most recent version of FOFEM was released in June 2004. This version (5.21) fixed a discrepancy in the smoke report between total consumed and the breakdown of flaming and smoldering consumption components.

FEPS (Sam Sandberg)

FEPS version 1.0 replaces the Emissions Production Model (EPM). EPM was designed to help land managers estimate and mitigate the rates of heat, particles, and carbon gas emissions from controlled burns of harvest slash residue in Northwest forests. In updating EPM, a significant number of improvements were made to the usability, applicability, and accuracy of the model. The calculation approach was totally redesigned, and the model has been renamed FEPS.[7]

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Dr. Sandberg gave a demonstration presentation of FEPS. Users are prompted to describe a fire event using either system defaults or user-specified inputs. Event name, fire type, event type, fire shape (e.g., linear progression or freely spreading oval), and location information are required to create a fire event. Pre-burn loading can be specified by the user or taken from NFDRS defaults. FEPS can also link to the FCCS as it becomes available. Multiple fuel types can be entered, and a percent consumed can be specified for each type. Fuel loading can be entered for canopy, shrub, woody, litter, duff, piled, and/or broadcast fuels. Fuel moisture can be entered for 1-hour through 1000-hour dead fuels, live fuels, and/or duff. Fuel consumption can then either be computed by FEPS or manually specified by the user. Hourly inputs, including meteorology and percent fuel consumed can be interpolated by FEPS or manually altered by the user. All the consumption algorithms, coefficients, and equations are provided to the user in lookup tables, and may be changed or replaced by the user. FEPS can also be used as a smoke management tool, and its outputs can be exported.

The following reports and charts can be created in FEPS:

- Event Data
- Consumption/Emissions Results
- Buoyancy
- Consumption by Combustion Stage (flaming, smoldering)
- Plume Rise
- $PM_{2.5}$ Emissions by Combustion Stage
- CO Emissions

There was some discussion about the plume rise equations used in FEPS. The plume rise chart compares the plume maximum and minimum predicted by FEPS with the Briggs Delta H Maximum. The Briggs equation is used to determine stack plume rise in other applications, but may not be appropriate for modeling fire plumes. Fires have two distinct plumes from lofted emissions and ground drift emissions, which Briggs cannot adequately capture. The output chart simply includes the Briggs model to provide EPA with a known benchmark for modeling plume rise.

David Lavoue mentioned ongoing plume research in Los Alamos, York University in Canada, and Utah. This research uses numerical models to develop plume rise based on fuel consumption. He suggested looking at these equations to replace the Briggs model for fires.

AIRFire: Atmosphere and Fire Interactions Research and Engineering (Sue Ferguson)

Sue Ferguson presented information on current efforts of the AIRFire team at the Pacific Wildland Fire Sciences Laboratory in Seattle, Washington. The mission of AIRFire is to understand the role of weather and climate in ecological disturbance and develop decision tools for ecosystem management, fire operations, planning, and smoke management. The BlueSky modeling framework is among the various air quality products produced by AIRFire. BlueSky was designed to predict cumulative impacts of smoke from forest, agricultural, and range fires. The BlueSky smoke modeling framework links computer models of fuel consumption and

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emissions, fire, weather, and smoke dispersion into one system for predicting the cumulative impacts of smoke across the landscape.

Output products are produced by the Fire Consortia for the Advanced Modeling of Meteorology and Smoke (FCAMMS) including BlueSkyRAINS.[8] This product combines technology of the GIS Rapid Access INformation System (RAINS) developed by the Environmental Protection Agency Region 10 with BlueSky to create a web-based application for simulating smoke impacts from prescribed and agricultural fires.

4.3.3 Discussion

The following fuel consumption and emission production estimation requirements were used as discussion tools:

- Level of accuracy needed
- Current gaps in consumption and emission models
- Fuel consumption defaults in lieu of fuel consumption models
- Short term solutions
- Longer term solutions

What do land managers presently use to estimate fuel consumption and overall emissions for wildland fires?

Oregon is required to use equations from Consume 2.1. These equations are input into a custom spreadsheet to calculate fire emissions in batch mode and to implement the Statewide Smoke Management Plan (SMP). The model itself is used for fuel consumption calculations. Fuel loading is assumed 100 percent pile burning.

The South Coast Air Quality Management District (SCAQMD) in California uses look-up tables based on equations from Consume 2.1, FOFEM 5, and EPM/FEPS. Land managers are allowed to use whichever application suits their needs.

VISTAS begins with Consume 2.1 to calculate fuel consumption, then modifies the results based on expert opinion. Region-wide assumptions are made for different fuel classes.

The Midwest RPO links defaults found in the photo-series for the Midwest Region and uses those as inputs to FOFEM to calculate fuel consumption and emission estimates. Results are then modified based on expert opinion. Region-wide assumptions are made for different fuel classes.

Participants discussed using models for long-term residual smoldering combustion (RSC). Some of the larger fuels in the Pacific Northwest and Alaska smolder for weeks. Ron Babbitt has RSC estimates that he has given to Sam Sandberg for inclusion in FEPS. Oregon uses smoldering consumption but does not put the results in dispersion models. BlueSky does

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incorporate some RSC results. RSC is important for Oregon because half of the land is federally owned. If the Forest Service and the Bureau of Land Management conduct understory burning, it will impact emissions.

There was discussion of modeling fires in batch mode. States would prefer fuel consumption and emission models to incorporate batch mode equations, and to also have the equations available separately so they can be used in individual applications. This option needs to be robust. Roger Ottmar will follow up with Mike Ziolko and others regarding incorporating their equations into Consume 3.0.

Mike Ziolko added that Oregon processes fuel consumption on a daily basis, and reports compiled emissions statistics annually. Gross inputs are used, including number of acres and distinctions between grass and woody fuel loading. However, fuel loadings need to be refined. For example, the July 2002 Biscuit Fire approached 500,000 acres, and included all fuel consumption ranges from slight charring to complete consumption. He mentioned that Northeast Oregon has capped prescribed fire emissions for boreal forests, and have a tradeoff policy in their SMP for wild and prescribed fire emissions. They estimate that forest wildfires can produce up to 15,000 tons of PM per year.

Jim Brenner discussed prescribed burning practices in Florida. Florida can burn up to 2 million acres per year. Every prescribed burn is authorized by the State for all landowners. A fuel map has been developed for the State that was very accurate one year ago. The map is based on the 13 BEHAVE fuel models, and does not include duff other than what is already in the models. For bush fires like palmetto-galberry, the fuel model is assumed to be 7 for fuels under 6 feet and 4 for fuels above 6 feet.

Based on the fuel maps and the PSU/NCAR mesoscale model (MM5) for meteorological information, Scott Goodrick developed an algorithm for the HYbrid Single-Particle Lagrangian Integrated Trajectory Model HYSPLIT[9] to estimate plume rise and emission impacts for every burn in every burn period. Burners can access this smokescreen system and digitize their burn information to determine which smoke receptors would be impacted with each burn. Although Florida is not a non-attainment area, there are visibility problems. Some dispersion modeling is conducted for projected impacts on Class I areas, but the information is limited. Information from the field contains large uncertainties, and often the most accurate information available is a commentary like “more acres burned at night than during the day.”

> *What is the standard approach for estimating fuel consumption and emissions production for a national emissions inventory?*

For emissions calculations, the key is flexibility. Other States may elect to do different things based on their needs. Alaska does not have the staff to calculate emissions, and would like to see a projected emission estimate on each burn plan. In calculating emissions for inventories, the WRAP data management system works nicely, with equations brought in as a module.

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Oregon has historically only been interested in PM emissions, but is now examining toxic and HAP emissions. As emission factors change, States need access to equations.

List steps/elements required to estimate fuel consumption and emission production from wildland fire

Scale: The group discussed developing emission inventories at different scales. Different levels of resolution are needed for regional-scale inventories vs. site or stand specific inventories. The main difference in scales is the issue of data availability. Specific fuel types, acres, and weather information is not available at the regional level, and many States are left to make their own assumptions. California, for example, always assumes the worst-case scenario for lack of better information

Fuel Inventory: A robust fuel inventory is crucial in estimating fuel consumption and emissions production. Different fuel maps need to be developed at the regional and stand levels. For example, Oregon requires site-specific information, while States in the Northeast may not need as detailed information. However, regional scale has fewer reliable inputs available and thus less precise estimates of consumption and emissions than site specific scales.

Activity Data: Missing data elements are also required to develop fuel consumption and emissions production. While this issue is being discussed in the Fire Activity section, the group felt it was important to point out in the inventory development section as well. This applies to all types of fires.

Model Uses: The group discussed how dispersion and fuel consumption/emission production models could be used in emission inventory development. Air managers would use dispersion models for validation. Models could answer questions like the following: Did the smoke spread in the predicted fashion to the predicted area? How is the smoke impacting the area?

Burn managers attempt to validate fuel consumption after a burn, but it is difficult to determine consumption without pre-burn measurements. Most burn managers leave measurements to the researchers. Roger Ottmar noted that he receives calls that the fuel consumption models are over predicting, but he has not heard of any evidence to support this.

Jim Russell noted that the National Park Service has been conducting burn severity experiments. Monitoring crews, or fire effects crews, set up plots before a prescribed burn, monitor during the burn, and conduct immediate post-burn measurements. Duff and woody measurements are taken, as well as fuel moisture and weather. He recommended using local, trained crews to conduct these types of experiments on a seasonal basis.

Mr. Russell pointed out that data from field experiments does not always get to modelers. On-site work does not include emissions calculations. The FARSITE model will calculate

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emissions, but it is usually not available in the field, and there is no training for people interested in learning the model.

4.3.4 Short-term Recommendations

Participants recommended short-term tools to estimate fuel loading, fuel consumption, and emissions. Recommendations for estimating fuel loading can be categorized into two geographic scales. At the site-specific scale or State level, FCCS 1.0 and LANDFIRE protocols are available for Western States to develop site specific fuel bed maps and local fuel characteristics inventories. State-specific fuel bed maps (e.g., Florida), local expert opinion, and look-up tables may also be used.

Region-specific scale fuel loading recommendations include using FCCS 1.0 and LANDFIRE regional fuel bed map, or the NFDRS fuel characteristics map. LANDFIRE will have 11 prototypes available in a year.

Recommendations for estimating fuel consumption and emissions include using Consume 2.1, FOFEM 5 (most current version is 5.21), FEPS, look-up tables, and expert opinion for both local and regional scales.

The following short-term needs were identified:

- Tracking systems for fire activity, specifically fire location and area burned (i.e., blackened acres)
- Improved fuel moisture and weather data
- Emission factors need to be updated in the models as they become available.
- Current monitoring data needs to be folded into fuel consumption and dispersion models for validation purposes.
- Feedback to model developers needs improvement.
- Models need to be flexible: equations need to be available for use in different applications
- Models should be developed to run in batch mode.
- A comparison is needed between the fuel models.

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Consume, FOFEM, and FEPS, and other models can estimate emissions from individual fires, and are being adapted so that they can be used with large fire incident databases. However, these models have not been used by the RPOs for the development of regional emissions inventories, because of difficulties in compiling input data for large numbers of fires.

A follow-up conference call was held to discuss methods available in the short term for using Consume, FOFEM, or FEPS to calculate fuel consumption and emissions. In this call, a method adopted by the Midwest RPO was discussed, which uses FOFEM but avoids the need to develop detailed inputs for each fire. In this method, FOFEM was not applied to each individual fire. Instead, a set of representative fuel models was developed, and each fire incident was assigned to one of these fuel models. Fuel consumption and emission factors were calculated for each fuel model, and the resulting factors were applied to the fire incident database. The Photo Series model fuel loadings (discussed in the preceding section) were used as input to the FOFEM 5.11 model. Fuel moisture was assumed to be dry for wildfires and average prescribed fires. All other inputs were set at the FOFEM default values. With these inputs and assumptions, FOFEM 5.11 was used to compute fuel consumption and emissions for a typical fire within each fuel model. The FOFEM 5.11 outputs were used to compute fuel consumption factors (in terms of percent burned) and emission factors for each fuel model. These emission factors take into account the relative amount of fuel consumed under flaming conditions and under smoldering conditions in each fuel model. Each fire in the incident database was then matched with fuel consumption and emission factors for the appropriate fuel model.

4.3.5 Long-term Recommendations and Needs

The following long-term recommendations and needs were identified:

1. At the local and State-level scale, more detailed fuel consumption tracking and monitoring are needed. The cost of conducting fuel consumption experiments could be considered as part of the cost of burning.
2. At the region-specific scale, the FCCS 2.0 and LANDFIRE maps will be available. The LANDFIRE project will attempt to fill in some fuel inventory gaps in the next five years. The project will result in a national map.
3. Consume 3.0 and FOFEM 6 will be available to estimate fuel consumption and emissions.
4. Regional-scale and stand-level scales need to be correlated. A disconnect exists between the two levels when comparisons are made with fuel consumption and acres burned. If national maps are developed, they should have a placeholder or link to local fuel mapping efforts.
5. Activity data collection systems need improvement from the emission inventory development perspective, including agricultural and rangeland data.
6. Better fuel moisture and weather data are needed.

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4.4 Emission Factors

4.4.1 Purpose

Fires emit a wide array of pollutants that can contribute to a number of air pollution problems, including regional haze, elevated levels of the criteria pollutants (particulate matter and ozone), and ambient concentrations of Hazardous Air Pollutants (HAPs). This session discussed the emission factors used to estimate emissions from fire, and the methods used to develop these emission factors. Particular emphasis was given to pollutants needed for regional modeling of haze and criteria pollutants, including $PM_{2.5}$, PM_{10}, methane (CH_4), volatile organic compounds

(VOC), nitrogen oxides (NO_X), sulfur dioxide (SO_2) and ammonia (NH_3). Speciation factors for VOC and $PM_{2.5}$ were also addressed, as well as emissions of HAPs.

Ron Babbitt provided background information on the techniques used to measure fire emissions, and on the results of recent measurements. Bill Battye discussed standard emission factors used in fire emission and fuel consumption models, and emission factors and speciation factors for other pollutants that are not currently included in the fire models. Participants provided suggestions on the framework for developing emission factors and on the data sources that are available.

4.4.2 Presentations and Discussion

Background on Emission Factor Measurement (Ron Babbitt)

The chemical formula $C_6H_9O_4$ has been suggested by Byram as a chemical model for wood. This model is about 50% carbon, by weight, and seems to hold for all woody fuels. Using this model, the complete combustion of wood can be represented as:

$$4\,C_6H_9O_4 + 25\,O_2 \rightarrow 24\,CO + 18\,H_2O$$

In this reaction, wood is completely converted to carbon dioxide (CO_2) and water (H_2O); however, complete combustion is never achieved in nature. Products of incomplete combustion are always produced, including carbon monoxide (CO), methane (CH_4), nonmethane volatile organic compounds (VOC), particulate organic carbon (OC) and particulate elemental carbon (EC). The “combustion efficiency” (CE) for a fire is defined as the fraction of burned carbon that is converted to CO_2 on a molar basis. CE is calculated as follows:

$$CE = \frac{CO_2}{CO + CH_4 + CH_2O + 2 \cdot C_2H_2 + \ldots..}$$

The Fire Sciences Laboratory (FSL) also uses a modified combustion efficiency (MCE) term based on only CO_2 and CO:

$$MCE = \frac{CO_2}{CO_2 + CO}$$

MCE correlates well with CE, since CO_2 and CO account for about 95% of the carbon burned. In addition to CE and MCE, a fire can be characterized by the relative amounts of flaming and smoldering combustion. The term “flaming” generally refers to combustion with a CE greater than 90%, and smoldering generally refers to a CE less than 90%.

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For fire, an emission factor is defined as the amount of a particular pollutant produced per amount of fuel consumed, typically expressed in pounds of emission per ton of fuel burned or grams of emission /kilogram burned. Emission factors are used to estimate total emissions for a specific compound from a site by the following equation:

$$Emis_i = F \times EF_i$$

where $Emis_i$ is the total emission of pollutant i, F is the amount of fuel burned, and EF_i is the emission factor for pollutant i. The fuel combustion at a fire site must be known in order to estimate emissions. (Previous workshop sessions have addressed the modeling of fuel consumption.)

Emission factors for many pollutants increase as CE decreases. Therefore, these emission factors can be expressed in terms of another quantity such as the CE or the predicted CO emission factor. These expressions can take one of the following formats:

$$\begin{aligned} &EF_i = a + (b \cdot CE) \\ &or \\ &EF_i = c \cdot EF_{CO} \end{aligned}$$

where EF_i is the emission factor for pollutant i (g/kg fuel consumed)

Separate emission factors can also be calculated for flaming and smoldering combustion.

Recent Measurements (Ron Babbitt)

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The FSL has an extensive database of measurements for CO, $PM_{2.5}$, and other pollutants from surface fuels in the western U.S. This database has been used to develop emission models for wildland fire. Recently, the laboratory has been carrying out a number of measurements which broaden the existing database. These measurements include:

- residual smoldering combustion (RSC) in large fuels and subsurface fuels
- emissions in other regions
- detailed emission measurements for VOC species

Figure 4-5 illustrates the differences between emission relationships for surface fuels and residual smoldering combustion. The figure plots emission factors for CH_4 versus CE. The red diamonds and the line in the upper portion of the figure represent the relationship between CH_4 versus CE for residual smoldering combustion. The blue diamonds and the lower line represent the relationship between CH_4 and CE for surface fuels. The figure shows that residual smoldering emissions of CH_4 are higher than emissions from surface fuels, and are not as well correlated to CE as emissions from surface fuels.

Figure 4-5. Relation of CH_4 emission factor to combustion efficiency for residual smoldering combustion (RSC) and surface fuels.

