



Smoke. Credit: © Wei O'Connell.

Have It Your Way: Open Source Software Brings Common Ground to Smoke Management and Emissions Inventories

Summary

The Fire Emissions Production Simulator (FEPS) is an open source, user—friendly computer program designed for a wide range of users. The software manages data about consumption, emissions, and heat release characteristics of wildland fires and prescribed burns on an hourly basis. Designed for easy use by anyone with a working knowledge of Microsoft Windows applications, FEPS allows users with differing objectives, backgrounds and experience to come to scientifically sound, quantitative agreement regarding the emissions impacts of a given fire scenario. It incorporates fuels data from the most popular fuelbeds in the Fuel Characteristic Classification System and fuel models from the National Fire Danger Rating System. It also accepts exported consumption data from First Order Fire Effects Model (FOFEM) and CONSUME. Total burn consumption is distributed over the life of the burn to generate hourly emission and release information - including effects of nighttime smoke and residual smoldering. Fuel loadings, fuel moistures, fuel consumption algorithms, fuelbed proportions, and fire growth rates can all be easily adjusted to fit specific burn events within specific time frames. Daytime changes in weather conditions that affect plume rise can be adjusted as well. FEPS can be used for most forest, shrub and grassland types in North America and may be tailored to suit applications in other regions of the world. The software is supported by an outstanding suite of training tools including interactive tutorials, student and teacher workbooks, a detailed user manual and instant online help.

Key Findings

- Open source design offers user the ability to modify input, output, equations or results.
- Fast and easy way for a wide variety of users with different levels of knowledge and experience to generate valid emissions and smoke transport predictions.
- Available to anyone interested in quantifying emissions from prescribed and wildland fires.
- Can be applied to most forest, shrub and grassland types in North America and adapted to many vegetation types throughout the world.

It's ten o'clock—Do you know where your smoke is?

Managers, fire fighters and air regulators face an increasingly restrictive and complex array of emissions regulations before prescribed fires can be implemented. Moreover, fire managers have the affirmative responsibility to improve air quality. There is increasing pressure to minimize emissions and reduce smoke as much as possible at a time when acres burned annually by wildfire are skyrocketing, and controlled burns have become a primary tool for reducing wildland fuels.

The *Federal Wildland Fire Policy* (1995) and *Clean Air Act* as Amended (1990) created the need to significantly raise the level of knowledge about fire's effects on air in order to meet regulatory and management requirements. The subsequent *Regional Haze Rule* (1999) was generated by concerns about reducing smoky days and visual impairment in wilderness. It signaled a turning point in how fire emissions were to be treated under Federal and State law. For the first time, the role of fire in forest ecosystems was formally recognized. Emissions from “natural” sources, including prescribed fires to maintain ecosystem integrity, became distinctly separate from man made sources. Fire emissions became subject to regional air quality planning processes and responsible parties were required to achieve “reasonable progress” toward reducing emissions.

The history of smoke management science and model development has essentially paralleled the implementation of increasingly demanding regulations. As air quality rules have become more stringent, science has had to expand and deepen in order to support compliance.

The issue is complicated by the fact that smoke is not known for its ability to recognize or respect state, regional or international boundaries. With each passing season there is new demand for more detailed collaboration, communication and agreement between regulatory and management agencies across borders. As smoke transport and its cumulative impacts have grown in importance, a complex web of geographically and ideologically diverse stakeholders has grown right along with it. Multi-state and interagency partnerships continue to expand to coordinate burning and smoke mitigation efforts. Everyone has a stake in the both the costs and benefits of informed and collaborative smoke management and air quality compliance.

The ability to balance the use of prescribed fire with environmental, legal, social and public health requirements has always been the key to successful smoke management endeavors—and that's more easily said than done. Compliance requires more than just accurate measurement and estimates of emissions and their components. Effective communication and agreement on findings, responsibilities and proposed actions are essential. As is often the case in such complex collaborations, these can be difficult to achieve.



Credit: FERA USFS Pacific NW Research Station.

Parlez-vous PM_{2.5}?

