



Reducing Emissions from Open Burning: Overview of US Agricultural Burning & Smoke Management

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Overview of U.S. Burning of Agricultural Burning & Smoke Management

- US cropland practices: past and present
- Who controls cropland burning?
- US EPA Smoke Management Role
- Components of a Smoke Management Plan
- Estimating PM emissions from agricultural burning
- Why burn crop residues?
- Alternatives to burning

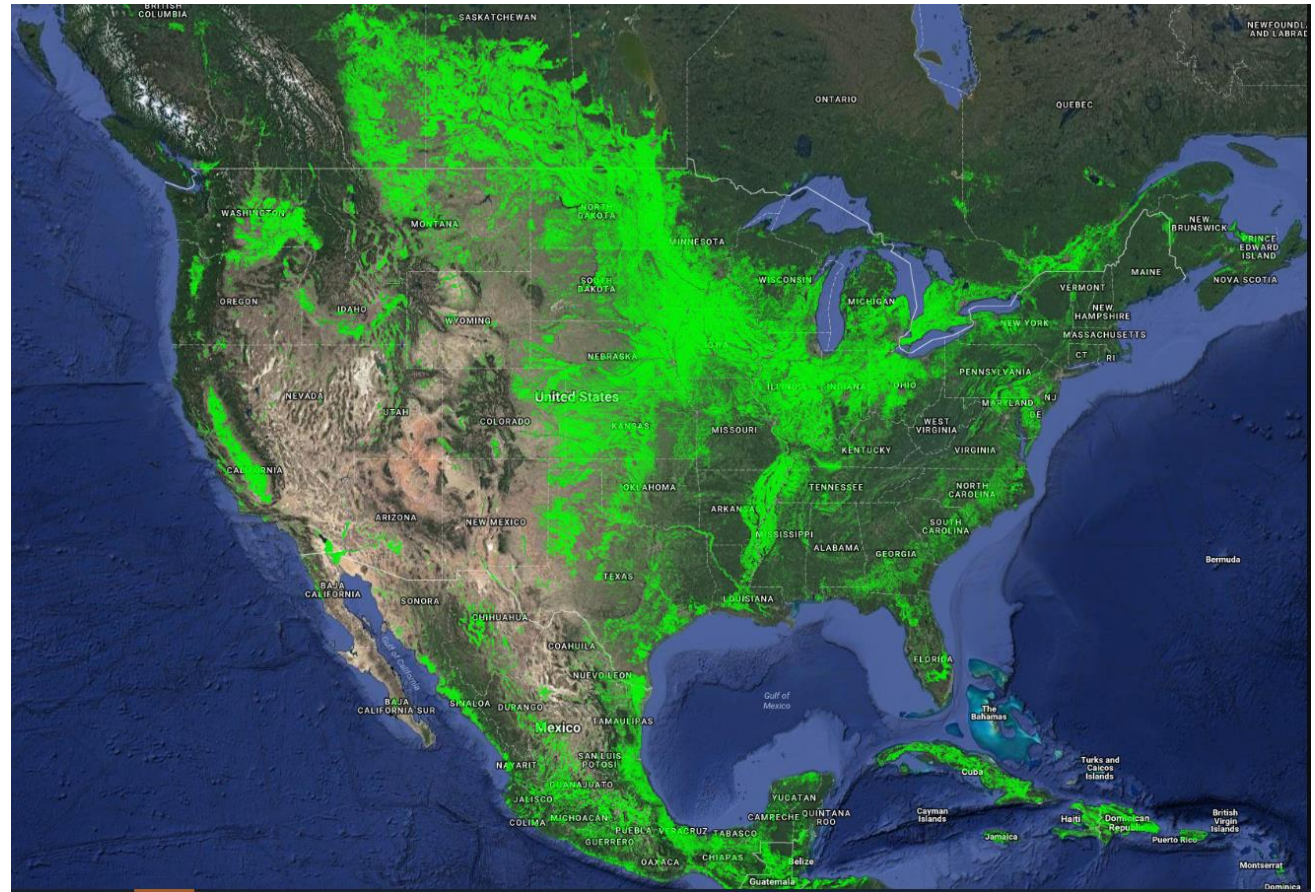
US Cropland Practices: Past

“Just as carbon fueled the Industrial Revolution, nitrogen has fueled an Agricultural Revolution” -Viney Aneja, NC State U

- 1940s-1990s: growth of “intensive agriculture”
- Abandonment of traditional practices (fallowing and crop rotations) in favor of mechanization
- Better pesticides and increased use of nitrogen fertilizers
- Cultivation of marginal land
- Availability of hybrid and genetically modified crop varieties
- Improvements in production efficiency; increased field size; concentrated production; less people employed
- Government policies encouraged intensification; magnified by commercial factors

US cropland - 2015 Landsat image

- The US has 166 million hectares (~410 million acres) of net cropland area.
- Ranked second in the world after India, which has 180 million hectares of cropland.