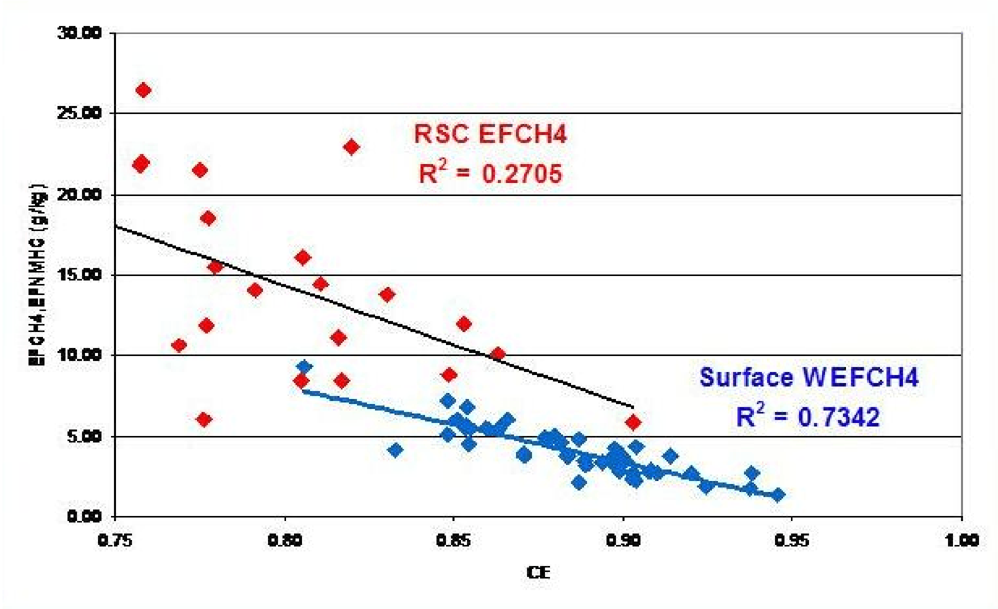

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Table 4-2 compares recent test results for the Southeast U.S., Alaska, with previous results for the Western U.S. The table illustrates that the differences between RSC, flaming, and smoldering are much more pronounced than the differences between emission factors for the same combustion phase in different geographical regions.

Table 4-2. Comparison of Flaming, Smoldering, and Residual Smoldering Combustion Emission Factors from Different Regions

Region	Combustion phase	Emission factor (g/kg)				Modified combustion efficiency
		CO_2	CO	CH_4	$PM_{2.5}$	
Western[a]	Flaming	1648	91	3.5	13.4	92
	Smoldering	1563	133	5.8	15.6	88
	RSC	1464	217	14.3		81
Alaska	Mixed	1660	89	2.8		92
	RSC	1437	246	9.2		80
Southeast	Flaming	1681	73	2	11.7	94
	Smoldering	1605	116	3.3	11.6	90
	RSC	1338	295	10.6		74

[a] Primarily ponderosa pine understory burns.

Emission Factors and Equations Currently Used in Fire Models (Bill Battye)

The two major fuel consumption models developed by the U.S. Forest Service both include subsystems to calculate emissions. These are the First Order Fire Effects Model (FOFEM), and the Consume model. The Forest Service is also developing the Fire Emission Production Simulator (FEPS), which replaces the Emission Production Model (EPM). In addition, the integrated BlueSky and Community Smoke Emissions Model (CSEM) include emission calculation algorithms. The emission algorithms in FEPS, BlueSky, and CSEM are all derived from the algorithms used in FOFEM and Consume. All of the models have been discussed in other sessions of this workshop.

FOFEM and Consume emission factors are closely tied. FOFEM calculates emission factors using equations based on CE, which were developed from a database of measurements carried out by the FSL. FOFEM calculates CE based on fuel consumption in various forest types and under various fire conditions. Consume incorporates a table of emission factors for flaming and smoldering in different forest types. These factors are also derived from the FSL measurements database.

Table 4-3 shows the equations used in FOFEM to compute emission factors for CO_2, CO, $PM_{2.5}$, PM_{10}, NO_X, and SO_2.[10] Consume emission factors are published in the Smoke Management Handbook.[11] In future versions of Consume, developers are planning to use emission factor equations in future versions of the model. These equations will be developed in coordination with FOFEM developers.

Table 4-3. Emission Equations Currently Used in FOFEM

Pollutant	Emission equation (resulting factors are in g/kg of fuel consumed)		
CO_2	1833 × CE		
CO	961 – (984 × CE)		
CH_4	42.7 – (43.2 × CE)		
$PM_{2.5}$	67.4 – (66.8 × CE)		
PM_{10}	1.18 × $PM_{2.5}$		
NO_X	(10.8 × CE) – 7.3	or	3.27 – (0.011 × CO)
SO_2	0.98		

In addition to the pollutants listed in Table 4-3, The Consume 2.1 model and Smoke Management Handbook provide emission factors for nonmethane hydrocarbons (NMHC). For combustion sources, NMHC emissions are generally taken as equivalent to VOC emissions, which are used in gridded models for ozone and secondary particulate matter formation.

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However, NMHC emission factors for fire are derived from measurements made by flame ionization detection (FID),[12] which has a reduced sensitivity to oxygenated organic compounds such as formaldehyde, other aldehydes, and carboxylic acids.[13]

Recent fire studies have used Fourier Transform Infrared Spectroscopy (FTIR) to measure emissions of a wide array of individual VOC. Dr. Robert Yokelson and others at the FSL have compiled FTIR measurements from the continental U.S., Alaska, African Savannah, and Indonesia.[14] Based on the FSL compilations, Dr. Yokelson estimated that total VOC emissions from forest fuels range from 18–28% of CO emissions.

Regional air quality simulation models require emissions data for ammonia (NH_3) and volatile organic compounds (VOC), and speciation factors for VOC and $PM_{2.5}$. Estimates of HAP emissions are also needed for the National-scale Air Toxics Assessment (NATA) program. Emissions information for these pollutants was compiled in an EPA resource document published in 2002. In addition, the Fire Sciences Laboratory compiled additional measurements prior to the workshop. Sources of information on these pollutants were reviewed in the workshop session.

Emission models such as SMOKE use speciation factors to divide VOC emissions into different reactivity classes, which are used in photochemical ozone models and in regional particulate models. Current VOC speciation factors for wildland fire are based on 1975 estimates, which cover only hydrocarbons and include a large portion – about 48% – of unidentified compounds. Recent FTIR measurements allow a much more comprehensive evaluation of VOC species. The recent measurements show a high fraction of oxygenated organic species.

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4.4.3 Discussion

Emissions have been measured for wildfires and prescribed fires in various fuel beds and under various conditions. Emission factor developers should make sure that all fuels are represented. Oily fuels and desert fuels may be under represented in current emission factors. In addition, participants pointed out the need to address the variability among fires and the 1 in 100 event where fuels have been exposed to chemicals or materials that could increase the emission of toxic and hazardous air pollutants. These special conditions should also be reported and tracked.

Fuels burned in residual smoldering are under represented in current emission factors. The WRAP has used augmented factors which account for additional fuel consumption on the day after a fire. However, the emission factors for residual smoldering consumption may also need to be revised.

This session addressed the utility of a standard emission factor set of emission factors or equations for the broad array of air pollutants emitted by fires. Participants indicated that a standard set of emission factors and emission equations are helpful, since State agencies will need the information and will use whatever is available to them. However, some participants cautioned against the dangers of standardization. Researchers should also guard against overstatement of emission factors, which could result in overly stringent limitations on prescribed burning.

Participants indicated that emission factors for air curtain burners would also be useful. However, it was also noted that air curtain burners are not a practical replacement for prescribed burning.

Participants indicated that emission factors and equations should be compatible with Forest Service models, although the models do not need to explicitly calculate emissions of all pollutants. In addition, emission factors and equations should be compatible with existing emission modeling frameworks such as EPA’s Biogenic Emissions Inventory System (BEIS). Participants indicated that separate emission factors for EC and OC would be helpful, in addition to the speciation factors for these pollutants.

Available data sources were reviewed for NH_3, VOC and HAP emission factors, as well as for VOC and $PM_{2.5}$ speciation factors. One participant suggested the emission summary by Andreae and Merlet as a source of additional data on emissions of various pollutants.[15] Researchers have found that emissions of NO_X and NH_3 are dependent on the nitrogen content of fuels burned in a fire. However, fuel-nitrogen values are not generally available.

Participants indicated that emission factors are needed for HAPs, and that additional test data may be needed in some cases. HAPs do not necessarily have to be calculated by the fuel consumption models, but can be estimated in terms of CE or other pollutants estimated by the models.

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Mercury emissions were flagged as a particular issue due to the lack of good measurement data. FSL researchers disagree with some aspects of the methodology used in a recent mercury test, reported by Friedli et al.[16] FSL researchers believe that all of the mercury will be emitted from any fuels consumed, but that the amount of mercury in an ecosystem will vary from region to region depending on the proximity of industrial sources. Workshop participants suggested that mercury emission factors could be refined for specific regions by estimating the historical deposition from industrial emission sources.

Potential differences were discussed between speciation factors for flaming and smoldering emissions. One participant indicated that such differences may be important to atmospheric simulation modelers, since the flaming and smoldering emissions are subject to different atmospheric transport regimes. VOC speciation data do show a dependence on combustion efficiency. However, additional analyses of these differences have indicated that they may result from differences between forest fuels and grasses. Separate speciation factors have been developed for forest fuels and grasses, but relationships have not been developed between speciation factors and combustion efficiency.

4.4.4 Short-term Recommendations

The following are short term recommendations for the development of fire emissions inventories based on the material presented and the discussions held in this session:

1. Use Forest Service models such as FOFEM, Consume, FEPS, or BlueSky where possible to calculate fuel consumption and combustion efficiency. Use the emission factors generated by these models for $PM_{2.5}$, PM_{10} and CO. Use the modeled emission factors for NO_X and SO_2 where available (some models do not include these pollutants).
2. Emission factors for VOC and NH_3 will be updated based on data provided by the Fire Sciences Laboratory.
3. Average emission factors will also be calculated for HAPs, and speciation factors will be updated for VOC and $PM_{2.5}$.
4. Adjustments should be made to average HAP emission factors when fuels have been exposed to chemicals or materials that could increase the emission of toxic and hazardous air pollutants.
5. Use techniques similar to those used by the WRAP to adjust for emissions from residual smoldering.

4.4.5 Long-term Recommendations and Needs

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The following are long term recommendations for the development of fire emission factors based on the discussions held in this session:

1. Maintain a set of standard emission factors.
2. Make sure that all fuels are represented. Also, measure emission factors for air curtain burners.
3. Develop revised emission factors for residual smoldering combustion, if appropriate.
4. Guard against overstatement of emission factors in standard data sets.
5. Address the variability among fires, including situations where fuels have been exposed to chemicals or materials that could increase HAP emissions or other toxic emissions.
6. Maintain compatibility with existing emission modeling frameworks such as Forest Service fuel consumption models and EPA’s BEIS.
7. Add separate emission factors for EC and OC to standard tables and fuel consumption models.
8. Evaluate potential differences between VOC speciation factors for flaming and smoldering emissions as additional FTIR data become available.

4.5 Other Air Quality Model Input Needs

4.5.1 Purpose

A number of sessions at this workshop addressed the development of fire incident databases and the estimation of fire emissions. This session covered the broad range of other inputs that are required for air quality modeling. These inputs include:

- distribution of fire emissions by hour of the day
- speciation of emissions

- initial height of the plume, and distribution of pollutants within the plume

4.5.2 Presentations and Discussion

The session included seven presentations. In the first presentation, Mark Janssen provided background on emission modeling to provide input photochemical air quality models, and outlined emission modeling activities in the Midwest RPO. Gail Tonnesen then provided an overview of fire emissions processing for the WRAP. Jeff McQueen discussed the use of a meteorological model for real-time prediction of fire impacts on air quality. Tom Pierce discussed the ongoing collaboration between EPA and the Forest Service to incorporate the BlueSky fire emission model into EPA's Community Multi-scale Air Quality (CMAQ) system. The final three presentation discussed a project by the U.S. Forest Service Southern Research Station (SRS) to model the impacts of emissions from prescribed fire using CMAQ. Scott Goodrick discussed emission modeling for the SRS project, Yong Liu discussed the processing of emissions estimates, and Gary Achtemeier discussed the modeling of plume rise.

Emissions Modeling by the Midwest Regional Planning Organization (Mark Janssen)

Emissions models, such as those developed for fire, calculate daily emissions estimates for a generic spatial scale and for broad chemical groups, such as $PM_{2.5}$ or VOC. Photochemical emission models have been designed to meet the needs of air quality simulation models, and produce model-ready emissions estimates for a specific day using that day's meteorology. Estimates are made for specific model grid cells (e.g. 36 km, 12 km, 4 km), and also for specific VOC reactivity classes (e.g. other aldehydes, ALD2; or paraffin, PAR) or particle fractions (elemental carbon, EC; or organic carbon, OC).

Both types of emission models are distinguished from emission processors, which perform spatial allocation, temporal allocation, and speciation operations on point source or area source emissions. Emission processors do not calculate emissions, but instead require annual or daily emissions as an input. Photochemical emission models are more data intensive. The primary input to these models is some measure of the activity of the emission source. Local meteorology is also an input. Examples of photochemical emission models are the mobile source and biogenics processors of the Emission Modeling System (EMS-2002) and the Sparse Matrix Operator Kernel Emissions (SMOKE) Modeling System. The Midwest RPO is also developing the CONCEPT emission model, which will include processors for agricultural ammonia emissions, non road mobile sources, and possibly for electric generating units. CONCEPT also designed to ensure that all data and assumptions used to calculate emissions are transparent and accessible.

Fires have not yet been incorporated into the CONCEPT model or other photochemical emission models. Therefore, the Midwest RPO fire project has used FOFEM 5.11 to estimate fire emissions. Fire emissions are treated as pseudo-point sources within the point source emissions inventory. The inventory is compiled in NIF 3.0 format. Each fire is represented by a separate facility code within the NIF 3.0 system. Each plant community or fuel model is represented by a

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specific emissions unit (boiler) code. Different forest fuel types within a plant community (e.g. small wood, crowns) can be represented by a separate process code within NIF 3.0.

Fires produce complex plumes that are dispersed over a broad range of vertical levels. Therefore, each fire was generally characterized using multiple emission release records, with a separate pseudo-stack height assigned to each emission release record. The heights of these pseudo-stacks were hard-coded to correspond to the midpoints of vertical layers used for CAMX air quality modeling in the Midwest RPO.

The NIF 3.0 files for the Midwest RPO fire inventory are designed to be transparent, in that the emission factors, acreages, and other assumptions used to calculate emissions are included in the NIF 3.0 files. This design facilitates updates of the emissions estimates if emission factors or other assumptions need to be changed. In general, the NIF 3.0 format was able to accommodate most fire data. However, some information was placed in point-source fields that are normally used for unrelated parameters. For instance, the heat content field of the process record has been used to store the preburn fuel load (tons/acre), the ash content field has been used to store the percentage of fuel that is burned in the fire, and the sulfur content is used to store the percentage of burned fuel that is consumed in a flaming combustion mode (as contrasted with a smoldering combustion mode).

Mark Janssen asked if it would be possible to develop a common photochemical emissions model for fire that could be used by all of the RPO’s. One hurdle is that the RPOs use different photochemical models. They also have different quality assurance procedures, operational goals, and processing goals.

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Emissions Processing of Fire Sources by the Western Regional Air Partnership
(Gail Tonnesen)

The WRAP has developed emissions inventories for wildfires (SCC 2810001000), agricultural burning (SCC 2801500000), and prescribed burning (SCC 2801500000). Inventories have been developed for a base year (1996) and for future projection years. In addition, projection year inventories have been developed for three scenarios: no smoke management, a “base” smoke management strategy, and an optimal smoke management strategy.

Fire emissions inventories were processed using the SMOKE emission processing system. The inventories were merged in SMOKE, with matrixes for speciation, gridding, temporal allocation, and plume rise. Results were output to a three-dimensional net-CDF file. The gridding matrix was developed using fire event locations (latitude and longitude). Daily emissions were based on event dates, and diurnal variations were calculated using standard hourly allocation factors. VOC was speciated into CB-IV reactivity classes as follows: 55.1% paraffin (PAR), 3.10% olefin (OLE), 19.1% ethylene (ETH), 0.21% other aldehyde (ALD2), and 22.5% nonreactive. $PM_{2.5}$ speciation factors were 63.6% organic carbon (OC), 9% elemental carbon (EC), and 27.4% other for wildfire and prescribed burning; and 45% OC, 26.2% EC, 1.54%

particulate sulfate (SO_4), 0.63% particulate nitrate (NO_3) and 26.6% other for agricultural burning.

The plume rise matrix was developed using three parameters: the fraction of pollutants released in a drift plume (in the first vertical layer of the model), the height of the top of the lofted fire plume, and the height of the bottom of the lofted plume. These parameters were precalculated on an hourly basis for different fire size categories. Emissions in the lofted plume were distributed among model layers between the top and bottom of the plume based on atmospheric pressure gradients. The fraction of emissions assigned to each layer was calculated by taking the ratio of the pressure gradient across the layer to the total pressure difference between the top and bottom of the plume. Pressure differences were obtained from the MM5 meteorological model.

Eight quality assurance checks were performed within SMOKE and after SMOKE processing. Within SMOKE, the following reports were created for quality-assurance:

- Daily tonnage per State & county by pollutant
- Daily tonnage per SCC by pollutant
- Daily tonnage per State/county/SCC by pollutant
- Hourly tonnage per layer by pollutant

The following post-SMOKE processing quality-assurance steps were taken:

- Diurnal time-series each day (hourly domain total emissions).
- Vertical profiles – sum of each layer.
- Spatial plots – sum all layers.
- Episode time-series – daily total emissions

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Some potential issues were noted, particularly with the speciation step. First, the speciation factors were based on a dated speciation profile which includes a relatively large fraction of unidentified compounds. In addition, the same VOC speciation factors were used for wildfire, prescribed fire, and agricultural burning; and the same $PM_{2.5}$ speciation factors were used for wildfire and prescribed fire.

It was also noted that fires were treated as pseudo-point sources, even though they often cover large areas. This was not viewed as a major issue, since emissions are averaged into the modeling grid. (For example, the 36 km modeling grid used by the WRAP equates to about 320,000 acres. Even a relatively fine 4 km grid would equate to about 4,000 acres.) A question was raised on the handling of multiple grid fires. Currently, each fire in the inventory is placed in a single grid, which is selected based on the latitude and longitude values listed in the fire event database.