David Sandberg, emeritus scientist with the USDA Forest Service Fire and Environmental Applications Team (FERA) has studied fire emissions and smoke longer than many of us have been breathing the air it impacts. Throughout his research career he has always worked as a translator of sorts, endeavoring to clarify the realities of fire smoke to all interested parties, facilitate the use of common descriptive language and foster understanding of its true effects.

“I've always considered my role and my team's role as one that bridges the gap between differing perceptions and reality—whether the perceptions are those of the public or agencies such as the Forest Service or the Environmental Protection Agency,” he explains. Continuing in this role, Sandberg along with programmer Gary Anderson of the URS Corporation, and Robert Norheim of the College of Forest Resources at the University of Washington, developed the Fire Emission Production Simulator

(FEPS) in response to the fading utility of its widely used predecessor, the Emissions Production Model (EPM).

EPM was originally designed to estimate and mitigate the rates of heat, particles and carbon gas emissions from controlled burns of timber harvest-slash in Northwest forests. In 1985 Sandberg and his colleagues were charged with designing an emission reduction program for the states of Washington and Oregon, where the burning community faced new requirements to reduce emissions by 30% to 50% over a five year period. It was then that Sandberg pioneered the idea of emissions reduction; the concept that it's possible to reduce the amount of smoke generated without reducing the acres burned.

"Prior to this everyone just assumed that burning X amount of acres would generate X amount of smoke —period—and that the only way to reduce smoke was to reduce acres burned," he explains. That assumption created a somewhat adversarial situation between those who were managing fire and those who were managing smoke. Agreements between parties were difficult to achieve.

Sandberg's team demonstrated that prescribed fire could be more effective and efficient, not only in dealing with harvest slash but with wildfires and general vegetation management too. They created a toolkit of smoke reduction techniques that made prescribed burning cheaper and more effective in terms of ecosystem effects while simultaneously cutting emissions by half or more. Sandberg created EPM to measure, quantify, predict and reduce smoke in a way that everyone could agree on.

"We wrote EPM to create a standard of accountability that would be accepted by the states, agencies and private industries that were burning at the time," he explains. "It created a standard that was accepted by all—the standard by which the emissions from each operation or fire event would be calculated, and by which any smoke reduction would be measured. It gave people the ability to take credit for action they took to reduce smoke from year to year by automatically creating a credible quantification of how much smoke they had avoided generating."

The results of the project were a resounding success. Washington reduced its emissions by over 50% (with a goal of 30%) and Oregon reduced emissions by 60% (with a goal of 50%)—all with no reduction in acres burned. It all added up to better air, more effective prescribed burning, better communication and less conflict.



Credit: FERA USFS Pacific NW Research Station.

Open source flexibility: Putty in your hands

A hallmark of FEPS is its open source design. Open source means that the source codes in the software are not a mysterious, proprietary secret. The way the program does its work is visible and available for the entire world to see, use and modify if they care to, through individual contribution or collaboration.

"The tone I set from the beginning was that FEPS must be available to and adaptable by anybody. Every time you make a calculation you can decide whether or not to override it. For example if somebody has better information about how fuel moisture in their specific region responds to a certain situation, they can substitute their own formulas. They can generate answers specific to their knowledge and conditions without having to write their own program. I want people to have that flexibility when they feel they know more than I do—which is a lot of the time!"

Indeed, you can see for yourself how FEPS generates information and change any of it any time you want if you don't agree with the process. All of the calculations, algorithms, consumption formulas, etc., are listed in plain sight in the back of the User Manual.

Sandberg likes giving users the freedom to play with the underpinnings of the model because he feels it encourages users to take a more active, responsible role in the process. At the same time, the System Defaults are always available and can't be modified or erased. They allow a common comparison and provide a fairly safe grounding for people who don't have other resources or information and need something solid to go by.

Sandberg laments the tendency of some managers to discount the value of their own knowledge and their direct experience of the ecosystems under their stewardship. "Managers on the land are responsible for the outcome of their actions. When they use a model—they've just based a decision on a simplification of their reality. On the other hand if they didn't have the model they'd probably simplify the reality even more to make a judgment. We're trying to help them make better, more informed judgments by offering them some middle ground. But they have to understand what that means, and how to see what they may be overlooking. I think those of us who are developers and scientists have to be much more open and fair by not just purporting that our model is the best, but by being *very clear* about what our assumptions are and what formulations we're using so everybody can see *into* it—so you don't have to be a scientist to get to it—to access it."