<https://www.usgs.gov/media/images/map-croplands-united-states#:~:text=The%20United%20States%20has%20166,180%20million%20hectares%20of%20croplands.>

US Cropland

- Croplands: Crop areas that produce food, fiber, and seeds
- Main crops: barley, corn, cotton, oats, peanuts, rice, sorghum, soybeans, wheat (other: bluegrass, sugarcane, soy, etc.)
- Each year, between 300 to 400 million acres are harvested, with burning done on 1-3% of this land, mostly in Southeast, Great Plains, and Pacific Northwest

<https://www.usda.gov/topics/farming/crop-production>

[https://www.nass.usda.gov/Charts and Maps/Crops County/](https://www.nass.usda.gov/Charts_and_Maps/Crops_County/)

Recent changes in conservation practices

- Between farmer surveys in 2003–06 (CEAP I) and in 2013–16 (CEAP II), there has been a warming climate, longer growing season, advances in seed technology, and higher yielding crop varieties
- Demand for commodities increased, particularly corn and soybeans, and higher prices encouraged production expansion.
- Farmers have increasingly adopted advanced technology, including enhanced-efficiency fertilizers and variable-rate fertilization.
- More efficient conservation tillage systems, particularly no-till, became the dominant form of tillage, reducing erosion and fuel use.
- Conservation crop rotation and cover crop use increased, as did the use of high-biomass crops in rotation.
- Irrigators shifted toward more efficient pressure-based systems, and improved water management strategies decreased per-acre water application rates.

Conservation Practices on Cultivated Cropland

https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcseprd1893222.pdf

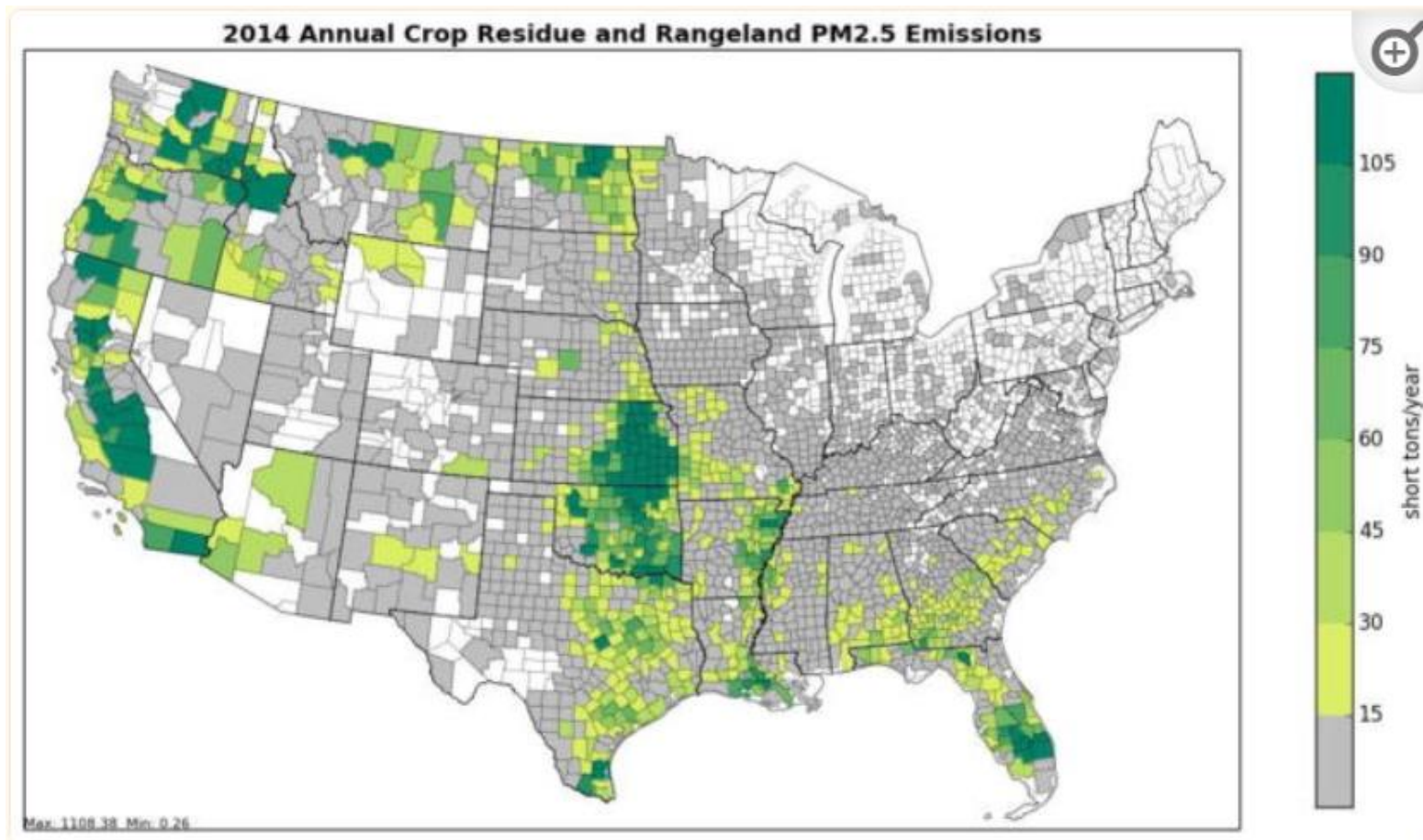
https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcseprd1893221.pdf

Estimating crop residue/rangeland burning

- In the 2011 National Emissions Inventory, wildland fires, prescribed fires, and crop-residue burning were the largest source of PM_{2.5} ... however, crop-residue burning has been poorly characterized.
- Main problem: variability between states that submitted data due to use of different methodologies to estimate emission factors and area burned.
- Newer approach: estimate emissions from crop-residue and grass/pasture burning using satellite and field data as well as crop-specific emission factors.
- NOAA's Hazard Mapping System (HMS) product, the USDA Cropland Data Layer (CDL) (<https://nassgeodata.gmu.edu/CropScape/>) was used to identify crop type and distinguish agricultural fires from all other fires
- Satellite detections are at best known to 100 m and the CDL information is known to 30-m resolution, the process of intersecting these two data sets results in some uncertainty with respect to spatial accuracy of the fire locations.