There was some discussion of the interactions between meteorological models, fire emission models, and air quality simulation models. First, meteorological parameters such as mixing height and stability class will affect the initial plume height of a fire. These factors could be obtained from meteorological models, but are not currently used in computing plume heights.

Second, particulate matter from fire emissions can obscure sunlight, and thus affect photochemical reactions at the bottom of the fire plume. This effect is not currently taken into account in air quality simulation models.

Fire Weather Support From NCEP: Selectable Runs of Nonhydrostatic Mesoscale Model (Jeff McQueen)

The National Centers for Environmental Prediction (NCEP) are currently providing fire weather support for the prediction of downwind air pollution impacts from ongoing fire incidents. The Weather Research and Forecast (WRF) Nonhydrostatic Mesoscale Model (NMM)[17] is being used for meteorological predictions. The NMM is a highly refined upgrade to NCEP's workstation model, which retains full hydrostatic capability, and also incorporates nonhydrostatic effects. Prognostic equations are split into hydrostatic parts plus corrections due to vertical acceleration. The high resolution of the NMM is expected to yield better prediction of low level winds, temperatures, and dew points than previous models. The nonhydrostatic dynamics are expected to produce better predictions in cases with strong vertical circulation or acceleration.

Runs are made within dedicated run slots at 00 GMT, 06 GMT, 12 GMT, and 18 GMT. An 8-km resolution is used, and hourly output grids are produced. The HY-SPLIT 4 semi-Lagrangian model is currently used to calculate fire plume trajectories based on the NMM modeling results. NCEP and EPA are currently working to integrate the NMM with the CMAQ model.

Integrating BlueSky into the CMAQ/SMOKE modeling system (Tom Pierce)

The EPA is working with the U.S. Forest Service to incorporate the BlueSky fire model into EPA's CMAQ modeling framework. The CMAQ modeling system is a "one atmosphere" air quality simulation model that enables the evaluation of the efficacies of multiple pollutant control strategies. The model requires comprehensive data on emissions from manmade and natural sources.

EPA has developed a national fire emissions inventory for use in CMAQ, which includes PM_{10}, PM2.5, NO_X, CO, VOC, SO_2, and about 30 Hazardous Air Pollutants (HAPs). However, the current fire inventory methodology is very basic. Coverage is incomplete and inconsistent for State, Tribal, and private burners. Fire activity is not derived from incident databases. Instead, State-level annual fire activity summaries are allocated to counties and grids based on forested area. Fuel consumption and emission factors are based on State level averages. Annual emissions are allocated to months based on historic data. Finally, fires are treated as ground-level non-point sources, with no plume rise.

EPA's goal is to improve the current methodology by incorporating model components from BlueSky. Fire locations, durations, and sizes would be obtained from an incident database or from user inputs. Fuel loading will be obtained from NFDRS or FCC coverage maps, and fuel moisture will be calculated from the meteorological model. Fuel consumption will be calculated

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using Consume or FOFEM. Emissions and plume rise will be calculated using FETM and modified Briggs equations. The system is expected to provide gridded hourly emissions, resolved to vertical model layers. The work is expected to be completed by early 2005.

Modeling Emissions from Wildland Fires (Scott Goodrick)

The U.S. Forest Service Southern Research Station (SRS) is working on a system to model the impacts of emissions from prescribed fire using CMAQ. The overall approach is similar to the EPA approach using BlueSky and CMAQ (described in the preceding section). However, instead of using the BlueSky model in its entirety, this project draws on various BlueSky modules. In addition, this project is aimed at predicting the impacts of prescribed fire in real time, while the EPA project is aimed at a comprehensive analysis of all emission sources and is not being carried out in real time.

This presentation highlighted some of the problems and limitations in estimating emissions from prescribed fire. First, the actual acreage burned often differs from the planned acreage. In addition, it is difficult to characterize the preburn fuel loading for wildland fires. Emission rates will also vary widely depending on the relative amounts of flaming and smoldering combustion. Emissions of $PM_{2.5}$ from a smoldering fire are about twice as high as emissions from a flaming fire. Different types of fires will have different amounts of smoldering. For instance, head fires have a higher degree of smoldering. Residual smoldering emissions also are not entrained in the lofted plume from a fire, but remain near ground level.

In the Southern Research Station project, a fire is represented as a collection of different sources, each in different phases of combustion. The project will evaluate the impacts of the different phases of combustion on emissions and downwind impacts. Emission processing and estimation of plume rise under the SRS project are discussed in the following sections.

Point versus Area Source Treatment Fires and Vertical Distribution of Smoke in CMAQ (Yong Liu)

This presentation discussed the application of the SMOKE emission processing system in the SRS CMAQ fire modeling project. (Emission modeling aspects are discussed under the preceding section and the following section discusses the estimation of plume rise for the SRS project.)

Researchers at the SRS evaluated the advantages and disadvantages of handling fire as a non-point source or a point source within SMOKE. (To date, EPA has treated fire as an area source in CMAQ modeling; however, a pseudo-point source approach is currently being used in modeling efforts by the WRAP and the Midwest RPO.) A point source treatment of fire was viewed as superior, because of difficulties in handling temporal variations and plume rise under the emission processing framework for non-point sources.

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Injecting Smoke into CMAQ – An Approach to the Problems of Time Variance and Vertical Distribution (Gary Achtemeier)

The U.S. Forest Service SRS is developing the Daysmoke model to estimate the vertical distribution of emissions from wildland fire. This effort is being carried out as part of a broader project to predict the impacts of prescribed fire using CMAQ. (Other aspects of the project are discussed in the preceding two sections.)

The Daysmoke model is designed to quantify plume changes during the course of a fire, and the vertical distribution of pollutants within the plume. Both of these are important factors in estimating the downwind impacts of a fire. Daysmoke combines two models: an entraining turret model, and a detraining particle trajectory model.

In the entraining turret model, the plume is assumed to be a succession of rising air parcels, characterized as turrets (cylinders). The rate of rise of each turret is a function of its initial temperature, vertical velocity, effective diameter, and entrainment. The turrets sweep out a three-dimensional path that defines the plume boundary.

In the detraining particle trajectory model, particle movement within the plume is described by the horizontal and vertical wind velocity within the plume, turbulent horizontal and vertical velocity within the plume, particle terminal velocity. Detrainment occurs when stochastic plume turbulence places particles beyond plume boundaries, when the plume rise rate falls below a threshold vertical velocity, or when the absolute value of the Large Eddy velocity exceeds the rate of plume rise. After detrainment, particle movement within the ambient air is described by the horizontal wind velocity, the turbulent horizontal and vertical velocity of large eddies and small scale turbulence, the particle terminal velocity, and the particle mass-induced downdrafts.

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Daysmoke requires inputs on 4-dimensional meteorology from MM5 or another mesoscale weather model. For the fire being modeled, the model requires inputs on the initial plume temperature anomaly, the initial plume vertical velocity, and the effective plume diameter.

Figures 4-6 through 4-8 give sample results from Daysmoke for different fire sizes and atmospheric conditions. The green horizontal line in each figure represents the atmospheric mixing height. Figure 4-6 shows results after a 40-minute simulation for a weak smoke plume, and with a weak large eddy velocity in the atmosphere. Under these conditions, the predicted height of the plume oscillates but the top remains below the boundary layer. As the smoke plume grows stronger or the large eddy velocity grows stronger, the plume is distributed from ground level to the boundary layer. Figure 4-7 shows results for a moderate fire plume and with strong eddies after a 40-minute simulation. For strong smoke plumes, the bulk of emissions is lofted above the boundary layer, as shown in Figure 4-8. This figure shows results for a strong plume (from a large fire) and with strong eddies after a 1-hour simulation. For comparison, tests of an 800-acre fire in Georgia showed that about 30% of the plume was above the boundary layer, carrying about 50% of the pollutant mass.

Figure 4-6. Daysmoke results for a weak fire plume with weak eddies after a 40-minute simulation.

Source: Achtemeier, 2004.

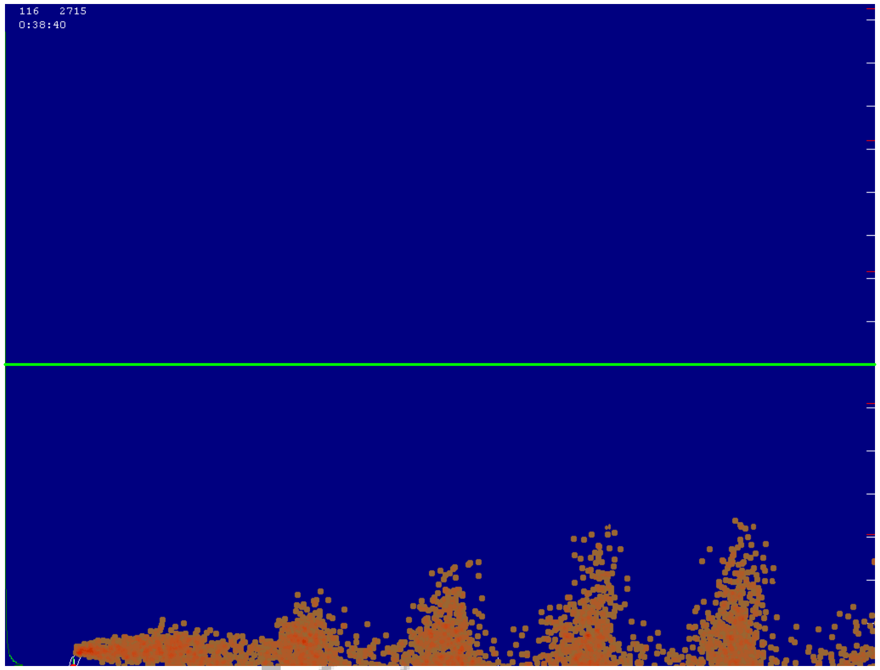


Figure 4-7. Daysmoke results for a strong plume and with strong eddies after a 1 hour simulation (fumigating and fanning)

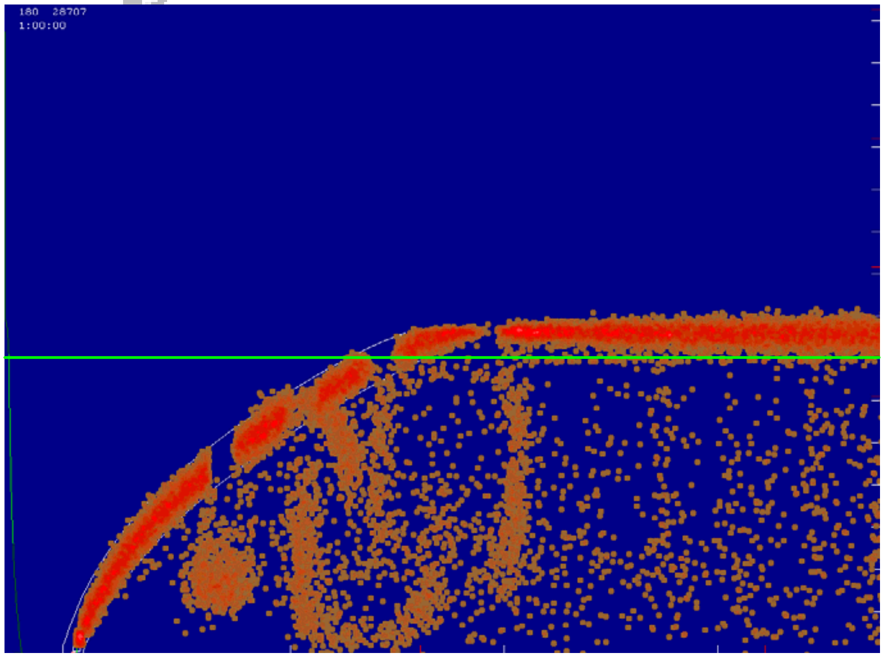
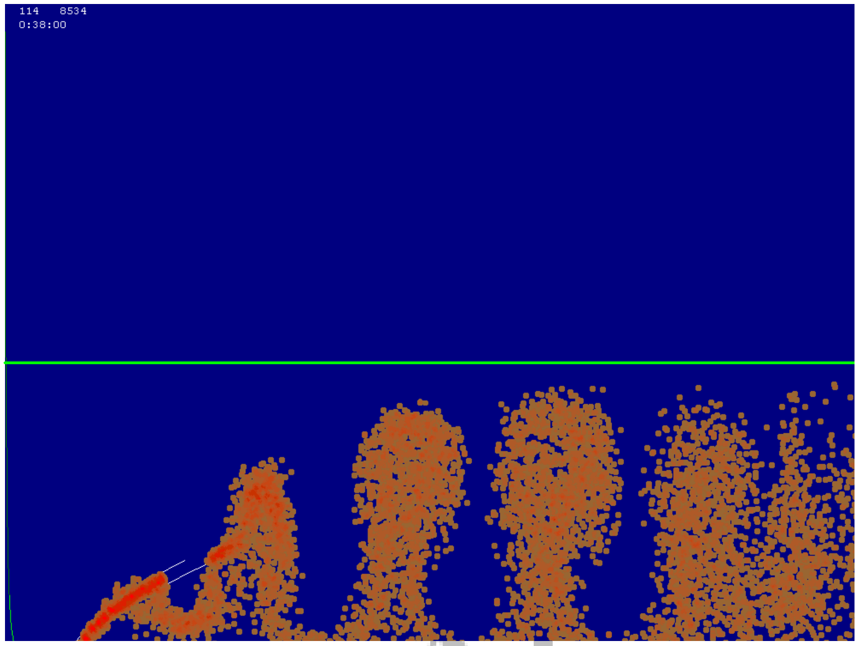


Figure 4-8. Daysmoke results for a moderate fire plume and with strong eddies after a 40 minute simulation (looping)



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Daysmoke can generate multiple plumes simultaneously, for different portions of a fire. SRS is currently working on methodologies for assigning plumes for the duration of a prescribed burn, and to allocate emissions to each plume. In addition, work is currently underway on integrating Daysmoke with MM5 and CMAQ.

There was some discussion of the computer resources required to run Daysmoke. Mark Janssen indicated that computer constraints may limit the Midwest RPO's ability to use a model like Daysmoke for fires on a regional scale.

4.5.3 Discussion

One of the main points of discussion was plume rise. Several people were concerned that current models are using a default plume rise that was developed for the western US, and that these defaults will not accurately depict plume columns in the eastern US. One option would be to use Daysmoke. A good test of Daysmoke's capabilities would be to test it against current data and review the output.

Another prominent issue discussed was the immediate need of plume rise models for the 2002 RPO inventories. Regional inventories are being developed now for 2002. By the end of 2004 all the data will have to be analyzed and reported. Some of the models presented here will not be validated by the time the RPOs need to deliver their inventories. One suggestion was to use FEPS, but this model uses Briggs equations, which provided the default plume rise mentioned above. Another recommendation was to use remote sensing information, however, this will not be available in the short-term.

There was also some discussion of plume dispersion goals in the planning of prescribed burns. Foresters indicated that it is common practice in the Eastern U.S. to carry out prescribed burns in such a way that the plume is lofted above the boundary layer. In this way, most of the emissions are transported away from nearby receptors.

There is no explicit link between fire behavior and plume rise. There need to be models developed to predict plume rise given fire behavior. An implicit part of the problem revolves around the fact that fire duration is not accurately recorded. The time at which a wildfire starts, or stops, is difficult to determine. Normally, only the discovery time is reported. Duration is important to modeling programs, even if the exact time of ignition is only reported as after twelve o'clock noon, as the dispersion, plume and pollutants emitted will be different with time of day. Although information from the National Weather Service is available, it is not precise enough to provide an accurate link. Changes in the way fire duration is reported will need to be the first step.

A question was raised about whether Daysmoke includes moisture processes. Mr. Achtemeier indicated that these are not included in the model, but should be included in an ideal situation. For instance, large fires can sometimes create thunderstorms, which affect plume dispersion. Some participants also indicated that the water vapor from fires could affect the processes simulated by CMAQ. It was pointed out that most of the smoke column is water vapor.

Predicting an accurate plume height is also an issue. Knowing the height to which a plume rises will determine the chemical reactions occurring within the plume. The results of dispersion of those pollutants will also change, given differing plume heights. Apparently dispersion within the plume is not being modeled at all. This problem will also need to be addressed in the long-term.

4.5.4 Short-term Recommendations

1. There was a consensus among presenters that, with current emission processing systems, fires should be treated as point sources. The point source subsystem allows more flexibility than the non-point subsystem in characterizing the initial plume height.
2. Test DaySmoke using 2004 data against model output.
3. Use interim modeling programs over current plume models.
4. Issue a call for any existing data sets that may be beneficial.

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4.5.5 Long-term Recommendations and Needs

1. Put together a team to identify approaches and models to use, by including international and interagency membership.
2. Include real time weather information in models.
3. Model both wildfire and prescribed plumes.

4.6 Quality Assurance of the Modeling Process (Emissions, Meteorology, and Air Quality)

4.6.1 Purpose

There are uncertainties associated with any emission modeling, dispersion modeling, and photochemical modeling. For example, a recent emission and dispersion modeling analysis of a Colorado fire gave lower concentrations than what was observed. The cause of the discrepancy is unknown, and could be a number of different factors, including fuel consumption, the emissions, wind speed, boundary layer, or the dispersion. In another example, satellite fire data returned an estimate which was a factor of 4 lower than a corresponding EPM estimate.

However, model evaluation is in infancy stages, especially with respect to model performance near the surface. In conference calls leading up to this session, the following conclusions were reached:

1. Measurements taken at least hourly are needed for model evaluation. Ideally, for a three-dimensional analysis, more measurements are needed from aircraft, tethered balloon, and surface.
2. The cost of verification could be prohibitively expensive.
3. Inter-agency coordination is needed.
4. Model evaluation should occur in three parts: (1) overall inventory–checking the accuracy of it based on all inputs; (2) separate components of the model (i.e., fuel consumption, emissions, dispersion); and (3) integrated dispersion.

The purpose of this session was to continue discussions on issues from the conference calls, and to ultimately develop a quality assurance protocol for wildfire emissions inventories. The session focused on quality assurance as it relates to model evaluation.