Plunge right in: FEPS step by step

In FEPS, individual cases of prescribed or wildland fires are called Events. An Event stores information about and calculates emission and release information for an entire burn at a single location. You begin your process by describing an Event. This description includes the name, location, start date, end date, and other miscellaneous properties. You can then specify up to five unique fuel

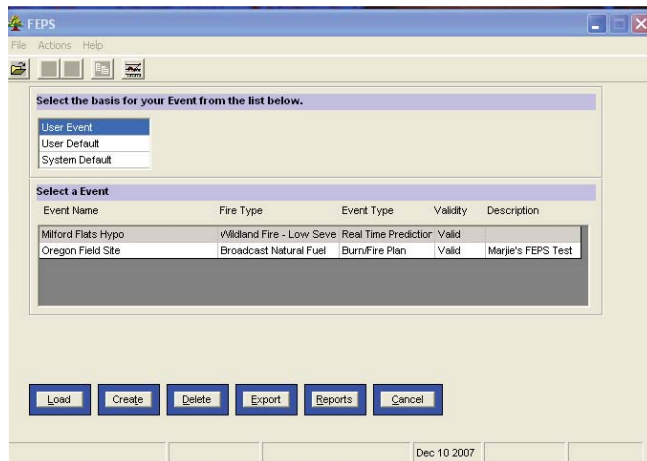
profiles. Each profile includes fuel loading and fuel moisture information. FEPS will then calculate total fuel consumption for each profile and determine flaming, short-term smoldering, long-term smoldering involvement and consumption. You can then indicate how the Event behaves over time. FEPS calculates emissions and heat release parameters on an hourly basis. Fuel characteristics for each hour are managed by distributing the fire across the five user-specified fuel profiles.

FEPS stores events in three categories:

User Events—A User Event is a dataset you create yourself that describes an actual or hypothetical burn at a single location over a period of time. Your Event can include multiple ignition periods and extend up to 30 days following the initial ignition period.

User Default Events (Library)—Once you’ve created your own User Event, you can save it so it’s handy for future use or reference. You do this in the User Default Events category. It’s your library where you can store events that you’ve taken the effort to create, that you might want to use again as a starting point for creating other Events with the same or similar initial conditions. You can also share your work by exporting your Events to your colleagues.

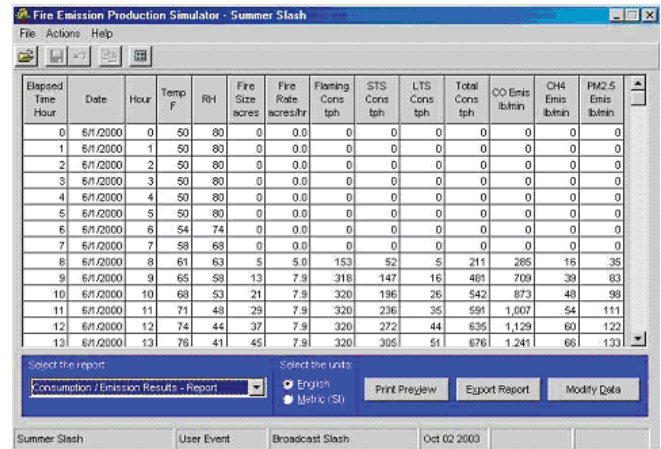
System Default Events (Library)—System Default Events are intended to represent a variety of generic burn scenarios that serve as good starting points for creating User Events. These defaults have been tested as valid so the detail work has been done for you if you need it. System Default Events can’t be deleted or altered. You can’t create additional System Default Events.



FEPS First Step—The Events Management screen. From this screen you may select, create, delete or export events. You may also go directly to the results for an Event.