Estimation of 2014 emission inventory for crop residue burning and rangeland burning

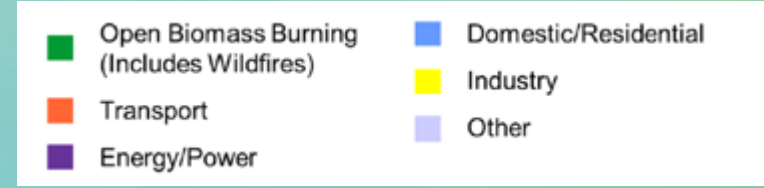
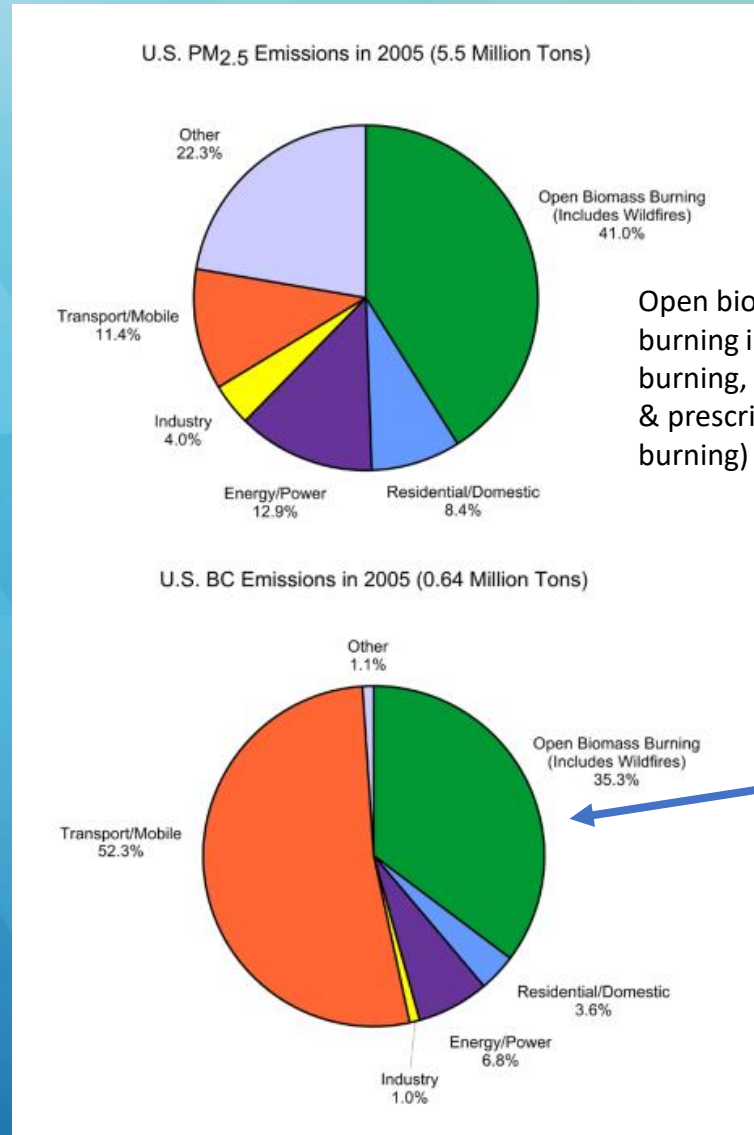
<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6088810/>



- PM_{2.5} emissions from burning of crop residue and rangeland occur mainly in California, Kansas, Oklahoma, and parts of the SE US, lower Mississippi Valley, Pacific NW.
- Total US estimate of area burned annually: 1,542,280 acres



US $PM_{2.5}$ and BC emissions by source category



Open biomass burning includes ag burning, wildfires, & prescribed burning)

% open biomass burning about the same at global level

Who Controls Cropland Burning in the US?

- Federal (US Department of Agriculture, US Forest Service, and US EPA), State, and local agencies
- Centerpiece of USDA “Agricultural Burning Policy” is recommendation that States/Tribes adopt a Smoke Management Program/Plan (SMP)
- US EPA authority is Title I of Clean Air Act
 - Sets national ambient air quality standards (NAAQSs) for "criteria pollutants" (CO, Pb, NO₂, PM/PM_{2.5}, ozone, SO₂)
 - Areas that meet standard = “attainment areas”
 - Areas that don't meet standard = “nonattainment areas”

Role of US EPA in Smoke Management

- EPA concern for controlling smoke is greater for nonattainment areas and areas in or near Class I Federal areas (national parks, wilderness areas)
- EPA:
 - Facilitates cooperation among burners, regulators and public
 - Provides support for State/Tribal Smoke Management Programs (guidance, reviews, funding)
 - Provides technical support (modeling, forecasting tools)
 - Conducts Smoke Management meetings
 - Keeps parties informed about policy issues such as Wildland Fire Policy, Exceptional Events, Regional Haze, air-quality standards (NAAQS).
- EPA encourages State and tribal air-quality managers to develop a Smoke Management Program (SMP): Framework of requirements and procedures for managing smoke from prescribed fires, typically developed by States or Tribes with cooperation from stakeholders.