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4.6.2 Presentation Summary and Discussion

Quality Assurance (QA) of Emissions Modeling Process (Sue Ferguson)

This interactive presentation encouraged the group to answer the following questions:

- What have we learned from evaluations to date?
- What are existing QA methodologies?
- What is the purpose of QA?
- Can existing measurements be used for model evaluation?
- What additional measurements are needed?
- What types of field audits and QA procedures can be used to assure the quality of the inventory and assess its accuracy?

Differences in scale (i.e., regional vs. site-specific) were emphasized in answering these questions. Levels of detail needed for both scales were addressed. In this context, discussions centered around dispersion models, which are used on a smaller, smoke management scale, and photochemical models, which are used in regional haze.

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Models are accustomed to dealing with point source data from States and IMPROVE sites, but RPOs are much larger in scope. Regional-scale modeling does not need the level of detail that point-source modeling requires.

<u>What have we learned from evaluations to date?</u>

Although sensitivity analyses on emissions models have been few and far between, some conclusions have been reached about model variability:

- Fuel loading impacts emissions calculations to a much greater extent than emission factors, and is extremely scale-dependent.
- The size of the burn is also largely scale dependent, and introduces uncertainty into emissions calculations.
- Fuel consumption depends on fuel condition and fuel bed types involved, and on whether the area was completely burned, or if the burn created a mosaic of green, brown, and black areas.
- There is not enough speciation in emission factors.
- Emission models are less sensitive to emission factors than fuel consumption.
- Combustion phase influences emissions (i.e., residual smoldering, flaming).
- Anthropogenic emissions (toxics, etc.) have been avoided in calculating emissions for regional haze, but are important for health impacts.

In dispersion models (smoke management scale):

- Plume trajectory is well-captured.

- Concentration data is good at the source, but secondary particle formation introduces uncertainty at distances.
- Lack of good meteorological data creates uncertainty.
- Numerical Weather Prediction (NWP) models have many problems in boundary layers.

In photochemical models (regional haze scale):

- Plume height has been poorly captured, affecting plume trajectory.
- Concentration measurements depend on grid size, and are affected by plume height.
- Re-suspension into the grid after deposition causes downwind concentrations to be too high.
- Spatial averages of the grid agree best with time-averaged observations (i.e., day-to-day variation is poorly correlated with point observations).
- Temporal averages of fires cannot be created – the model under-predicts on days with fires and over-predicts on days without fires.
- The sensitivity of models related to physics vs. chemistry is unknown.

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What are existing QA methods?

The group discussed current QA methods. Sue Ferguson noted that eight QA methods were outlined in a presentation given by Gail Tonnesen on development of the WRAP emissions inventory (see page 64). Other QA methods include checking fire locations for accuracy (e.g., ensuring fires do not occur over water), and that fuel type exists in the region. These QA checks are done by plotting fires and visually checking them for reasonableness.

QA methods were discussed for fuels. It is important to keep fuel QA in context with different scales. When using a national fuel map to develop regional defaults, the user will obtain different results than if fuel were obtained at the burn site. Map resolution can grossly affect the fuel type inputs. Map developers have received complaints from local burners that the map does not accurately reflect what is burned. However, maps at a national scale use regional averages at best to describe fuel types. This does not make maps invalid; rather, users need to be aware of the scale difference and use appropriate resolutions when developing local vs. regional inventories.

QA for combustion efficiency includes defining fuel loading and fuel moisture with fuel consumption estimates.

What is the purpose of QA?

Participants agreed that the ultimate goal of QA is to accurately track emissions changes over time. For example, in the monitoring trends network, changes are tracked annually. It is necessary to know the frequency of measurements and understand their accuracy in order to see a change of a specified magnitude. This information is used for emissions credit trading. A similar process could be used to track fire emissions, but first questions like the following must be answered: “How accurate must emission factors, fuel loading, fuel classifications, and fuel consumption be? Which factor(s) are most important?”

Different regions have different requirements. States and Tribes may track emissions for their purposes and charge fees for local exceedances, but regions may not require emissions tracking at all.

Model sensitivity is a factor in determining QA protocol. Sensitivity analyses need to focus on a regional scale.

Can existing measurements be used?

Existing measurements can be used in the short term, but measurements do need to be improved. Without complementary modeling, measurements are insufficient. For example, back trajectories would be helpful in determining where and when fires occurred, and how they impact visibility.

Sue Ferguson referred to a statement made by Bill Malm in the SOA session, saying that modeling is crucial for projections, but the Regional Haze rule is verified through monitoring. It would be nice to have background concentrations in monitoring reports, but there is currently no agreed upon method.

What additional measurements are needed?

There is value in both filter-based and light-based measurements, but it is difficult to determine the ratio needed of these measurement techniques. It would be impractical to set up nephelometers everywhere. Remote sensing is improving for regional haze. The remote sensing community is working on optical depth improvements and speciation. Some aircraft remote sensing work is underway in Mane-Vu.

Participants agreed that they need better understanding of model inputs in order to run model sensitivity analyses. Remote sensing may not be able to help with this issue. As discussed in the “Other Air Quality Model Inputs” session, there is no time to do case studies or sensitivity runs, but modelers need to deliver a usable product to RPOs.

What types of QA can be used to assure the quality of the inventory and assess its accuracy?

Although Federal data is available, it is inconsistent and difficult to process. A short list of essential data is needed, as well as an easy way to obtain it. It is also important to get all the available data from all sources, both on Federal and more local levels.

The group discussed what QA processes individual RPOs are using. The WRAP is using the same QA techniques that were used in developing their 1996 emissions inventory and their

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2018 projections inventory. ManeVu is obtaining raw data from individual States, and will perform QA themselves. EPA does not perform special QA on fire data, such as QA for fuel consumption. There is basic QA for spatial allocation and emissions.

4.6.3 Short-term Recommendations

1. Current methods should be documented as much as possible. Transparency is crucial in data submittals to ensure that differences in submittals are defined.
2. Consistent collection methods should be pursued whenever possible to ensure a complete story from all available databases.
3. Make sure fires located where fuel exists.

4.6.4 Long-term Recommendations and Needs

1. QA is conducted at the stand level in approximately 1 percent of burn units. Some level of QA needs to be developed at the regional level. Local information should be pursued whenever possible.
2. Sensitivity analyses, validation, and verification testing are badly needed to determine if existing measurements are adequate.
3. Water-soluble potassium measurements are needed.
4. Spatial array needs to be evaluated.
5. The ratio of filter- vs. light-based analyses needs to be investigated.
6. Moving toward a consistent set of inputs with options for calculating emissions.

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5 AGRICULTURAL BURNING

5.1 Overview and Purpose

Emissions from agricultural fires are not easily captured. None of the current models include characterizations for agricultural fuels, nor do they include emission factors. Nonetheless, emissions from these types of fires can significantly impact the air quality in the region.

RPOs have been charged with identifying and estimating emissions from agricultural fires. There have been two emission inventories that have included emissions from agricultural burning to date, and a third is in development. The methods used in the two inventories regarding activity and emission factor development are summarized below.

5.2 Agricultural Emission Inventory Development Efforts

5.2.1 Presentation Summaries and Discussion

Development of Emission Inventories of Planned Burning Activities in the CENRAP (Dana Coe)

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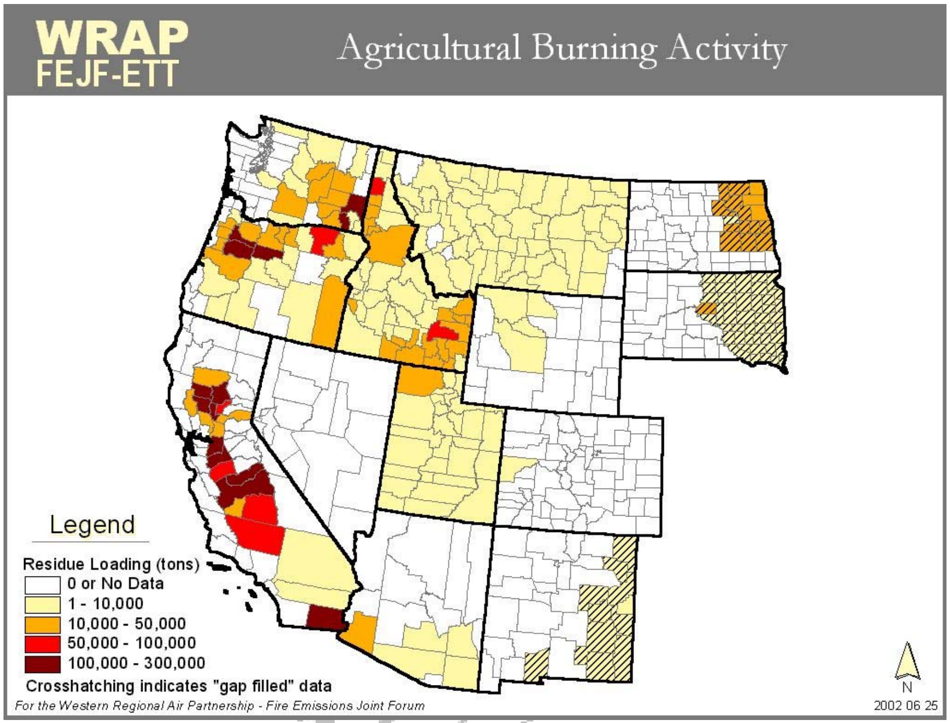
The Central States Regional Air Planning Association's (CENRAP) emission inventory was developed for planned burning activities.[18] Although this inventory primarily focuses on prescribed burning, it also included agricultural burning. Agricultural information regarding dominant crop species and burning practices were compiled from different sources. Crops grown in each State in the region were determined from 2002 National Agricultural Statistical Service (NASS) data. The fraction of harvested acres that are burned per year per State was created from surveys of Agricultural Extension Service (AES) personnel. Approximately 969 county AES offices were contacted, resulting in 549 completed surveys. It was estimated that 13 million acres of agricultural land are burned in the region annually. Fuel loads were obtained from EPA's AP-42 database. Emission factors for barley, wheat, rice, and corn were obtained from a wind-tunnel study report by Brian Jenkins,[19] and all other emission factors were obtained from the AP-42.

Agricultural Burning Activity Data in the WRAP Region (Paula Fields)

A non-burning management alternatives project was completed for the Western Regional Air Partnership (WRAP) in 2002.[20] This project included crop production and agricultural burning activity for 1996 from a former study. Agricultural burn data was compiled by county by crop for each State, where available. These data included information from burning permits maintained by some States, completed emission inventories, and unpublished information from surveys (Figure 5-1). The calculated percent burned in each State was also compared to the United States Department of Agriculture's (USDA) Agricultural Air Quality Task Force (AAQTF) study conducted in 1997. This comparison also allowed for a peer review process. It

Figure 5-1 Agricultural Burning in the WRAP Region.

Source: Fields, 2004.



was estimated that more than two million acres of selected crops were burned in 1996 across the region. In some instances gap fill data was used to estimate acres burned for States like Nevada that have little or no agricultural burn data available. Emissions were also calculated.

Data available regarding activity and emission factors is highly variable for agricultural burning for both studies. Data nominally resides in burning permits collected by a State agency, however, this only occurs where air quality is a problem, and therefore does not exist for every State or tribal land. Also, regulatory exemptions exist for agricultural data, so burning often goes undocumented. Agricultural burning is defined differently from State to State, and even county to county, so data is collected inconsistently. There are different governing bodies for agricultural practices in each State which also makes data collection difficult. Additionally, there are few instances of published data regarding emission factors for the various crops that are burned annually. Some emission factors exist within the AP-42, State emission inventories and the USDA, but these are not complete. Also, these factors are not included in current models like FOFEM and Consume**.**

5.2.2 Short-term Recommendations

In order to address emissions garnered from agricultural burning there are several actions to follow in the short-term. The existing information must be validated, and existing burn plans examined to see if they would make a suitable template. Also, quality control objectives need to be clearly identified. In a follow-up call, leaders in the modeling community felt that it would be relatively easy to add agricultural fuels to the existing models, given the proper information. The emission tools and data requirements should be discussed with the USDA/NRCS. This would will open lines of communication for the agricultural community to provide better technical information on fuel loading & emission factors.

5.2.3 Long-term Recommendations and Needs

In the long-term, the community needs better estimation tools for emissions from agricultural sources. More field studies on crop residue burning are needed, with a focus on the large sources of burning. Additionally, identification of alternatives to burning, such as composting, returning to soil, and mulching needs to be researched to determine the best course of action. Further, development of burn permits for the agricultural community so that data can be collected in a central repository is paramount for adequate emission estimation. Lastly, exploring the use of remote sensing may prove beneficial as agricultural areas are not covered by a canopy layer.

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6 PROJECTIONS

6.1 Overview

The Regional Planning Organizations (RPOs) have selected 2018 as a common initial projection year. Although 2064 has been identified as another important milestone, other years beyond 2018 have not yet been researched. However, longer term projections will be needed to analyze progress with respect to the 60-year "glide path" under the Regional Haze Rule. States and RPOs may require inventories for additional projection years in order to meet the needs of specific modeling efforts.

A number of tools can be used in the development of projection inventories for fire. For instance, the Grand Canyon Visibility Commission (GCVTC) Fire Emission Project (FEP) included extensive surveys of land managers in order to estimate future prescribed fire activity and emissions. The Western Regional Air Partnership (WRAP) and VISTAS have also used historical average prescribed fire activity as a basis for predicting future prescribed fire activity. They have also used historic wildfire inventories as a surrogate for future wildfire inventories. The Western States Air Resources Council (WESTAR) has made use of ecological fire frequencies. The Fire Emissions Tradeoff Model (FETM) can also be used to determine policy tradeoffs between broadscale prescribed fire activities.

Projections may be designed to assess various scenarios. For instance, different emission control strategies may be modeled. Potential control strategies are discussed in more detail in the sessions on Emission Reduction Techniques. Projections of fire activity can also reflect an estimated natural fire regime, or a fire regime that reflects anthropogenic activity, for instance maintenance burning versus restoration.

Projections may be designed to provide the following: an accurate picture of a particular year, a realistic estimate of future conditions in a given year, or a representative picture of a multi year future period. For instance, models like Consume can be used to produce precise estimates of emissions under different control scenarios, or an average percentage rollback can be used to provide a representative estimate of the impacts of control strategies.

The largest source of error in calculating projections occurs during climate forecasting. Weather data cannot be accurately projected for future years. Therefore, it is difficult to determine whether a system will be wildfire dominated or prescribed burn dominated. Given the lack of an accurate weather forecasting system, it may be more appropriate to look at projections as a range of values instead.

A number of issues arise in the projection of future fire emissions. First, control strategy analyses for regional haze require an estimate of natural emissions. However, there are currently no criteria for determining whether prescribed fire emissions should be treated as natural for regional haze analyses; and, if so, which fires should be included in the estimates of natural emissions.

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Projections also require estimates of the fire cycle, or the average number of years between fires, for different ecosystems. The fire cycle can be determined by various factors, including ecological factors, political factors, and funding. If the projection is to be based strictly on ecological factors, then Coopler's Fire Condition class system can be used to estimate the fire cycle. This approach removes artificial boundaries, and focuses on the estimated average natural burning period. For instance, ponderosa pine in Arizona is burned every four years. However, this method is probably unrealistic, since it removes the management and political inputs to the estimates.

Management and political inputs are important in determining the amount of prescribed fire. For instance, in 1995 there was less focus on activity fuels, the Wildland Urban Interface (WUI), and Wildland Fire Use (WFU) because ecosystem management was the predominant focus. By 2002 the focus had changed dramatically due to the increased activity and public attention. Also, the WUI had increased dramatically. The use of WFU, as a tool, had also increased. These factors changed the spatial allocation of the data. Therefore, the ability to project fires to 2018 is important to all stakeholders.

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The fire cycle affects not only the frequency of fires, but also the amount of fuel that is available per acre burned. The Fire Regime Condition Class (FRCC), is used to measure changes in the amount of fuel in an ecosystem. The classifications are conducted by field surveys, and each piece of landscape is scored according to detailed guidelines. Therefore the short fire return interval that stands normally experience has been altered due to changes in land use, which allows the fire return interval to lengthen and the vegetation to change. The FRCC measures how much the system has changed. There are three different classes ranging from 1 (slightly changed) to 3 (severely changed). This system is predominantly used in the western US because it predicts changes in ponderosa pine systems, and these systems are not typically found in the eastern portion of the country. This system is being used to classify stands on Federal lands and a national map will be available in 2005, the Department of the Interior (DOI) will have classifications on their lands by 2006. These studies will be useful for projections especially when comparing strategies for ecosystem restoration.

6.2 Methods for Developing A Projection-Year Inventory

6.2.1 Purpose

Air quality planners prepare comprehensive projections of future emissions in order to assess the levels of pollution control that will be needed to achieve air quality management goals established under the Clean Air Act. These projections will be used in the development and evaluation of air pollution control programs to attain the $PM_{2.5}$ and ozone National Ambient Air Quality Standards (NAAQS). Projection inventories will also be used to assess progress toward regional haze goals.

Projected emissions inventories have focused primarily on manmade sources of emissions. However, fire emission projections are taking on an increasing importance. Recent outbreaks of large wildfires have accentuated the potential air quality impacts of fire. These wildfires have also emphasized importance of prescribed fire in managing fire-dependent ecosystems, with a resulting increase in projections for the used prescribed fire in future years.

6.2.2 Presentation Summaries and Discussion

Example Projection Method – Grand Canyon Visibility Transport Commission Fire Emission Project (Pete Lahm)

A number of methods have been used to project fire emissions. The first projection inventory of fire emissions for regional modeling was developed by the Grand Canyon Visibility Transport Commission (GCVTC). The GCVTC initiated a Fire Emission Project (FEP) to investigate strategies for managing emissions from prescribed fire. Under the FEP, prescribed fire emissions inventories were developed for 1990 and 1995, and also for expected conditions in 2015 and 2040.

The FEP included an extensive survey of land managers in the western States. First, a 50x50 km grid was overlaid onto the GCVTC domain. Within each grid cell, the land was further subdivided by land ownership, vegetative cover, and State (for those grid cells falling on State boundaries). Based on the survey, a database of fuel load, fire type and frequency, and control measures was developed for 1995, 2015, and 2050. Based on this database, visibility impairing emissions were estimated by season. The 2015 FEP projection was later converted to 2018 for the Western Regional Air Partnership (WRAP) fire inventory, which is discussed in more detail below. In addition to information on prescribed fire, land managers were then asked to characterize ecological fire frequencies for each parcel. WESTAR used this information to develop projections based on ecological fire frequencies.[21] Both the FEP and WESTAR methodologies are outlined in Figure 6-1.