FEPS provides five data input tabs: Event Information, Fuel Loading, Fuel Moisture, Consumption and Hourly Input. The most recent FEPS update, version 1.1, includes fuels data from the most popular fuelbeds in the Fuel Characteristic Classification System and NFDR fuel models. It produces hourly emission and heat release data for prescribed or wildland fires throughout the duration of the event. It also accepts data imported from FOFEM,

Consume .1, and Consume 3.0. The hourly emissions data you generate can be used by BlueSky or other systems to create maps of predicted smoke transport as well as charts and reports. All can be exported or printed.

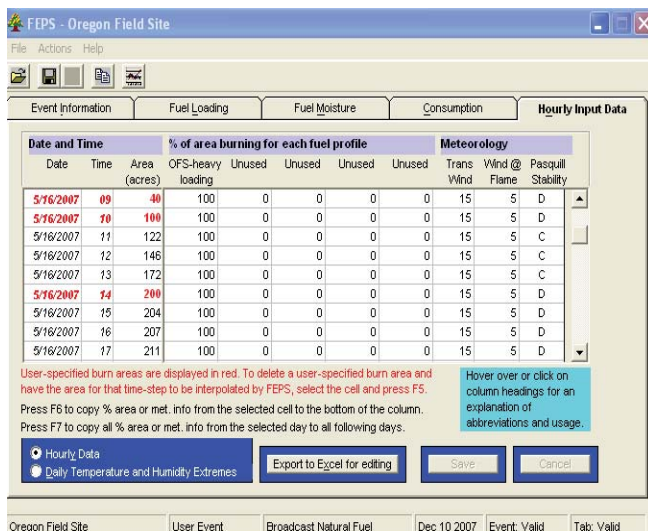


Consumption / Emission Results—This report lists consumption for each phase of the fire (flaming, short-term smoldering, and long-term smoldering) and emissions of CO, CH₄, and PM_{2.5} for each hour of the Event. It also includes basic Event information and total consumption and emissions of the specific Event. Consumption results are calculated using equations found in the appendix of the User Manual.

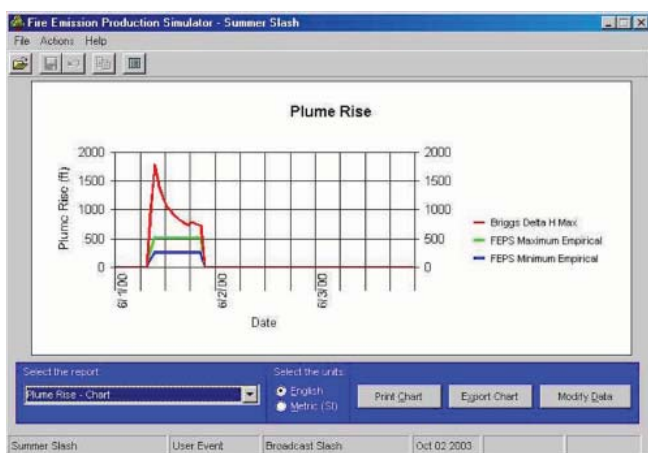
Users can adjust fuel loadings, fuel moistures, fuel consumption algorithms, fuelbed proportions and fire growth rates to fit specific Events. You can specify diurnal changes in meteorological conditions that will modify plume rise. Many intermediate results are shared in the user interface. Users may accept these calculations or enter their own values. If you have an extremely complex operation you have the option of exporting from FEPS into Excel to accelerate your calculations. For example, if you have ten fires burning over a period of several days in highly variable fuel types, you’ll be able to make changes much more rapidly in Excel. You can easily bounce back and forth between Excel and FEPS—using, re-using or customizing information as needed.

Almost goof proof

FEPS validates data entered on each data entry tab and over the entire event. If you unwittingly enter something that is either way off track or either in format or content, FEPS will catch it. FEPS analyses all input to determine whether or not it makes sense. FEPS will warn you if it finds that an entry is not valid, and gives you options for correcting it. Once everything is deemed valid you can finalize your Event and move on to generating reports, maps and charts. Report types include Event Data, Consumption / Emissions Results, Buoyancy Results, and Emissions Results. Available charts include Combustion by Combustion Stage, PM_{2.5} Emissions by Combustion Stage, CO Emissions, and Plume Rise.