Smoke Management Program (SMP) Components

- **Process for assessing and authorizing burns:** recommended reporting of burn-plan information to administering agency
- **Plan for minimizing emissions and impacts:** promotion of alternatives to burning and use of emission-reduction techniques
- **Smoke management goals and procedures:** actions to minimize fire emissions, evaluate smoke dispersion, notify public and reduce public exposure, monitor air quality
- **Public education and awareness**
- **Surveillance and enforcement of SMP compliance**
- **Program evaluation and plan for periodic review**
- **Optional programs (e.g., special protection zones or buffers)**






<https://www.nwccg.gov/sites/default/files/publications/pms420-2.pdf>

Considerations when planning to burn

- Expected emissions and airshed capacity
- Proximity to other burns
- Moisture content of fuels
- Distance from Sensitive Populations & Critical Infrastructure (schools, hospitals, highways, airports)
- Meteorology
- Mixing height (need profiles of atmospheric parameters from a remote- sensing system from ground to 1 mile or so)
 - Surface wind speed (>3mph, <15mph)
 - Ventilation (or clearing) Index (*see next slide*)
 - Cloud cover and Relative Humidity
 - Surface wind direction (away from sensitive receptors)

Ventilation Index (VI) or Rate

- VI (or ventilation rate or clearing index) is the US National Weather Service's indicator of the relative degree of air circulation for a specified area (potential for smoke or other pollutants to ventilate away from a source).
- Used by fire managers as diagnostic tool to assess potential for dispersion of smoke from fires.
- Ventilation Rate = Transport Wind (kts) x Mixing Height (ft) (#kts x 1.15 = mph; #mph x 0.87 = knots)
 - Higher values indicate faster dispersion of PM generated by fires.
 - Transport wind: average wind over a specified time period within a mixed layer near Earth's surface.
 - Mixing height: height to which parcel of air, or column of smoke, will rise, mix or disperse. A column of smoke will remain trapped below this height.

	Smoke Dispersal	Vent. Rate, knot-feet (x1000)
	Excellent	150 or greater
	Very Good	100 to 149.99
	Good	60 to 99.99
	Fair	40 to 59.99
	Poor	less than 40

	Ventilation Index (kt ft) = Mixing Height (ft) x Average Transport Winds (kts)	
Excellent	>= 150,000 kt ft	>= 23445 m*m/sec
Very Good	>= 100,000 kt ft and < 150,000 kt ft	>= 15630 m*m/sec and <23445 m*m/sec
Good	>= 60,000 kt ft and < 100,000 kt ft	>=9378 m*m/sec and <15630 m*m/sec
Fair	>= 40,000 kt ft and < 60,000 kt ft	>=6252 m*m/sec and <9378 m*m/sec
Poor	<= 40,000 kt ft	<=6252 m*m/sec

https://www.weather.gov/riw/fire_smoke_dispersal

Example: Arizona DEQ

- Acres to be treated?
- Acres lined? (to stop burn from exceeding acreage)
- Multiple or consecutive day burn?
- Expected daytime smoke?
- Expected diurnal smoke behavior?
- Expected impact on Sensitive Areas?
- Amount fuel expected to burn?
- Likely to be a lot of smoldering?

REMINDER: All burn requests are due by 2 pm the business day BEFORE your planned ignition day. Burn requests for Saturday, Sunday, and Monday are due by 2 pm Friday.

To see current particulate levels, visit [ADEQ's Portable Particulate Monitors page](#)

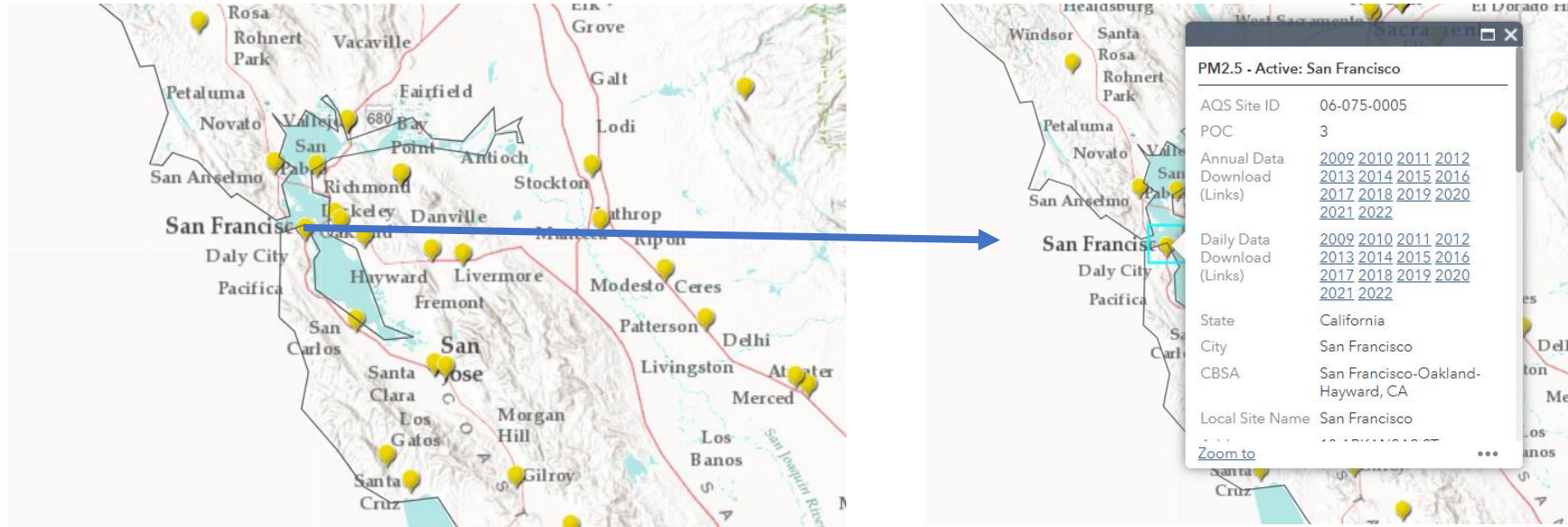
To file an official smoke complaint, you can access the complaint forms [here](#)