The Regional Haze Rule (RHR) developed by the EPA adopted the GCVTCs recommendations regarding degradation to visibility in the GCVTC States. The RHR indicates that all agencies with smoke management programs must include the components necessary to minimize emissions, evaluate smoke dispersion, and outline alternatives to fire; identify and remove any administrative barriers in the use of alternatives to burning; and minimize emission increases from fire to the maximum extent feasible. Therefore, the RPOs have been tasked with not only quantifying wildfire emissions impacts, but also those from prescribed burns, to the extent that future activity and emissions will be impacted.

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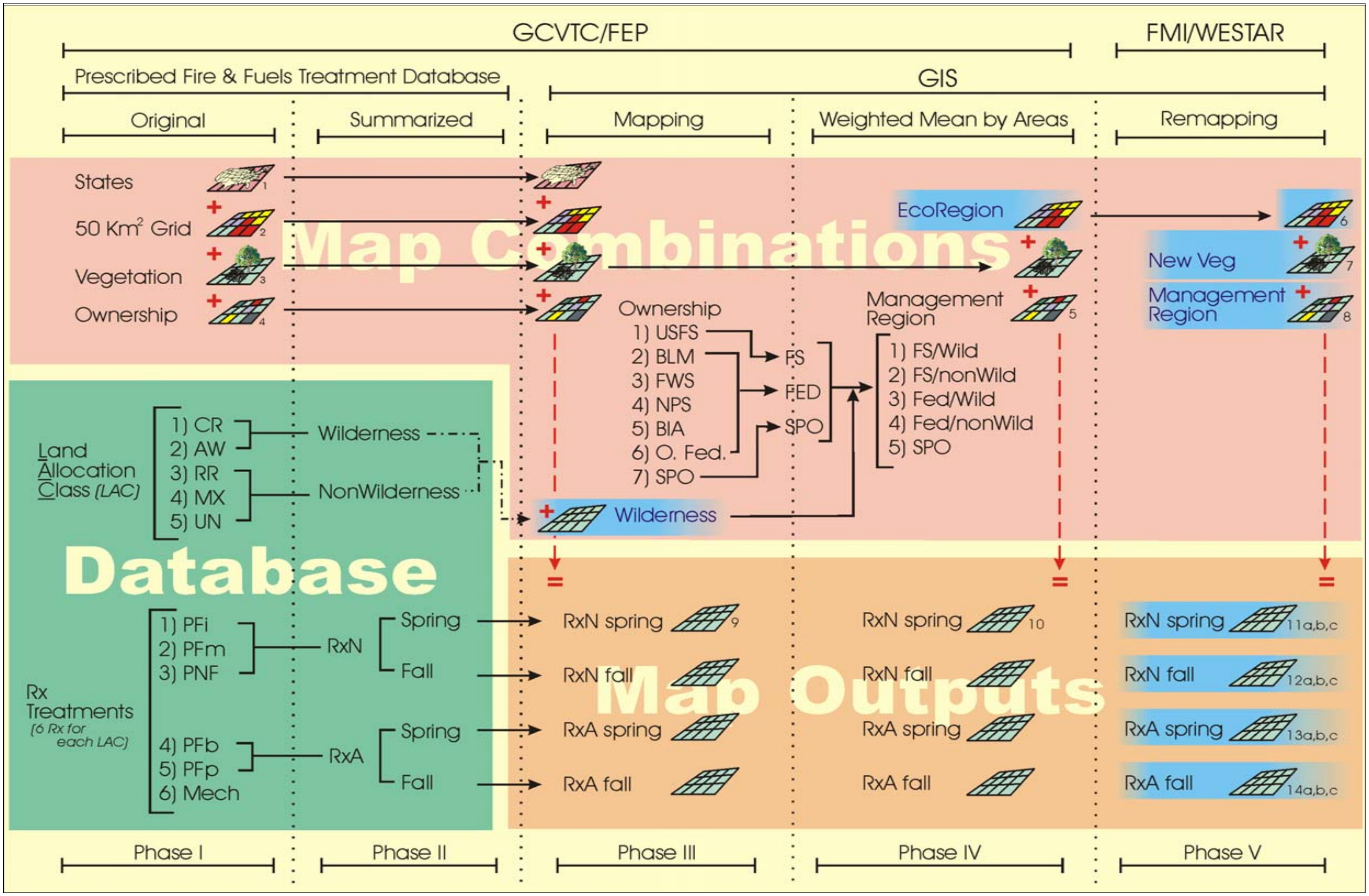
Figure 6-1. Overview of the projection methodology used in the GCVTC Fire Emission Project (FEP).



Three control scenarios were analyzed in the 2018 projection: a no smoke management case, a base case, and an optimal smoke management case. Optimal smoke management techniques for prescribed burns identified by the GCVTC/FEP for 2018 include:

- Use of backing fires
- Burning before green-up
- Burning before large fuels cure
- Firewood sales
- High, large diameter fuel moisture
- Mass ignition/shortened fire duration
- Moist litter and/or duff
- Other biomass utilization
- Rapid mop-up
- Under-burn before litter fall
- Whole tree harvesting or yarding of unmerchantable (YUM)

A number of uncertainties were noted in the FEP emission projections; and, based on experience gained in the FEP, potential improvements to the methodology were identified. First, there are uncertainties in the base year data used to create the projections. These emissions estimates were either modeled or developed based on field data and expert opinion. Fire sizes were based on size ranges such as 0 to 10 acres and 10 to 100 acres. An alternative would be to estimate future incident sizes based on the size distribution of historic fires. Finally, plume characteristics were based on a combination of empirical data and expert judgement.

Example Projection Method – Western Regional Air Partnership 2018 Fire Inventory (Dave Randall)

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The WRAP commissioned a refined projection inventory for fire emissions in 2018, which built on the 1995 base year FEP inventory. On average, a 10-fold increase was projected for prescribed burning in the WRAP domain between 1996 and 2002. The FEP starting point consisted of seasonal emissions estimates resolved by land owners and into 50 kilometer grid cells. The WRAP 2018 projection refined the temporal distribution of the FEP inventory from seasonal to biweekly and then to daily emissions, and increased the spatial resolution from a 50-kilometer grid cell to a 1-kilometer grid cell.

The temporal refinement was done by dividing the 13 States into terrain regions, which were used to define unique burning schedules based on the mix of vegetation types and climactic regimes in each region. These burning schedules were used to allocate seasonal emissions into 2-week periods. Fires were then randomly distributed to days within each 2-week time block and within each 50-kilometer grid. Each fire was also randomly assigned to a 1-kilometer parcel within the 50-kilometer grid cell. In the random fire assignment, fire sizes were based on the historic fire size distribution. Fires were assigned a standard hourly emission profile, with peak emissions in the afternoon, and low emissions at night.

Some potential accuracy issues were noted for the 2018 projection inventory. First, activity data from jurisdictions without data reporting systems are omitted or under-represented. In addition, rangeland burning is omitted or under-represented. The inventory is also only as accurate as the input Federal databases. Finally, time and budget constraints limited the ability to improve on input data.

Some uncertainties were also identified. First, emission estimates are based on combinations of field data and expert opinion. Also, event sizes are based on historic size distributions which may not be representative of future conditions. Finally, plume characteristics are based on a combination of empirical data and expert judgment.

Example Projection Method – VISTAS Fire Inventory (Greg Stella)

VISTAS prepared a projected inventory of fire emissions in 2018 for ten States in the Southeast U.S. The methodology for this projection was developed through consultation with fire experts participating in the VISTAS Fire Special Interest Workgroup.

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The initial forecast was based on a planning baseline or “typical year” acreage of fires at the State and county level of aggregation. VISTAS collected these acreage estimates for recent time periods thought to be representative of the conditions of the planning base year readily available to stakeholders participating in the process. The goal was to try to obtain a minimum of five years worth of data and develop an average number of acres per State for each fire type. These averages were used to normalize the 2002 base year inventory to “typical” conditions. Seven VISTAS States were able to provide historical wildfire data. Six States had prescribed fire data readily available for this purpose.

The projection inventory was obtained by multiplying the 2002 base year emissions by an estimated normalization factor that accounts for deviations from planning base in the acreage burned for each fire type. This methodology assumes that fuel loading and characteristics in the base year are representative of future years. In addition, the spatial and temporal distribution of emissions remained the same as in the base year.

Some alternative methods were identified for spatial and temporal distribution. For instance, future fires could be allocated to non-burned acres, or based on an assumed fire cycle. VISTAS is also seeking suggestions for improving on the temporal and spatial distribution, fuel loading assumptions, plume rise assumptions and speciation estimates used in projections.

6.2.3 General Discussion

Participants noted that the VISTAS methodology had the advantage of maintaining a consistent spatial and temporal pattern of emissions between the base year and the projection year. This allows for an assessment of control on a common basis. In contrast, when the location or timing of fire emissions changes, it is difficult to ascertain the impact of control measures. The consistent spatial and temporal pattern will simplify the analysis of control strategies not only for prescribed fire, but also for other emission source categories.

Participants also suggested that an easy-to-use projection methodology would allow multiple projection runs to evaluate different control strategies or assumptions.

There was discussion of including a meteorological input to projections so that fires are not assigned to days when meteorological conditions would not promote burning. One participant suggested incorporating the impact of changes in climate and meteorology on parameters such as fuel loading and the fire cycle.

There was discussion of the methodology for quantifying the potential emission reductions achieved by a reduction in wildfires through increased use of prescribed fire. None of the current projection inventories include this type of tradeoff.

6.2.4 Short-term Recommendations

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Projections can have different purposes, for instance to analyze a glide slope under the regional haze program, or to analyze the differences between controlled and uncontrolled emissions. In the later case, there is an option to maintain static temporal and spatial distributions between multiple projection scenarios, or from the base year to the projection year.

There is a hierarchy of options from projection inventories. The choice among these options depends on the relative importance of fire emissions in the region being modeled and the purpose of the projection inventory. In the simplest case, the actual 2002 inventory can be retained for fire emissions. Alternatively, projections can be based on a historical average (typical year) without any long term change in fire activity. Future land management objectives can be incorporated, and the effects of climate can be incorporated. The effects of control measures on prescribed fires can be incorporated, and finally, the relationship between wildfire and prescribed fire can be incorporated.

6.2.5 Long-term Recommendations and Needs

This session identified a broader policy question. The WRAP has developed a policy for categorizing fire emissions.[22] However, there are currently no national criteria for determining whether prescribed fire emissions should be treated as natural for regional haze analyses. If criteria are developed, which fires should be included in the estimates of natural emissions?

In addition, methodologies are needed for quantifying the reduction in emissions achieved by replacing wildfire with the increased use of prescribed fire.

7 INTERNATIONAL FIRE EMISSIONS INVENTORY DEVELOPMENT

7.1 Overview and Purpose

Wildland and agricultural fires in Canada, Mexico, and the United States can have cross-boundary impacts. Characterizing emissions from all three nations in a manner that can be easily communicated and evaluated is an important step in improving international air quality. Representatives from these countries brought to the workshop new techniques for addressing some of the inherent problems with management, data, and modeling. The following sections describe ongoing and future efforts to quantify emissions from wildland and agricultural fires in Canada and Mexico. Long-term needs required to further these efforts are also discussed.

7.2 Fire Emission Inventory Efforts in Canada and Mexico

7.2.1 Presentation Summaries

Canadian Emissions Inventory for Forest Fires and Prescribed Burning (Marc DesLauriers)

Marc DesLauriers presented background information on Canadian wildland fire inventories. Canada has historically prepared its National Emissions Inventory, which includes wildland fires, every five years. However, they are starting to compile their inventory annually, beginning with 2002. The 2002 inventory should be available near the end of 2004. Annual emissions from wildfires were compiled by Environment Canada with some provincial collaboration. Prescribed burning is only performed in Ontario and British Columbia. Similar to the United States, large fires represent about 2-3% of the total number of fires but account for 97-98% of the total area burned.

Emission factors were derived from: 1) AP-42, section 13.1 for all provinces except for British Columbia; 2) A report entitled *Biomass Consumption and Smoke Emissions from Contemporary and Prehistoric Wildland Fires in B.C.* for British Columbia, and 3) average factors from FOFEM and Consume. Area burned was obtained from the Canadian Large-Fire Database for wildfires, and the Canadian department of Natural Resources for prescribed fires. National fuel loading averages were used, including 2.24 Kg/M^2 for timber productive land burned and 1.22 Kg/M^2 for unproductive timber productive land burned and other areas for wildfires. A national fuel loading average of 8 Kg/M^2 was used for prescribed fires.

Canadian Wildfires Emission Modeling (David Lavoue)

David Levoue presented modeling aspects of Canadian fire inventories. He has developed a GIS application to map monthly emissions of vegetation fires and other source types on a 1^{o} x 1^{o} scale. These emissions maps are adapted to global transport and climate models. Dynamic

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emission model for forecasting Canadian forest fires is also under development, and will eventually be coupled to the weather forecast model GEM.

The goal of the dynamic model is to calculate gas & particle emissions with time step of less than 1 hour. It is based on regional weather, fuel, and topography data, coupled with firefighting activities. Basic requirements include ignition point, natural barriers to fire, propagation, firefighting activities, and precipitation schemes.

The model includes five modules: 1) fire danger, which uses the fire weather index (FWI) system; 2) spreading rate, fuel consumption, and intensity, which uses the fire behavior prediction (FBP) system; 3) fire growth, which uses elliptical wavelets (Huygen's principle); 4) emissions, including flaming and smoldering for 50 species; and 5) injection (or plume) height, including energy and fire front length.

Wildfire Information in Mexico National Wildfire Control Center CENCIF (Fernando Arenas)

Air quality in Mexico has diminished due to increases in wildland fires, as well as other anthropogenic sources. Quantifying emissions from wildland fires in this country is a relatively new concept, as most of the effort to date has focused on fire detection, management, and control. Activity data has been collected using remote sensing, wildfire weather information, wildfire risk reports, weekly status reports, season status reports, aviation use reports, incident reports, and monthly status reports from the National Activity Program. Mexico has also been getting help from Canada on fuel characterization derived from satellite information. These characteristics have been mapped following the Canadian Wildland Fire Information System. Much of this information is not collected electronically, and none resides in a national repository for use in emissions modeling.

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The major obstacles for Mexico are the identification and location of understory fires, which cannot be detected using satellite imagery; the completion of the fuel characterization maps; funding; manpower; and equipment.

Carbon Emissions from Spring 1998 Fires in Tropical Mexico (Ernesto Alvarado)

Fire data that has been collected in Mexico has been used in a 1998 carbon emissions inventory. The objectives of this inventory were to quantify the amount of carbon emissions for the peak of the 1998 fire season, to evaluate smoke produced by vegetation type and State, and to determine if the assessment could be reproduced for the 2002 fire season. Much of the study was funded by EPA's Global Change Program.

Tropical systems in Mexico have specific parameters which could potentially have an effect on carbon emissions, so it was not appropriate to use emission factors or models developed for the western U.S. for this project. To determine the best strategies for estimating carbon emission from tropical wildfires, many different sources were queried. The consensus was to use the following elements:

- The photo series “Cerrado” for the assessment of biomass loading and flammability
- The tropical section of Consume for predicting biomass consumption in a tropical ecosystem
- Combustion smoldering, which is a thermodynamic model for smoldering consumption
- Smoke management and health assessment tools from Air Quality Amazonia
- Biomass emissions to assess greenhouse gas emissions from wildfire
- Flammability to determine the vulnerability of an evergreen topical forest to fire.
- Tropical emission factors provided by studies conducted in Brazil.

The vegetation cover types for southern Mexico were developed using Landsat™. Nineteen fuel types were developed, of which 14 were identified for the land cover map used to determine fuel load. The northeastern portion of the area is dominated by perturbed cover, fragmented forests, and water bodies. The northwestern peninsula is dominated by pasture/grassland savanna, agricultural plantations, and cultivated land. The rest of the mapped region is fairly well mixed with no clear dominant vegetation type. As a caveat, using satellite imagery to determine fuel type does not adequately capture vegetation types in understory areas, which could impact emissions.

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Sources of error in this project were similar to the error experienced in developing emissions inventories in the U.S. The largest source of error was in determining the fuel loading. This was because there were few tropical fuel characteristics available. The second largest source of error was in fuel consumption due to insufficient knowledge regarding the behavior of a tropical wildfire. The smallest source of error was in development of emission factors. This was due to expert advice from the developers of Consume and the data from Brazil.

The project accounted for two categories of uncertainty: *extensive* and *intensive*. The extensive category included fire sampling, burned area and navigation/ecosystem. This category answered questions regarding area burned, fire behavior, and fuel characteristics. The intensive category included fuel load, emission factors, and combustion factors. This category also answered questions regarding fuel characteristics and fire behavior. The uncertainties in the extensive category ranged from a factor of 2 to 4. The intensive categories’ uncertainties ranged from a factor of 2 to 3 or from 20 to 60 percent.

In an average year there are approximately 6,800 fires which result in 223,000 hectares (ha) burned. In 1998 there were 12,000 large fires which resulted in 490,000 ha burned, and thousands of understory fires that went undetected. These understory fires occurred due to increased wood debris and litter, recurring canopy damage, ignition sources from clear cutting practices, and campfires.

To quantify the emission from understory fires, data from Brazil was used. Brazil conducted biomass burn tests in the Amazon forest in 1997 and 1999. The results in 1997 indicated that there was a high degree of incomplete combustion, whereas in 1999 the combustion rates were higher. The change in combustion rates and the increase in emissions was due to changes in land use. Using this information with the 1998 data changed the results of the two-month study period as the total emissions were 4.6 TgC, which contributed an additional 24% to the region's average annual net C emissions. These estimates for understory fires have direct impacts upon land, land change, and burning regulations as well as fire and smoke management plans.

The southern region in Mexico was most affected by fire in 1998. States in that region are bordered by both the Pacific ocean and the Gulf of Mexico, which increases air flow and potential transport. Land use practices have also changed the ecosystem and have increased the likelihood of fire occurrence by decreasing the moisture content of the forest.