The Hourly Input Data tab is the last of five. The *Export to Excel for Editing* button is highlighted at the bottom of the Hourly Input Data screen. You may export back and forth from FEPS to Excel when working in any of the five data input tabs to increase calculation efficiency when managing complex operations.



Plume Rise Chart—After you have filled out as much information as you can about your Event in the five data entry tabs, FEPS provides a series of tabular reports and charts that show your results. Reports may be viewed and/or exported in either “English” (Imperial) or Metric (SI) units.

Help is but a click away

FEPS has a suite of very user-friendly training tools. There is an Online Help function if you’re working with internet access. It can be accessed at nearly any point in the program with one key stroke. Online Help automatically opens with information specific to the data category in which you are working, and includes a searchable table of contents. The extensive and easy tutorial is available online, and downloadable so you can work through it offline if you prefer. FEPS has a clean and easy Student Workbook, complete with step-by-step case studies that allow almost anyone to generate a useful, valid Event in under an hour. An Instructor’s Handbook and a comprehensive, easy to follow User Manual round out the selection.

Management Implications

- Helps support managers in their efforts to comply with evolving air quality requirements in increasingly complex collaborative environments.
- Easily import fuel consumption and emissions data from Consume or FOFEM.
- Use hourly emissions data to generate maps of predicted smoke.
- Can be used for emission inventories, smoke management, carbon accounting, regulatory purposes, permitting, planning and public information.

Go build yourself a fire

Although a great deal of progress has been made over the years and FEPS is a big step in the right direction, there is no model yet that fully meets the needs of fire planners and air resource managers.

“There’s a lot of science that’s still missing,” Sandberg laments. “Some of the predictive equations are pretty much hypotheses or approximations, but other areas are dead on. You can’t do better with the fuel characterizations, fuel consumption or moisture content. The emissions factors are spot on too because there’s been such long standing research interest in it.”

Sandberg is the consummate mediator as he emphasizes the ongoing need to level the playing field and facilitate solutions to the challenges and responsibilities of managing fire smoke. “We’ve always had all these arguments and an inability to really come to agreement on common ground because we have such different claims, experience and information. So my goal, right from 1967 to the present, has been to continue with what we accomplished when we first got into it with Washington and Oregon: Create systems—and the science behind the systems—that allow both sides to accept the physical realities. If we can get that part right at least it reduces the differences in perceptions. It then becomes much easier to agree on specific goals and to monitor attainment or violation of those goals.”

So carve out 45 minutes, visit <http://www.fs.fed.us/pnw/fera/feps/index.shtml>, and build a fire. That way, the next time you need to predict and track emissions from your fires, or anybody else’s, you can rest assured you won’t just be blowing smoke.

Further Information: Publications and Web Resources

Fire Emissions Production Simulator – FEPS.

<http://www.fs.fed.us/pnw/fera/feps/index.shtml>

Wildland Fire in Ecosystems: Effects of Fire on Air. 2002. Rainbow Series state of knowledge publication.

http://www.fs.fed.us/rm/pubs/rmrs_gtr042_5.pdf

National Strategic Plan: Modeling and Data Systems for Wildland Fire and Air Quality. 1999. Sandberg, David V.; Hardy, Colin C.; Ottmar, Roger D.; Snell, J.A. Kendall; Acheson, Ann; Peterson, Janice L.; Seamon, Paula; Lahm, Peter; Wade, Dale. National strategic plan: modeling and data systems for wildland fire and air quality. Gen. Tech. Rep. PNW-GTR-450. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.
http://www.fs.fed.us/pnw/pubs/gtr_450.pdf

Scientist Profile



Dr. David (Sam) Sandberg has a PhD in Forest Fire Science and Air Resource Management from the University of Washington. He recently retired from the USDA Forest Service Research and maintains a National Emeritus Science status with the Fire and Environmental Applications Team. He also conducts research and consulting as *Sam's Fireworks*. Sandberg measured the first in-situ emission factors for prescribed burning in 1971. He is now active in the analysis of fire policy, fire research direction; and the role of wildland fire in air quality, global change, carbon offsets, and sustainable ecosystems.

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