Approved Daily Burns Today is 2022-08-23

Burn Number	Burn Name	Ignition Date	Approved Acres
XXH1502P	Fort Piles 20	2022-08-23	20

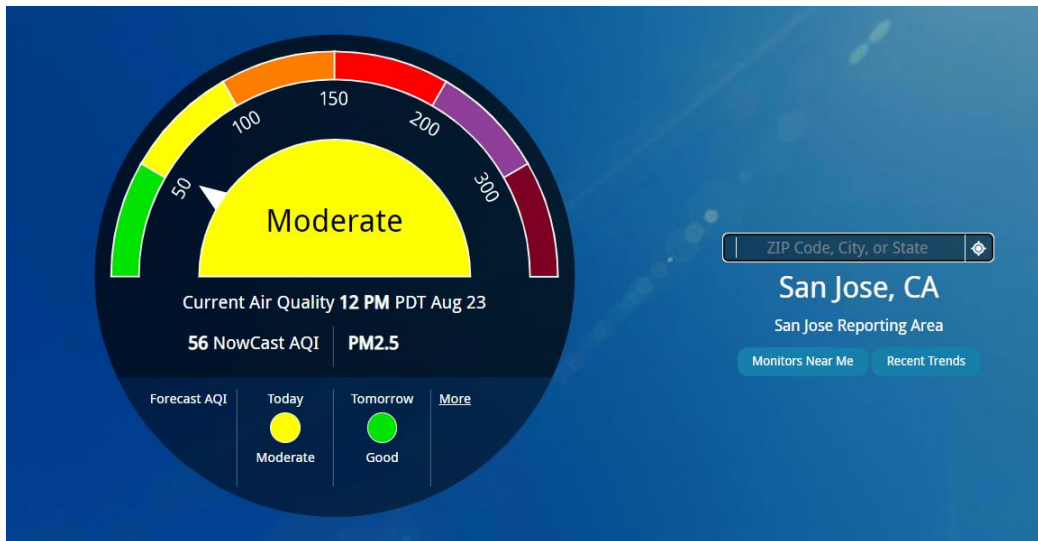
Air-quality monitoring

EPA's AirData



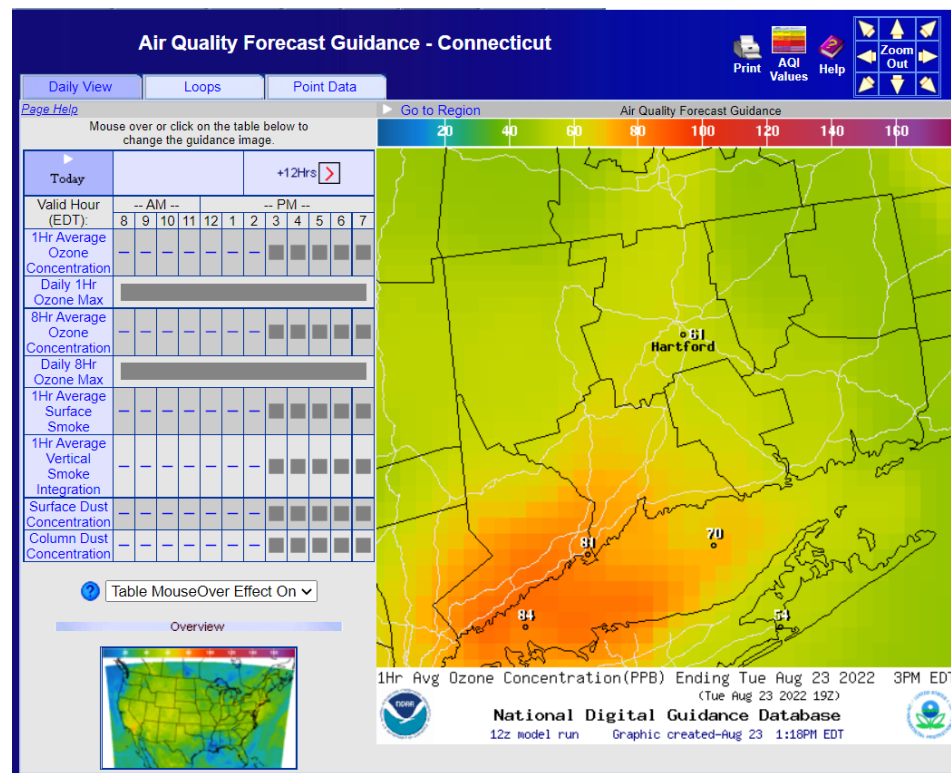
<https://www.epa.gov/outdoor-air-quality-data>
(with interactive map)