Carbon emission per Land use/Land cover (LU/LC) and above ground densities (AGD) are shown in Table 7-1. Emissions for other pollutants were not calculated, but given a table of emission factors, those results would be easily quantified.

The following uncertainties were identified in this project:

- Estimates of burnt area do not match Mexico's official estimates (pixel saturation by many small fires, underestimation of area burned in the fire reports, differences between definition of forested/non forested area, etc.).
- Ground validation. Fire behavior and consumption are unknown.
- Lack of a fuel model system that represents the fuel bed diversity.
- Most fires burn in the understory.
- Smoke production in flaming and smoldering is unknown.
- We still don't know much about tropical forest fires.

Estimating Wildfire and Agricultural Burning Emissions for the Mexico NEI (Paula Fields)

Also under development is a National Emissions Inventory (NEI) for 1999. The national inventory will be available as a draft by September 2004, with the final released by November 2004. The NIF files will be released in December 2004. A copy of the report can be accessed at www.erg.com/mnei. The User ID is Mexico and the password is emissions.

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Table 7-1: Tropical Mexico fire carbon emissions derived from aboveground biomass densities (ABD) and areas burned in each land use/land cover (LU/LC) class

LU/LC Class	**ABD (Mg/ha)**	**Area burned (ha)**	**C emissions (MgC)**
Cultivated land	11.6	38,320	198,757
	16.4	2,820	
Pasture/grasslands	21.2	25,883	474,061
	26.6	23,376	
Closed cloud forest	126.6	11,589	183,396
Open cloud forest	33.1	2,785	20,741
Closed oak forest	57.9	448	3,242
	87.5	127	1,389
Open oak forest	33.1	3,279	24,420
Closed pine forest	152.1	8,036	152,784
Open pine forest	45.2	4,270	43,426
	64.3	1,257	18,186
	77.5	168	2,930
Closed pine/oak forest	52.0	1,862	12,103
	145.3	7,034	127,755
Open pine/oak forest	45.2	3,746	38,097
	64.3	2,395	34,650
	77.5	442	7,707
Fragmented. forest	33.1	101,999	422,021
	33.8	249	
Tall/medium forest	111.2	81,440	1,844,253
	225.8	25,197	
Short forest	26.0	1,994	6,481
	71.2	18,029	160,458

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Table 7-1: Tropical Mexico fire carbon emissions derived from aboveground biomass densities (ABD) and areas burned in each land use/land cover (LU/LC) class

LU/LC Class	ABD (Mg/ha)	Area burned (ha)	C emissions (MgC)
Perturbed areas	18.0	61,900	799,160
	25.6	33,556	
Agricultural plantations	31.4	1,081	13,747
Forest plantations	90.7	1	11
Chaparral	11.8	59	282
Other	0.0	19,124	0
Water Bodies	0.0	3,167	0
TOTALS:		**485,633**	**4,590,058**

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The focus of the fire portion of the inventory was wildfires and agricultural residue burning. Prescribed burns were not included in the inventory and were not discussed. The emission factors used for agricultural burns were those outlined in the AP-42 for VOC, CO and PM, and by the ARB for size fractions of PM_{10} and $PM_{2.5}$. The collected data included hectares burned by crop and residue loading information. Some of the major assumptions with the project were that only wheat and sugarcane were burned; that there was 2,200,000 Mg of sugarcane residue burned and only 60% of the wheat stubble in the northern states was burned.

Forest types were compiled from the Department of Statistics and Geography (INEGI). Forest type information was available from the Directorate of Forestry (SEMARNAT) and fuel loading was derived from the Institute of Ecology (INE) and Elfonzo Garcia.

The inventory demonstrated that agricultural burring accounted for 2.6% of the $PM_{2.5}$ emission and wildfires accounted for 0.4% of the $PM_{2.5}$ emissions. It was determined that insufficient data existed to estimate the extent of agricultural burning. By utilizing enhanced fire tracking systems for wildfires, the data gaps will become much smaller, and may be completely resolved. Communication needs to improve, especially between the U.S. and Mexican agencies, which would increase the availability and quality of data.

7.2.2 Discussion

The discussion regarding the emissions inventory for Mexico focused on the data that is currently available, and the likelihood of acquiring that data. One workshop attendee inquired about the availability of emissions data, activity level data, and whether the information was in electronic format. Although much of the data is available, it is not in electronic format, nor is it located centrally. The most challenging task that the Mexican government faces is compiling the available data. Given sufficient resources, the data could be amassed to provide valuable information regarding wildfires in Mexico. When asked what was needed to complete a 2002 inventory, the response was sufficient, knowledgeable manpower and funding.

Participants discussed using satellites to aid in obtaining activity data in Mexico. Although satellites can be a valuable tool for data collection, they cannot map tropical areas accurately because of the cloud cover, and they are also not accurate in mapping the understory fires.

7.2.3 Short-term Recommendations

The main focus for both of these countries is completion of emission inventories with emphasis on improved modeling capabilities for Canada, and improved central data repository and analysis for Mexico. Opening the lines of communications among the three nations will allow for data transfer and sharing knowledge that will benefit all involved in the long term.

Efforts have already been initiated to improve the forest fire emission estimates in Canada, with the development of a dynamic emission estimation model, which takes or will take into account detailed forest inventory, fuel consumption, forest fire statistics, emission factors, fuel consumption, and combustion phases (FOFEM, Consume, FEPS). There has also been development of more detailed statistics to improve the emission estimates for prescribed and agricultural burning (location, time period, fuel consume) There is a need to investigate which of the available emission estimation models could be used for Canada, as some input parameters may not be available in Canada. Canadian monthly data for their 2002 inventory will be available in either November or December 2004. Mexico has data ready for processing and could be ready in the same time frame given the proper resources.

7.2.4 Long-term Recommendations and Needs

As more regions and nations develop fire protocols, it is important that the information and data be globally consistent. By adopting global strategies now, future decisions regarding fire management, ecosystem restoration, and global change response will make data sharing and communication easier. This will also help to develop a support system whereby development, validation, and applicability of data will be consistent.

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8 EMISSION REDUCTION TECHNIQUES

8.1 Overview

Controllability of prescribed fires is a major factor in achieving Regional Haze goals. Section 309 of the Regional Haze Rule specifies that smoke management programs (SMPs) must be utilized to minimize emissions, evaluate smoke dispersion, and create alternatives to burning wherever and whenever feasible.[23] Emission reduction techniques (ERTs) have been developed for use in SMPs to reduce emissions produced for a given area treated with prescribed fire. These techniques are valuable in demonstrating that reasonable progress has been made to reduce emissions from wildland and agricultural fires.

Many ERT options exist, and smoke managers may use each independently or in combination. They can be built based on surveys (e.g., GCVTC-Fire Emissions Project/WRAP), historical or average fire years (e.g., VISTAS, WRAP), ecological functions (e.g., WESTAR), and/or fire emission tradeoff models. Techniques are influenced by land management objectives, the type and/or amount of vegetation treated, safety considerations, cost, and laws and regulations.

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In general, emission reductions are accomplished through the following:

- Reducing area burned
- Reducing fuel load
- Reducing fuel production
- Reducing fuel consumed
- Scheduling burning before new fuels appear
- Increasing combustion efficiency

Reducing the area burned includes decreasing burn fuel concentrations, isolating fuels, and conducting burning in a mosaic instead of a total area burn. Figure 8-1 illustrates the emissions reductions accomplished by burning in a mosaic.

Reducing fuel load may include mechanical removal such as mechanical processing (e.g., wood chipping) and firewood sales, biomass for electrical generation, biomass utilization, and grazing. Reducing fuel production may include chemical treatment (e.g., herbicides), site conversion, and land-use change. Reducing fuel consumed may include burning woody fuels, litter, and duff with a high moisture content. Figure 8-2 illustrates the emissions reductions achieved by burning fuels with high moisture content. Reducing fuel consumed may include burning before precipitation and burning before large fuels cure.

Scheduling a burn before new fuels appear may include burning before litter fall in the autumn, or burning before green-up in the spring. Increasing combustion efficiency may include conducting burns in piles or windrows, backing fires, or burning in dry conditions. Rapid mop-up, aerial ignition, and air curtain incinerators (both refractory, or brick-lined, and non-refractory) may also increase combustion efficiency.

Figure 8-1. $PM_{2.5}$ Emissions from Total Area vs. Mosaic Underburn.

Source: Presentation by Roger Ottmar, "Emission Reduction Techniques"

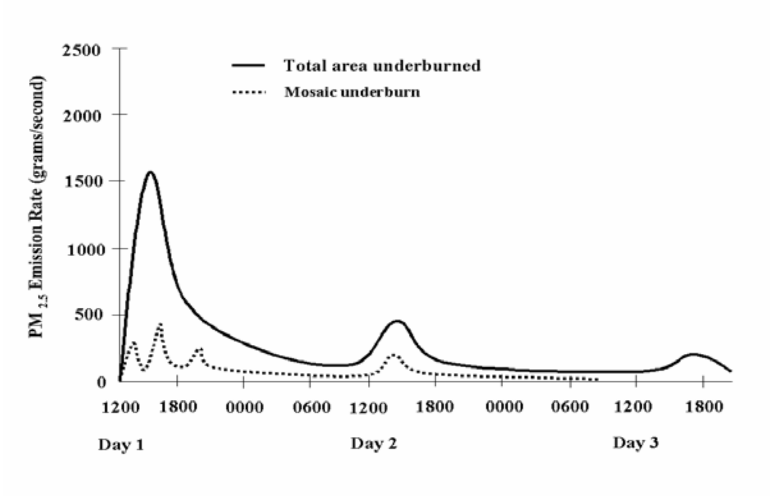

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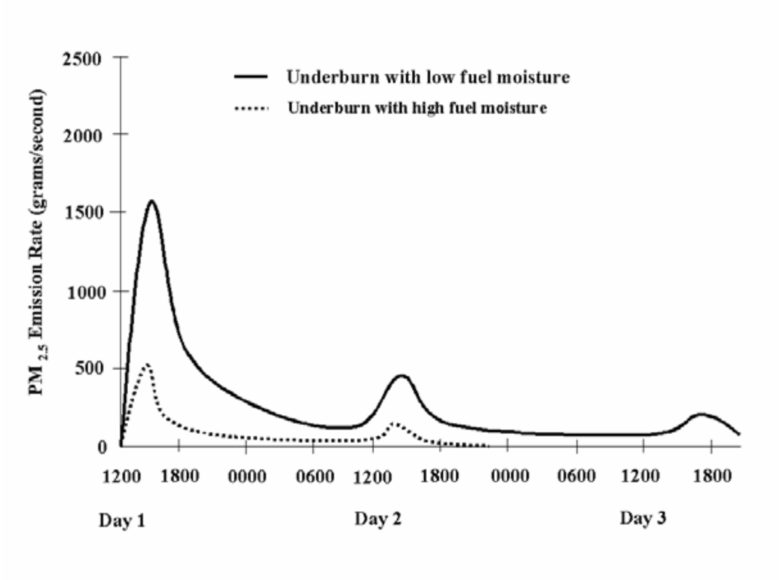
Figure 8-2. $PM_{2.5}$ Emissions from High vs. Low Fuel Moisture

Source: Presentation by Roger Ottmar, "Emission Reduction Techniques"



Tradeoffs must be considered when applying ERTs. These techniques may not always reduce impacts of smoke on visibility in Class I areas. For example, selling firewood to reduce fuel load may simply transfer emissions from a prescribed fire in a wildland area to wood smoke in an urban area. Burning dry fuels to increase combustion efficiency may actually increase emissions of some pollutants because large fuels and deep duff layers are available to burn. Burning plastic-covered piles could introduce toxics into the air.

In addition to considering tradeoffs, it must be recognized that ERTs cannot eliminate 100 percent of emissions, nor is it feasible to apply ERTs in all burning situations. For example, emission reductions may not be needed in a wilderness area, away from the urban interface and a Class I area. There may also be economic and political limits to using ERTs.

Mike Ziolko presented a case study of ERTs being incorporated into Oregon's Smoke Management Plan. Emission reduction goals were established as part of Oregon's Class I Area Visibility Protection Plan. The State uses many of the techniques described in the 2001 edition of the *Smoke Management Guide for Prescribed and Wildland Fire*[24], including mosaic burning to reduce area burned (primarily used on Federal lands); mechanical removal to reduce fuel load; chemical treatment to reduce fuel production (primarily used on private lands); conducting pile burns (and some windrow burns), using rapid mop-up and aerial ignition to increase combustion efficiency; and burning fuels with high moisture content and burning before large fuels cure to reduce fuel consumed. Figure 8-3 illustrates the emissions reductions achieved through Oregon's Smoke Management Program from a 1976-1979 baseline.

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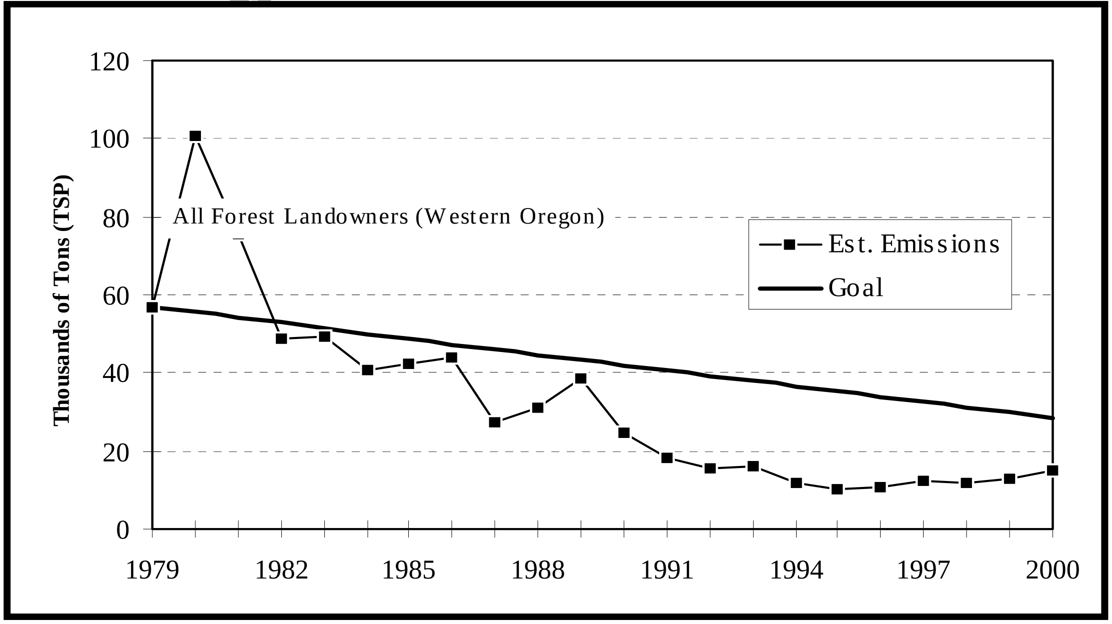
Figure 8-3. Forest Land Burning Emissions Reductions From 1976-1979 Baseline

Source: Presentation given by Mike Ziolko; "Oregon's Tracking of Emission Reduction Techniques"



Oregon collects very detailed data on fuel consumption from prescribed burning. Smoke managers use the Automatic Calculation of Slash Tonnage (ACOST) and Pile Calculation of Slash Tonnage (PCOST) spreadsheets to compute fuel consumption, which uses equations from Consume 2.1.[25]

A number of issues with tracking ERTs arose:

- How can air quality benefits be quantified with specific ERTs?
- How can States mesh their data where data collection does not exist or is significantly different? Is consistency AND transparency needed?
- What are the air quality tradeoff issues?
- How should alternatives to burning be addressed? How can we calculate the benefits of not burning?

The following sections further address emission reduction techniques and how they can be tracked, quantified and addressed in smoke management plans.

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8.2 Emission Reduction Techniques and Smoke Management Plans

8.2.1 Purpose

The purpose of this session was to discuss how ERTs are incorporated into smoke management plans, and how ERTs can be quantified and translated into credit for actual emission reductions.

8.2.2 Presentation Summary and Discussion

Emission Reduction Techniques (Roger Ottmar)

The presentation outlined answers to and encouraged discussion on the following questions:

- What data are to be collected to capture emission reduction techniques?
- How are emission reduction techniques currently addressed?
- How are emission reduction techniques going to be addressed in the future?
- What are the emissions tradeoffs?

<u>What Data are to be Collected to Capture Emission Reduction Techniques?</u>

The presentation listed seven data elements needed to capture ERTS: blackened acres, fuel loading, fuel condition, season, ignition type and time, and lightning patterns. There was some discussion about the level of detail needed for each element. For example, Oregon collects specific fuel moisture for each burn using the NFDRS map and augmented with weather data collected on-site or at a representative weather station. Is this information too specific? Would a simple “wet” or “dry” entry suffice, or would a moisture level above a certain percentage qualify as an ERT?

How are Emission Reduction Techniques Currently Addressed?

The techniques to address ERTs include reporting black acres; and recording season, fuel characteristics, and fuel consumption and emissions. Quantifying ERTs requires correct fuel loading inputs. Currently, fuel loading is determined by the old FCCS classes, the new FCCS 1.0 with change agents, stand-level inventory, and expert knowledge. Consume 2.1/FOFEM can be used to estimate fuel consumption and emissions for different prescribed burning scenarios.

How are Emission Reduction Techniques going to be Addressed in the Future?

In the future, reporting of black acres and season will be improved and consistent. FCCS 2.0 with change agents will be available to report fuel characteristics. Improved models, such as Consume 3.0 and FOFEM 6.0 will be available to track fuel consumption and emissions.

What are the emissions tradeoffs?

Smoke Management strategies are not without potential negatives and must be prescribed and used with careful professional judgment and full awareness of possible tradeoffs. ERTs can prevent accomplishment of objectives, increase future smoke episodes, cause negative impacts on other valuable resources through soil compaction, loss of nutrients, impaired water quality, etc., and can be expensive.

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Roger Ottmar presented four case studies to illustrate emissions tradeoffs. In the first case, a prescribed fire was conducted on a ponderosa pine stand to prepare the site for natural regeneration. In order to obtain this objective, low fuel moisture was required to burn litter and duff so that 60% of the mineral soil was exposed. Low fuel moisture resulted in large quantities of less buoyant smoke.

In the second case, a ponderosa pine/mixed conifer stand prescribed fire objective was to retain large logs for wildlife and retain an organic layer to reduce tree mortality. In this case, fuels will be wet to reduce consumption, which will result in very little smoke production and smoldering. However, an appropriate fuel reduction may not be accomplished to prevent future wildfires.

In the third case, a prescribed burn was conducted in longleaf pine understory to reduce accumulation of large wood, litter, duff, and grasses. Fuels must be dry to meet this objective, which creates the potential for a large amount of smoke production and long-term smoldering. High mop-up costs will also result from this type of burn.

In the fourth case, a partially dead mixed conifer stand was thinned mechanically, then burned. In this case, there were no prescribed fire or smoke management conflicts. There may be an impact on wildlife, soil, and water quality, however, and future wildfire problems may occur if chips are not removed.

There was some discussion about the fourth case. Burners do not account for emissions produced from off-road equipment used to mechanically remove fuel, or emissions from air curtain incinerators, but they should be held accountable for all these factors when implementing an ERT. In California, the solid waste industry is not allowed to use air curtain incinerators, but foresters are.

8.2.3 Discussion

The group discussed the following questions:

- What data are to be collected to capture emission reduction techniques?
- What processes are being used to quantify emission impacts and costs of ERTs?
- How can costs of ERTs be captured?
- List key steps used today and in the future to track and give credit for using ERTs?

What data are to be collected to capture emission reduction techniques?

There was general agreement that the same data elements that are tracked for an emissions inventory should be tracked for ERTs. The same data to develop an inventory is needed to track ERTs as a whole. If, for example, perimeter acres are collected to produce an emissions inventory, and a manager wants to see the impacts of reducing acres burned, the reduction should be calculated as perimeter acres.

Another issue dealt with educating the burn community about ERTs. Participants raised concerns that ERTs will not penetrate the burn community, and regulators will not be effective in educating the community to track the necessary data elements to develop both an emissions inventory and account for ERTs. Representatives from Arizona noted that they have implemented a training program, and will track ERTs on a burn-by-burn basis. However, they do not have any means to quantify emissions benefits from ERTs.

It was noted that daily burn tracking will impact regulations. BlueSky will be available to track daily prescribed burns. Although California tracks PM_{10} daily, a participant questioned if States lack regulatory authority to enforce tracking. Smoke management regulations give States the authority.

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What processes are being used to quantify emission impacts and costs of ERTs?

Arizona and New Mexico require burners to fill out forms listing ERTs used as well as other burn information. However, a tracking and/or permit system must be in place in order to

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track ERTs. Some RPOs or States may not have this capability. ERTs also need to be geographically centered, as RPOs will be faced with different air quality issues.

Sherri Fairbanks noted that California does not currently track ERTs. Instead, daily PM_{10} emissions are tracked, and burners are limited to 150 acres per day during permissive burn dates in April and June based on this tracking system. However, this does not allow burners to accomplish their objectives, and increases the chance for catastrophic wildfires in the no-burn months of May and November. For other sources, an overall PM limit has been imposed, so sources may not have to decrease activity if they can control PM emissions. She suggested expanding this principle to include prescribed burns.

Roger Ottmar suggested an approach to track ERTs holistically. Modeling already occurs for smoke management techniques. Perhaps an algorithm could be incorporated into dispersion models to include impact reductions from ERTs. This approach would incorporate weather data as well.

The *Smoke Management Guide*[24] used Consume to come up with algorithms and conditions to account for anticipated ERTs. It was a costly endeavor, but it could be used across all RPOs to track different ERT impacts. Oregon has employed equations in Consume 2.1 to track, quantify, and compare ERTs. A similar project could be undertaken with BlueSky. FOFEM also has the capacity to compare ERTs, including changing fuel moisture and loadings.

Different model inputs will be needed for different ERTs. For example, mass fire situations require a time of ignition, and techniques like lining snags and stumps requires spatial data. Also, models would not be able to track all ERTs, like wood chipping. Lookup tables could be used in these cases. Future model development work could center on including more ERT options.

How can we capture the cost of ERTs?

The economy largely determines which ERTs will be used. For example, chipping will only occur in a good economy when the landowner can afford it. Roger Ottmar recommended looking at the WRAP's alternatives to burning document for cost references.[26] It is fairly easy to cost a burn that is hand piled vs. broadcast.

Participants discussed how agencies apply and track cost. The National Fire Plan Operating and Reporting System tracks cost to some extent for Federal agencies. The forms used by New Mexico and Arizona do not track costs. In California, chipping charges are implemented on private lands. In the Southeast, the cost of litigation reduces the amount of burning substantially for State and private lands. Federal land managers are required to do upwards reporting, and prescribed burns at the urban interface are much more expensive.

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Concerning financial cost, RPOs would like to know if it would be more cost-effective to pay burn fines instead of implementing ERTs. A cost analysis for tradeoffs would be useful, as well as an analysis to determine what kinds of emission credits could be obtained by using ERTs.

List key steps used today and in the future to track and give credit for using ERTs

Consume 2.1 and FOFEM have the capacity to quantify differences in emissions from ERT and baseline scenarios. However, States with permit systems in place can track and credit ERTs much easier. WRAP States currently have individual tracking systems, but they will all have an emissions management database system (EDMS) in the future for Regional coordination purposes. States are pushing hard to incorporate ERTs into the system. Other RPOs are encouraged to examine the option of having an EDMS, but costs to States to implement the system are unknown. In States where fire emissions are swamped by other sources, an EDMS may not be practical.

Participants discussed which States have permit or tracking systems. California is developing its own tracking system, but it is unknown whether the system will include ERT tracking. The Midwest does not track ERTs, although Minnesota does have a Smoke Management Plan in place. Alabama does not track ERTs. South Carolina, Georgia, Alabama, and Florida all have permit systems, though, and South Carolina collects burn coordinates and fuel consumption based on meteorological conditions. Alabama's permit system could cause double counting. Burn permits expire after one day, and burners must get a new permit if they do not burn on the specified day.

There was some discussion about motives. Participants discussed the differences in management objectives vs. ERTs. A management objective was clarified as setting up burn scenarios, for example, to burn in the spring in order to burn different fuels. For example, burners may handpile a burn because it is easier not to achieve some emission reduction. ERTs must go beyond these objectives to intentionally reduce emissions, and strive to go beyond the justification of "I waited until it rained to burn." However, motives cannot be regulated or enforced by States. In the end, motives matter little if emissions reductions are achieved.

The WRAP has compiled a table of ERTs, but there is a lot of missing information. It may be worthwhile to discuss resources needed to finish the project. Also, some ERTs are being questioned. For example, burning chaparral may not reduce 80 percent of PM emissions, as stated in the guidance.

8.2.4 Short-term Recommendations

What data are to be collected to capture emission reduction techniques in a consistent manner?

1. The same data is needed for ERTs that have been collected for emissions inventories (i.e., fuel moisture content, acres blackened, etc.).
2. Arizona will track ERT data on a day by day basis.

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3. List of ERTs captured from the burn plan or NEPA document.
4. Use WRAP methods for activity tracking.

What processes are currently being used to quantify the impacts and costs of emissions reductions measures?

1. Use a checklist of ERTs, and identify appropriate ERTs for each burn (i.e., NM, AZ).
2. Permitting or activity tracking system needs to be in place.
3. Apply Consume to quantify emissions reduced thru utilization of ERT (i.e., OR).
4. 2001 Smoke Mgt Guide.
5. Refer to WRAP alternatives to burning to reference costs.
6. FOFEM can be used to compare treatment alternatives.
7. Use wildfires as the worst case scenario for comparison.
8. NFPORS.

What are emissions tradeoffs (net reductions) of ERTs (covering piles, wood stoves, chipping)?

1. High intensity burning increases NO_X. Seasonal use of fire may not result in NO_X being an issue.
2. Prescribed emissions are relatively low, so are they are important.
3. Low temperature fires may increase HAPs, especially from agricultural burning.
4. Already have a cost database for different treatment alternatives (i.e., handpiles vs. broadcast).
5. Cost of litigation and potential outcomes (primarily private land).

How should alternatives to burning be tracked and averted fire emissions not generated be accounted for? What are the benefits of alternative practices and how may they be quanitified?

1. Annually track reductions with a Smoke Management Plan database (i.e., Arizona, Oregon).

8.2.5 Long-term Recommendations and Needs

What data are to be collected to capture emission reduction techniques in a consistent manner?

1. Is forestry held to a different standard than other sources? Need to capture data from overall forestry management practices that affect emissions (i.e., diesel products from a chipper, air curtain incinerator emissions).
2. Need wild and prescribed fire emissions inventory monitoring to indicate tradeoffs.
3. Data to support impact determination method (BlueSky or other).

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What processes could be used in the future to quantify the impacts and costs of emissions reductions measures?

1. ERTs need to be geographically specific. What are acceptable ERTs in an RPO?
2. Add an algorithm to BlueSky modeling to assess impacts of ERTs.
3. Need holistic approach to include avoidance techniques (not just ERTs).

What are emissions tradeoffs (net reductions) of ERTs (covering piles, wood stoves, chipping)?

1. Related to permits: assess costs of different treatment alternatives.

How should alternatives to burning be tracked and averted fire emissions not generated be accounted for? What are the benefits of alternative practices and how may they be quantified?

1. Tracking system needs to be in place (EDMS as Region wide tracking system).
2. Go beyond management objective to determine whether ERT is applied (when do you give credit?).
3. Encourage research to cover existing data gaps.

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8.3 How to Reflect Emission Reduction Technologies (ERTs) and Alternatives to Burning

8.3.1 Purpose

This session discussed the methodologies that should be used to reflect emission reduction technologies and alternatives to burning in emissions inventories. The importance of tracking ERTs and alternatives to burning varies widely from Region to Region. Some Regions maintain extensive tracking systems for prescribed burning emissions and controls because of the magnitude of emissions and their potential impacts on local air quality. Prescribed burning is also expected to increase substantially on Federal lands, and on State and private lands in some areas. This increase in prescribed burning is expected to put a strain on the ability of air quality management agencies to meet the reasonable further progress goals under the Regional Haze Rule. In these areas, land managers will have to track prescribed burning controls in order to show equity with industry and other emission sources. Federal land managers also need to demonstrate that the increase in emissions from this increase in burning is being minimized.

8.3.2 Discussion

As a prelude to determining how to reflect control techniques in an emissions inventory, it is first necessary to determine when control techniques can be used. Factors affecting the applicability of a technique for prescribed fire include fuel type, fuel load and constituents, land classification, and seasonal or climate driven limitations. Cost is also a factor, for instance some control measures require a greater level of effort, in terms of practitioners' time. Safety is also important, both in terms of the risk to the community and the risk to burners. The fuel objective also plays a major role. For example, if the objective is to remove a large mass of downed woody fuels, then the control technique of burning under high moisture conditions would not be a suitable option. Burning under high moisture conditions would reduce emissions, but would not accomplish the objective. Participants agreed that the use of ERTs should be subject to review by stakeholders and peers. Practitioners' health and safety should be a key factor in this review.

In the Southeast, the net increase in prescribed burning is expected to be modest, because prescribed burning is already widely used on private lands. ERTs are implicitly included in fuel loading estimates used to develop emissions inventories, but their impacts are not explicitly quantified in the inventory. The issue of quantifying the impacts of ERTs in this Region has not arisen to date, but may become important in the future. In some States, fire emissions are very low in comparison with other emission sources. In general, these Regions do not foresee a need to track the impacts of ERTs for prescribed fire.

In developing a methodology for applying ERTs to emissions inventories, the scale of the ERT impact assessment is an important initial factor. Ideally, ERT impacts would be quantified at the prescribed burning project level. However, the necessary information is not available for evaluating each project. An alternative is to estimate the penetration of ERTs on different land categories, which is also difficult. The applicability of any particular set of ERTs is affected by both ecological and political divisions (such as States). In addition, ERTs can have different impacts within the same ecoregion.

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There is a range of available options for compiling activity data. Participants agreed that surveys of Federal, State, and private land managers are an acceptable approach for assessing the penetration of ERTs for various land classifications, ecoregions, and political divisions. In many cases, such as in the Southeast, the State forester can provide information on ERTs used by the forestry industry on private lands. Oregon tracks ERTs for each project within its prescribed burn database.

Once the penetration of ERTs has been evaluated, a range of options is available for representing their impacts in the emissions inventory. The level of detail possible is determined by the availability of data, the level of effort required, and other organizational constraints. Detailed emission reductions can be calculated for each prescribed burn using models such as Consume. However, the necessary input data for these calculations are not generally available. Alternatively emission reductions can be applied at different spatial levels. Participants agreed that it is acceptable to apply a simple percentage emission reduction at the Regional level and by fuel type.

Participants noted that expert opinion should be used to complement the results of fire models in estimating the effectiveness of ERTs. A Forest Service researcher noted that this evaluation should take into account the impacts of ERT on fuel objectives and land management objectives. If ERTs reduce the amount of fuel burned, then their emission reductions may be illusory, in the long term, since prescribed burns will need to be carried out more frequently.

Evaluations of ERT effectiveness should include the impacts of interactions among different techniques when ERTs are used together on the same fires. As noted earlier, stakeholder and peer reviews of ERTs should take into account practitioners' health and safety.

There was some discussion of whether it is possible to quantify the impact of prescribed fire on the incidence of wildfire. Some participants felt that this would not be possible. However, others stressed that the main justification for the projected increase in prescribed fire, and resultant emissions, is to reduce the risk of wildfire. Therefore, it is important to reflect the likely reduction in emissions from wildfires.

There was also discussion of how to incorporate the impacts of measures that are used to reduce the impacts of smoke, but that do not reduce the emissions from a particular burn. This would include burning windows and measures that affect the timing of emissions to increase dispersion. Participants noted that there is a benefit to maintaining the same temporal and spatial patterns in the base year and the projection year in order to evaluate the benefit of a Smoke Management Plan (SMP).

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8.3.3 Short-term Recommendations

The following are short term recommendations for the development of fire emissions inventories based on the material presented the discussions held in this session:

1. The use of ERTs should be subject to review by stakeholders and peers. Practitioners' health and safety should be a key factor in this review.
2. Surveys of land managers are an acceptable approach for assessing the degree to which ERTs are used or will be used in the future. However, more detailed tracking systems can be employed.
3. Participants agreed that it is acceptable to apply a simple percentage emission reduction at the Regional level and by fuel type. However, more detailed calculations can also be employed where input data and resources are available.
4. Expert opinion should be used to estimate the effectiveness of ERTs, rather than replying solely on fire models.
5. Evaluation of ERTs should take the following into account: 1) actual emission reductions or emissions averted, 2) the impacts on fuel objectives and land management objectives, and 3) interactions among multiple ERTs when they are used in combination. The WRAP has developed policies for evaluating ERTs which can serve as a starting point for other regions.[27]

8.3.4 Long-term Recommendations and Needs

A broader question was identified regarding whether emissions inventories should reflect the predicted impacts of increased prescribed burning on the incidence of wildfires. Methodologies would be needed to evaluate these impacts.

9 CONCLUSIONS AND RECOMMENDATIONS

Throughout the workshop, discussions centered around two tracks: current available inventory development methods, and future inventory needs. This section brings together major short term recommendations and long terms needs that were discovered in each session of the workshop.

Some of the items that are considered near or at closure are:

1. Availability of fuel characterization maps and the FCCS Fuel Classification System
2. Availability of fuel characterization maps.
3. Integration of emission and grid models.
4. Increased resolution in emission factors.
5. Up-to-date information regarding activity tracking in Canada and Mexico.
6. Emission modeling technology that's ahead of its utilization.
7. Improved Federal fire activity reporting and archiving.
8. Networking of stakeholders, RPO's, research, and developers
9. Engagement of the Fire Consortia for Advanced Modeling of Meteorology and Smoke (FCAMMS)
10. 2002 Emissions inventory submissions and revisions
11. Personal networking of stakeholders, RPOs, and developers.

Action items that will take more effort and attention to resolve include:

1. Insufficient activity tracking for input into emissions models.
2. Large gaps in agricultural burn activity and emission factors data.
3. Emissions speciation.
4. Improvements to plume rise modeling.
5. Lack of conceptual and technical consensus regarding long-term projections.
6. Further engagement of of Fire Consortia for Advanced Modeling of Meteorology and Smoke (FCAMMS), and the Fire Air Issues Coordination Group (FAICG) in the emissions development process.
7. Documenting emission reductions that may as a result of Regional Haze Rule programs.

9.1 Short-Term Recommendations

General

In the short term, data transparency was advocated over consistency. Requiring consistent reporting may discourage agencies and cause them to exclude otherwise useful data. There was general agreement that any data, however incomplete, was preferable to no data. However, it was also recognized that reporting requirements and formats needed to be fully explained, and any

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data submitted needs to be fully documented. Level of accuracy or detail was also discussed for short term goals. In general, discussions concluded that we should strive for whatever level of accuracy or detail is available. Requiring the reporting agencies to achieve any particular level of detail or consistency could impede the process.

It was also noted that in developing a fire emissions inventory, each element introduces a level of uncertainty. Of these elements, fuel loading and fuel consumption introduce the largest errors. Area burned also introduces error, as there are very limited methods in determining black, brown, and green acres in a fire event. While emission factors seem to introduce the smallest errors, many of these factors are outdated, and factors for pollutants such as certain air toxics have not yet been developed.

Fire Activity Tracking

The matrices entitled “Framework for Discussing Data Quality Objectives” are a good short-term guideline in determining data elements required for developing inventories for different modeling scales (i.e., Regional haze and highly resolved modeling). For wildfire reporting, fires less than 100 acres could be considered area sources, and may only need a county ID and acres burned. Fires greater than 100 acres must have specific locations, and Type I IMT incidents should report the fire centroid or actual perimeter burned. For prescribed and agricultural fires, any data available should be reported.