Air-quality forecasting



US EPA: daily and air-quality forecasts

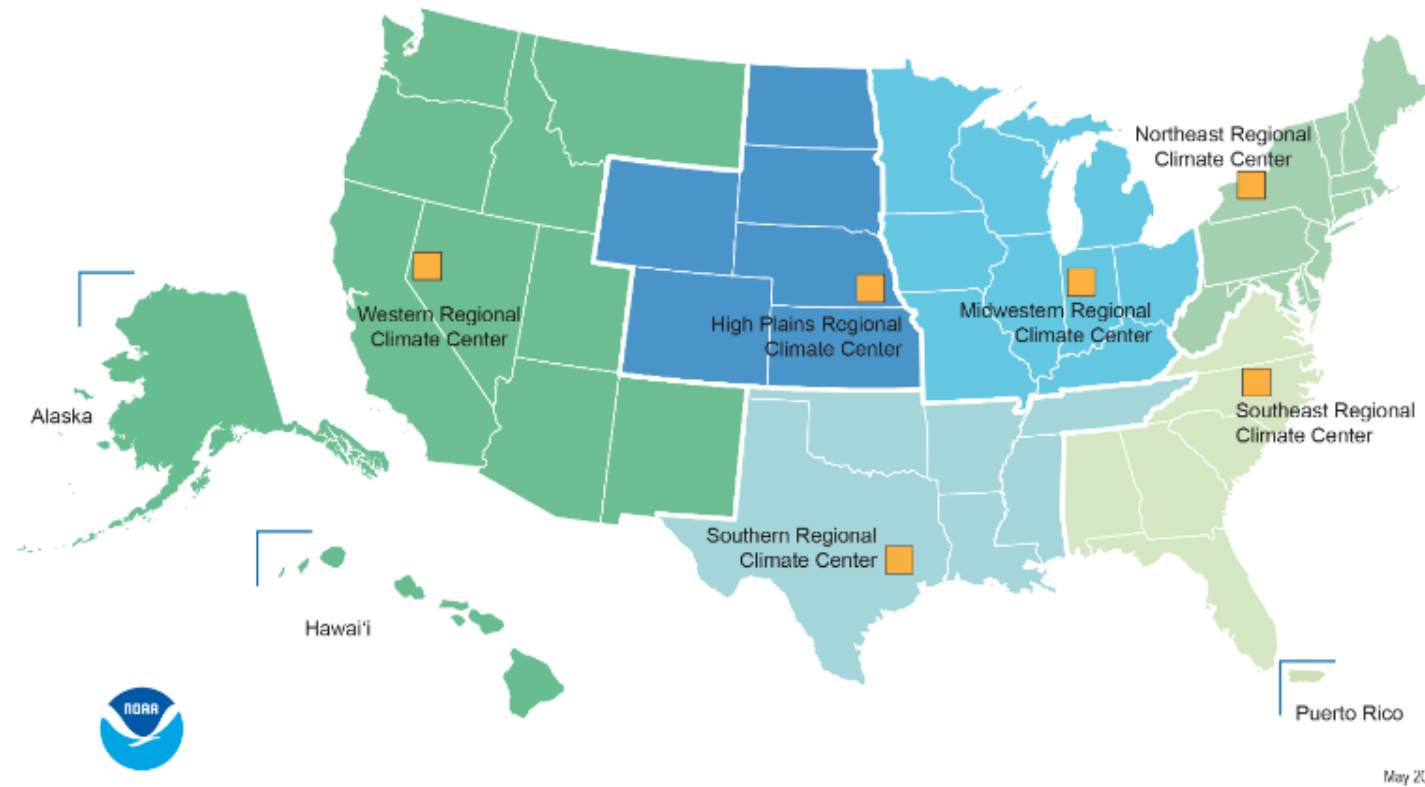
<https://www.airnow.gov>



National Oceanic and Atmospheric Administration (NOAA):

<http://airquality.weather.gov>

Six regional climate centers in US since 1989



<https://www.ncei.noaa.gov/regional/regional-climate-centers>

Estimating agricultural burning emissions

Method of estimating crop-residue burning emissions using remote-sensing data and field information

1. Located fires using multiple satellite detections via NOAA Hazard Mapping System (HMS), which shows hot spots and smoke plumes indicative of fire locations.
2. Identified type of crop (residue) being burned by using a year-specific crop map. Assigned an emission factor accordingly.
3. Looked at season (spring and fall) as well as annual changes in crop land use
4. Estimated field size (i.e., acres burned) based on state-specific field-size information.

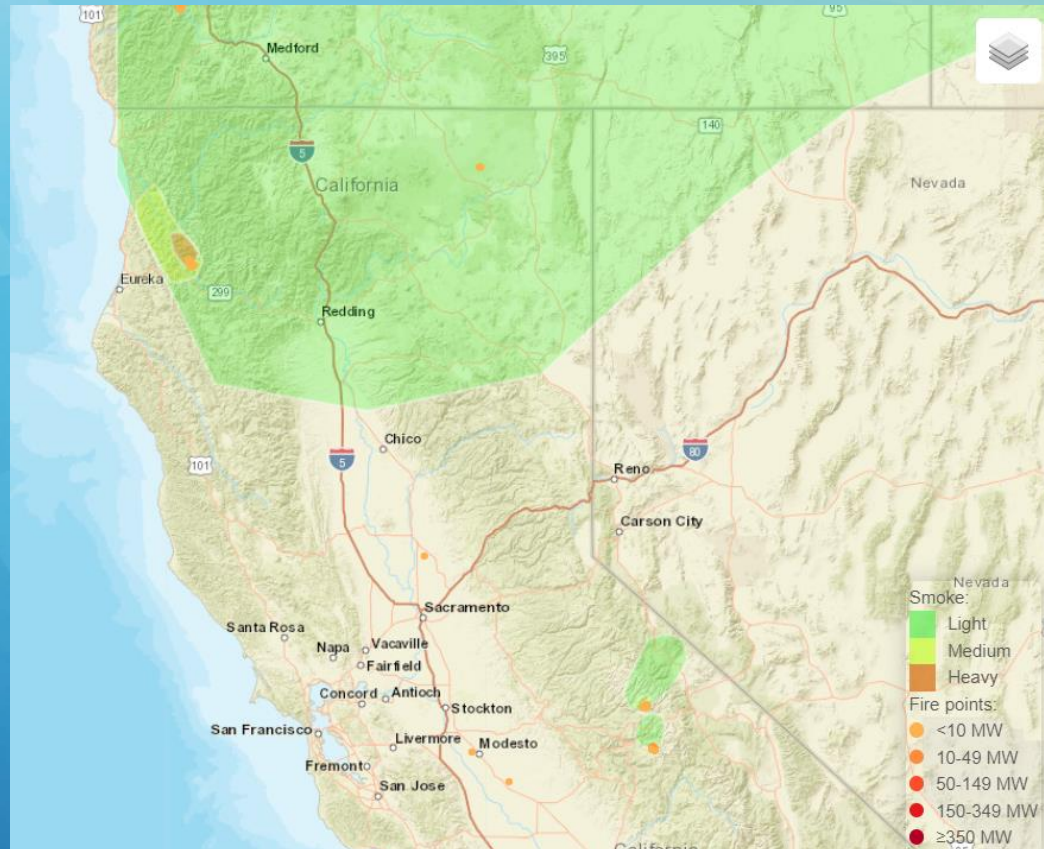
<https://www.tandfonline.com/doi/full/10.3155/1047-3289.61.1.22>