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IMPROVE, Tracers, & Source Apportionment

Data from monitoring networks like IMPROVE coupled with back trajectory modeling is the recommended method for source apportionment. Techniques that can be used to help determine whether the carbon is biogenic or from smoke include the C^{14}:C^{12} ratio and the use of molecular markers such as levoglucosan and water-soluble potassium. IMPROVE currently has the capability to measure water-soluble potassium, although its use as a marker decreases after a few days due to depletion.

Remote Sensing

In the short term, remote sensing tools like GIS and satellite may be used for QC and data augmentation purposes. Available satellites and sensors include AVHRR, MODIS, and LANDSAT. AVHRR coverage has been archived for the U.S. and Canada, and can be processed for 2002. However, this is not a current priority, and would require funding. GEOMAC has perimeters for Type I incidents, but has limited applications for developing and emissions inventory. MODIS is becoming a primary sensor for fire detection. Table 9-1 describes the attributes of the major sensors.

Table 9-1. Attributes of Available Satellites

Source: Presentation by James Scarborough: "Remote Sensing and GIS"

Sensor	Detection Limit	Size Accuracy Threshold
AVHRR	500 ac / day	25,000 / event 250 / day (when available)
MODIS	200 ac /day	1,500 / event (50% accuracy) 50 /day
LANDSAT	2 ac / event (not daily)	Event: Very good Daily: N/A

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The tools described above may be used for the following QC and data augmentation purposes:

- Fuel loading assignment by location.
- Georeference by legal location and county.
- FIPS and timezone assignment for model ready files.
- Coordinate system re-projection.
- Duplicate and complex checking by proximity, date, reporting system, and name.
- QC for spatial domain, water body, etc.
- Remote sensed fire activity mapping.
- Burn perimeter vs. blackened area assessment (acres).
- Fuel loading / vegetation assessment (ton/acre).
- Direct remote sensing of plume potentially useful for model performance and Emissions Inventory QA.

Fuel Characterization

In the short term, the methods currently available to characterize fuels include a modified NFDRS table developed by the WRAP, the natural fuels photo series developed by the Forest Service, stand- or Region-specific data from State/local agencies, GIS, and expert opinion.

In a follow-up conference call, a method was discussed that could be adapted to all Regions in the short term. Some fire incident databases contain fuel information, but this information is very limited. Therefore, the majority of fires in the database require some form of default fuel information. In this methodology, the starting point for default fuel information was the NFDRS national vegetation map for 1999. The NFDRS map was converted to a GIS database, which was then used to assign each fire incident to an NFDRS fuel class.

Fuel loading information was developed for each NFDRS fuel class, and for other fuel classes included in the initial incident databases. Each fuel class was compared with Photo Series fuel categories appropriate for the Midwest Region. [28,29] The Photo Series documents give detailed loadings, in tons per acre, for different fuel types and size ranges. In general, a number of possible Photo Series fuel models was identified for each NFDRS fuel class. In order to select among the possible Photo Series fuel models, expert judgement was elicited from foresters knowledgeable of the Midwest Region. For large fires, the forest classes identified in EPA's BELD database were also used in selecting fuel models.

Emission Factors

In the short term, use Forest Service models such as FOFEM, Consume, FEPS, or BlueSky where possible to calculate fuel consumption and combustion efficiency. Use the emission factors generated by these models for $PM_{2.5}$, PM_{10} and CO. Use the modeled emission factors for NO_X and SO_2 where available (some models do not include these pollutants). Use the emission relationships given in Table 4-10 for pollutants not included in the models. Use VOC speciation factors from Table 4-7.

Average emission factors for HAPs have been presented in Table 4-9. However, adjustments should be made to these factors when fuels have been exposed to chemicals or materials that could increase the emission of toxic and hazardous air pollutants.

Techniques similar to those used by the WRAP should be used to adjust for emissions from residual smoldering.

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Fuel Consumption and Fuel Emissions Modeling Systems

Consume, FOFEM, and FEPS, and other models can estimate emissions from individual fires, and are being adapted so that they can be used with large fire incident databases. However, these models have not been used by the RPOs for the development of Regional emissions inventories, because of difficulties in compiling input data for large numbers of fires.

A follow-up conference call was held to discuss methods available in the short term for using Consume, FOFEM, or FEPS to calculate fuel consumption and emissions. In this call, a method adopted by the Midwest RPO was discussed, which uses FOFEM but avoids the need to develop detailed inputs for each fire. In this method, FOFEM was not applied to each individual fire. Instead, a set of representative fuel models was developed, and each fire incident was assigned to one of these fuel models. Fuel consumption and emission factors were calculated for each fuel model, and the resulting factors were applied to the fire incident database. The Photo Series model fuel loadings were used as input to the FOFEM 5.11 model. Fuel moisture was assumed to be dry for wildfires and average prescribed fires. All other inputs were set at the FOFEM default values. With these inputs and assumptions, FOFEM 5.11 was used to compute fuel consumption and emissions for a typical fire within each fuel model. The FOFEM 5.11 outputs were used to compute fuel consumption factors (in terms of percent burned) and emission factors for each fuel model. These emission factors take into account the relative amount of fuel consumed under flaming conditions and under smoldering conditions in each fuel model. Each fire in the incident database was then matched with fuel consumption and emission factors for the appropriate fuel model.

Other Air Quality Model Input Needs

With current emission processing systems, fires should be treated as point sources. The point source subsystem allows more flexibility than the non-point subsystem in characterizing the initial plume height. For plume height estimates, any interim modeling programs may be used over current plume models.

Short-term needs include testing DaySmoke using 2004 data against model outputs, and acquiring any existing datasets that may be useful in developing models.

Quality Assurance

In order to maintain transparency in the short term, current QA methods should be documented as much as possible. Where possible, consistent collection methods should be pursued to ensure a complete story from all available databases.

Agricultural Fires

For fire activity tracking, emissions inventories are available in some States. Otherwise, burn permits can be used where available to collect data such as area burned, location, and date. Emission factors can be taken from the AP-42, the 1996 Jenkins report, or State-specific information.

In the next year, the following research needs will be investigated:

- Determine methods of gap analysis.
- Determine “how good” the existing information is.
- Determine “how good” the information needs to be.
- Examine Iowa’s Burn Ban and Enforcement Actions as well as programs in the San Joaquin Valley (CA), and the states of Washington and Oregon.
- Determine protocol for Quality Control objectives for future work.

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Projections

There is a hierarchy of options from projection inventories. The choice among these options depends on the relative importance of fire emissions in the Region being modeled and the purpose of the projection inventory. In the simplest case, the actual 2002 inventory can be retained for fire emissions. Alternatively, projections can be based on a historical average (typical year) without any long term change in fire activity. Future land management objectives can be incorporated, and the effects of climate can be incorporated. The effects of control measures on prescribed fires can be incorporated. Finally, RPOs could try to evaluate the potential for reductions in wildfire incidence as a result of increased prescribed fire activity.

Emission Reduction Techniques

The same data gathered for emission inventory development is needed in order to track ERTs. Surveys of land managers are an acceptable approach for assessing the degree to which ERTs are used. An easy way to track ERTs may be to develop a list of available ERTs that burners are required to fill out with every prescribed burn. WRAP methods for activity tracking are also recommended, as well as the 2001 Smoke Management Guide.

The use of ERTs should be subject to peer and stakeholder review. FOFEM may be used to compare treatment alternatives, but expert opinion should also be solicited to estimate the effectiveness of ERTs. Evaluation of ERTs should take into account the impacts on fuel objectives and land management objectives, as well as interactions between multiple ERTs.

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9.2 Long-Term Recommendations and Needs

General

Data quality objectives (DQO) are needed for emissions estimates from fire. These may depend on the size of the fire, the type of fire, and the proximity to population centers or Class I areas. The DQOs would help fire researchers to prioritize their efforts, and to ensure that measurements, data gathering efforts, and model development efforts provide the required outputs.

Some potential criteria were identified for the development of DQOs. From a control strategy development perspective, the uncertainty of error in the fire emissions estimates becomes a problem when it is large enough to affect the level of emission controls required for manmade emission sources. From an air quality modeling perspective, the uncertainty should be low enough to allow validation of air quality models. Modelers are performing sensitivity tests which may provide information for the development of DQOs for fire emissions estimates. Fire emissions data also needs to be good enough for use in ambient comparisons.

Fire Activity Tracking

A consistent central data reporting system is badly needed. This system will need to include all the required data elements necessary for developing a fire emissions inventory for all levels of detail. The system will also need to be easily accessible to all users and all reporting agencies. This protocol could be tiered that could be accessed at different levels depending on the needed resolution (e.g., WRAP inventories may need to be more detailed than the MWRPO).

Formation of a stakeholder group was recommended to identify and consistently define the data elements required to develop a fire emissions inventory. Some definitions that are currently inconsistent include burned vs. blackened acres, precursors to SOA formation, and methods to report fire complexes. Spatial and fuel loading data also need to be reported consistently.

IMPROVE, Tracers, & Source Apportionment

Methods to understand and measure SOA are needed. Specifically, efforts to develop an emissions inventory of hydrocarbon gases that are precursors to SOA should be encouraged.

Remote Sensing

Limitations of remote sensing that need to be addressed in the long term include:

- Burned area is more easily detected than total inside perimeter.
- Understory burns cannot currently be captured.
- Best for forest and shrub rather than grasslands / range and agricultural.
- Small fires may be overlooked.

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The Missoula Fire Lab has been studying differences between remote sensed burn size and reported burn size. A report is expected in December 2004. The lab is also working on fire mapping by energy release in order to effectively map and estimate biomass consumption. This report is expected by June 2005.

Fuel Characterization

For default Regional fuel characterization in the long term, an FCCS map developed by the Forest Service will be available, as well as a national map developed by LANDFIRE. The FCCS map will be at a 1-km resolution, and should be completed in the spring of 2005. That resolution will provide a useful default fuel type and loading, and the FCCS system will enable more precise assignment of fuel type and loadings where additional accuracy is required.

For stand-level and other smaller scale needs, more complete vegetation data will need to be collected by local burners and land managers.

Emission Factors

The following are long term recommendations for the development of fire emission factors:

- Maintain a set of standard emission factors.
- Make sure that all fuels are represented.
- Develop revised emission factors for residual smoldering combustion, if appropriate.
- Guard against overstatement of emission factors in standard data sets.
- Address the variability among fires, including situations where fuels have been exposed to chemicals or materials that could increase HAP emissions or other toxic emissions.
- Maintain compatibility with existing emission modeling frameworks such as Forest Service fuel consumption models and EPA's BEIS.
- Add separate emission factors for EC and OC to standard tables and fuel consumption models.
- Evaluate potential differences between VOC speciation factors for flaming and smoldering emissions as additional FTIR data become available.

Fuel Consumption and Fire Emissions Modeling Systems

Updated fuel consumption and emission models, including Consume 3.0 and possible FOFEM 6, will be available in the long term. Consume 3.0 is expected to be available by the Spring of 2005.

Long-term needs include more detailed fuel consumption tracking and monitoring, especially for agricultural and range lands, and correlation between Region- and stand-scale fuel information. The LANDFIRE project will attempt to fill in some fuel inventory gaps in the next five years, and FCCS 2.0 will also be available.

Other Air Quality Model Input Needs

Long-term needs include the following:

- A stakeholder group is needed to identify approaches and models to use, including international and interagency membership.
- Real-time weather information needs to be included in models/
- Wild and prescribed fire plumes need to be modeled.

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Quality Assurance

Long-term needs include the following:

QA is conducted at the stand level in approximately 1 percent of burn units. Some level of QA needs to be developed at the Regional level. Local information should be pursued whenever possible.

- Sensitivity analyses, validation, and verification testing are badly needed to determine if existing measurements are adequate.
- Water-soluble potassium measurements are needed.
- Spatial array needs to be evaluated.
- The ratio of filter- vs. light-based analyses needs to be investigated.

Agricultural Fires

The following long-term needs were identified for fire activity tracking:

- Burn information identifying crop, number of acres burned, days and times of burns by county (ideally would like lat./lon.).
- Central agency to collect data.
- Better Methods for estimating fire sizes.
- Explore use of Remote Sensing.
- Determination of seasonality of burns for different crops.
- Peer review of all data.

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The following long-term needs were identified for emission factor development:

- Field studies to collaborate crop residue information in different parts of the U.S.
- Data on fuel consumption by crop type.
- Moisture data of crop residue.
- Assessment of pre-harvest or post-harvest burns by crop.
- Data on crop rotations.
- Education of State/County Agriculture Commissioners on importance of collecting data.

Projections

Broader policy questions were identified as long-term needs. There are currently no criteria for determining whether prescribed fire emissions should be treated as natural for Regional haze analyses; and, if so, which fires should be included in the estimates of natural emissions. In addition, methodologies are needed for quantifying the reduction in emissions achieved by replacing wildfire with the increased use of prescribed fire.

Emission Reduction Techniques

The following long-term needs were identified:

- An assessment of all forestry practices, including emissions from off-road equipment and air curtain burners, needs to be conducted in order to capture the entire emissions contribution from the fire sector.
- Tracking systems need to be developed for ERTs, such as a national implementation of EDMS.
- There is no methodology to quantify emissions benefits of ERTs, nor is there a way to estimate the benefits of alternatives to burning.
- Data is needed to support impact determination.
- ERTs need to be geographically specific.
- Tradeoffs between prescribed and wildfires need to be investigated.

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APPENDIX A

TABLE OF PRESENTERS

Presenter	Email	Technical Presentation(s)
Gary Achtemeier	gachtemeier@fs.fed.us	*T2/B4: Injecting Smoke into CMAQ*
Ernesto Alvarado	alvarado@u.washington.edu	*PL8: Canada and Mexico's Available Data and Emission Estimate Techniques for Wildfires and Agricultural Burning* *T1/B7: Carbon Emissions from Spring 1998 Fires in Tropical Mexico*
Fernando Arenas	Contact Ernesto Alvarado	*PL8: Wildfire Information in Mexico National Wildfire Control Center CENCIF*
Ron Babbitt	rbabbitt@fs.fed.us	*PL6: Missoula Fire Chemistry Research Work Unit* *T2/B2: Emission Factors for Fire*
William Battye	battye.bill@ecrweb.com	*T2/B2: Emission Factors for Fire*
Marc DesLauriers	marc.deslauriers@ec.gc.ca	*PL8: Canadian Emissions Inventory for Forest Fires and Prescribed Burning*
Paula Fields	paula.fields@erg.com	*PL5: Agricultural Burning Activity Data in the WRAP Region* *T1/B7: Estimating Wildfire and Agricultural Burning Emissions for the Mexico NEI*
Sue Ferguson	sferguson@fs.fed.us	*PL6: Atmosphere and Fire Interactions Research and Engineering (AIRFire)* *T1/PL1: Fire Activity Tracking* *T2/B5: Quality Assurance of Emissions Modeling Processes*
Peng Gong	gong@nature.berkeley.edu	*T1/B2: Remote Sensing of Fire with AVHRR and Landsat*
Scott Goodrick	sgoodrick@fs.fed.us	*T2/B4: Modeling Emissions from Wildfires*
Wei Min Hao	whao@fs.fed.us	*T1/B2: Fire Monitoring and Air Quality Forecasting Using NASA Terra and Aqua Satellite Data*
Mark Janssen	janssen@ladco.org	*PL5: Highlights of the RPO Approaches to Fire Inventory*

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Presenter	Email	Technical Presentation(s)
		Development *T2/B4: Midwest RPO Chemical Transport Emissions Modeling*
Jennifer Key-Long	jlong@landfire.org	*T2/B1: Landscape Fire and Resource Management Planning Tools Project*
Pete Lahm	pete_lahm@compuserve.com	*TI/PL4: Fire Projections* *PL10: Emission Reduction Techniques*
David Lavoue	david.lavoue@ec.gc.ca	*PL8: Canadian Wildfire Emission Modeling*
Yongqiang Liu	yliu@fs.fed.us	*T2/B4: Point vs. Area Fires and Vertical Distribution of Smoke in CMAQ*
William Malm	malm@cira.colostate.edu	*T1/B1: Is It !@#$ or Is It Smoke?*
Don McKenzie	donaldmckenzie@fs.fed.us	*T2/B1: Mapping Fuels Using the FCCS System*
Jeff McQueen	Jeff.Mcqueen@noaa.gov	*T2/B4: Fire Weather Support from NCEP: Selectable Runs of Nonhydrostatic Mesoscale Model*
Roger Ottmar	rottmar@fs.fed.us	*PL6: Fuels and Emissions* *T2/B1: Fuel Characteristics* *T2/B1: Healthy Forest Initiative and Maintaining Air Quality* *T2/B3: Fuel Consumption and Emissions-Consume 3.0* *PL10: Emission Reduction Techniques* *T2/B6: Emissions Reduction Techniques*
Tom Pace	pace.tom@epa.gov	*T2/PL1: Current and Future WLF Emission Calculations and EPA/RPO Submission Issues*
Thomas Pierce	pierce.tom@epa.gov	*T2/B4: Integrating Bluesky into the CMAQ/SMOKE Modeling System*
Dave Randall	drandall@airsci.com	*T1/PL4: 2018 WRAP Projections–Methodology*

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Presenter	**Email**	**Technical Presentation(s)**
Sam Sandberg	dsandberg@fs.fed.us	*PL6: Emissions and Consumption Overview* *T2/PL2: Fire Emissions Modeling Systems* *T2/B3: Fire Emission Production Simulator (formerly EPM)*
James Scarborough	jscar@airsci.com	*PL5 & T1/B4: Remote Sensing and GIS*
Elizabeth Reinhardt	ereinhardt@fs.fed.us	*T2/B3: FOFEM 5*
Greg Stella	gms@alpinegeophysics.com	*T1/PL4: VISTAS Wildland and Prescribed Fire Forecasts*
Dana Sullivan	dana@sonomatech.com	*T1/B5: Development of Emission Inventories of Planned Burning Activities in the CENRAP*
Gail Tonnesen	gail.tonnesen@ucr.edu	*T2/B4: WRAP Emissions Processing of Fire Sources*
Sheldon Wimmer	swimmer@blm.gov	*PL5: National Fire Activity Tracking*
Mike Ziolko	mziolko@odf.state.or.us	*PL10: Oregon's Tracking of Emission Reduction Techniques* *T2/B6: Emission Reduction Techniques*

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