<https://www.researchgate.net/publication/49821771> Remote Sensing-Based Estimates of Annual and Seasonal Emissions from Crop Residue Burning in the Contiguous United States

https://gaftp.epa.gov/Air/nei/ei_conference/EI20/session2/jmccarty.pdf (fuel loading)



US: NOAA Hazard Mapping System



<https://www.ospo.noaa.gov/Products/land/hms.html#maps>

Estimating agricultural burning emissions

Calculate emissions:

Emission factor = representative value relating quantity of pollutant released to atmosphere with activity associated with that release

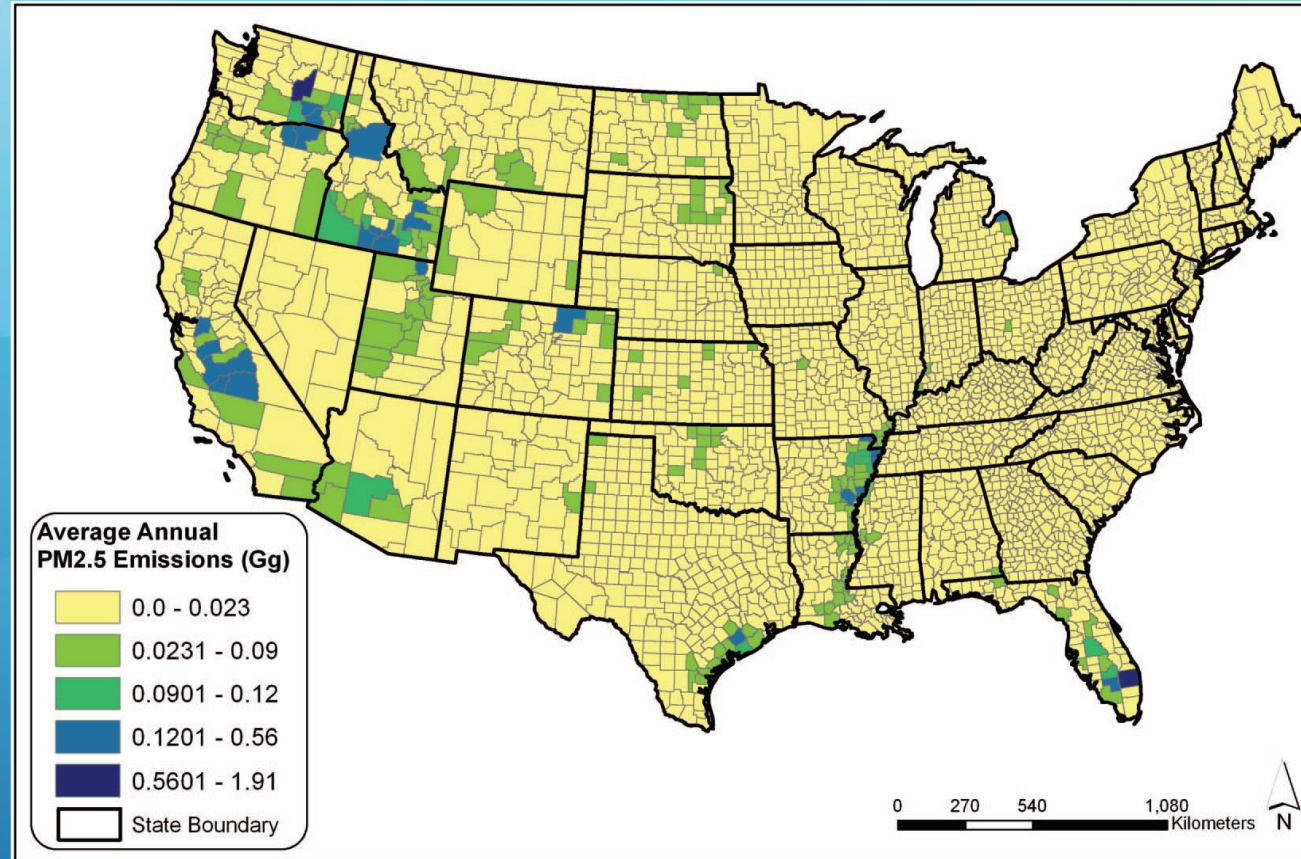
Emissions (E) = Area Burned x Combustion Completeness x Emission Factor x Fuel Loading

Crop Type	Fuel Loading	Combustion Completeness	CO	NOX	SO2	PM2.5	PM10
	tons/acre		lbs/ton	lbs/ton	lbs/ton	lbs/ton	lbs/ton
corn	4.19	0.75	106.10	46.00	2.38	9.94	21.36
cotton	1.70	0.65	146.12	68.90	3.13	12.38	17.73
Kentucky bluegrass	2.91	0.85	182.11	43.10	0.80	23.23	31.64
other crop/fallow	2.95	0.75	127.79	56.00	2.34	12.31	17.00
rice	2.99	0.75	105.27	62.30	2.77	4.72	6.61
soybean	2.50	0.75	127.70	63.30	3.13	12.38	17.73
sugarcane	4.46	0.65	116.95	60.60	3.32	8.69	9.83
wheat	1.92	0.85	110.28	47.50	0.88	8.07	14.10

<https://www3.epa.gov/ttnchie1/conference/ei20/session1/gpouliot.pdf>



Average annual $PM_{2.5}$ emissions from crop residue burning by county



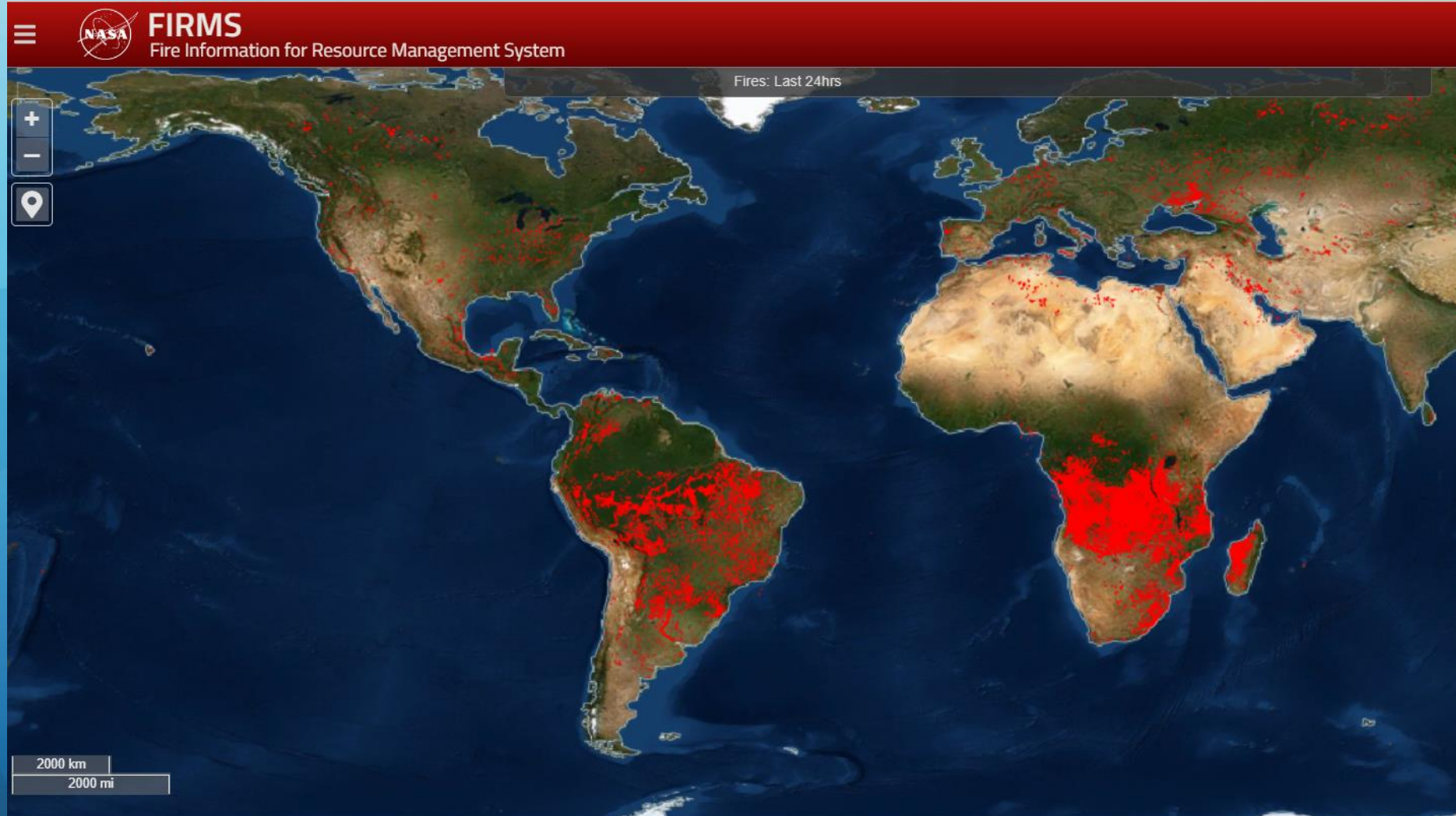
Calculate emissions:

$E = \text{area burned} * \text{combustion completeness} * \text{Emission Factor} * \text{Fuel Loading}$

Source: McCarty, 2011



Global Data: NASA's Earth Observing System Data & Information System (EOSDIS): Active Fire Data



<https://firms.modaps.eosdis.nasa.gov/map/#d:24hrs;@-4.4,-3.2,3z>

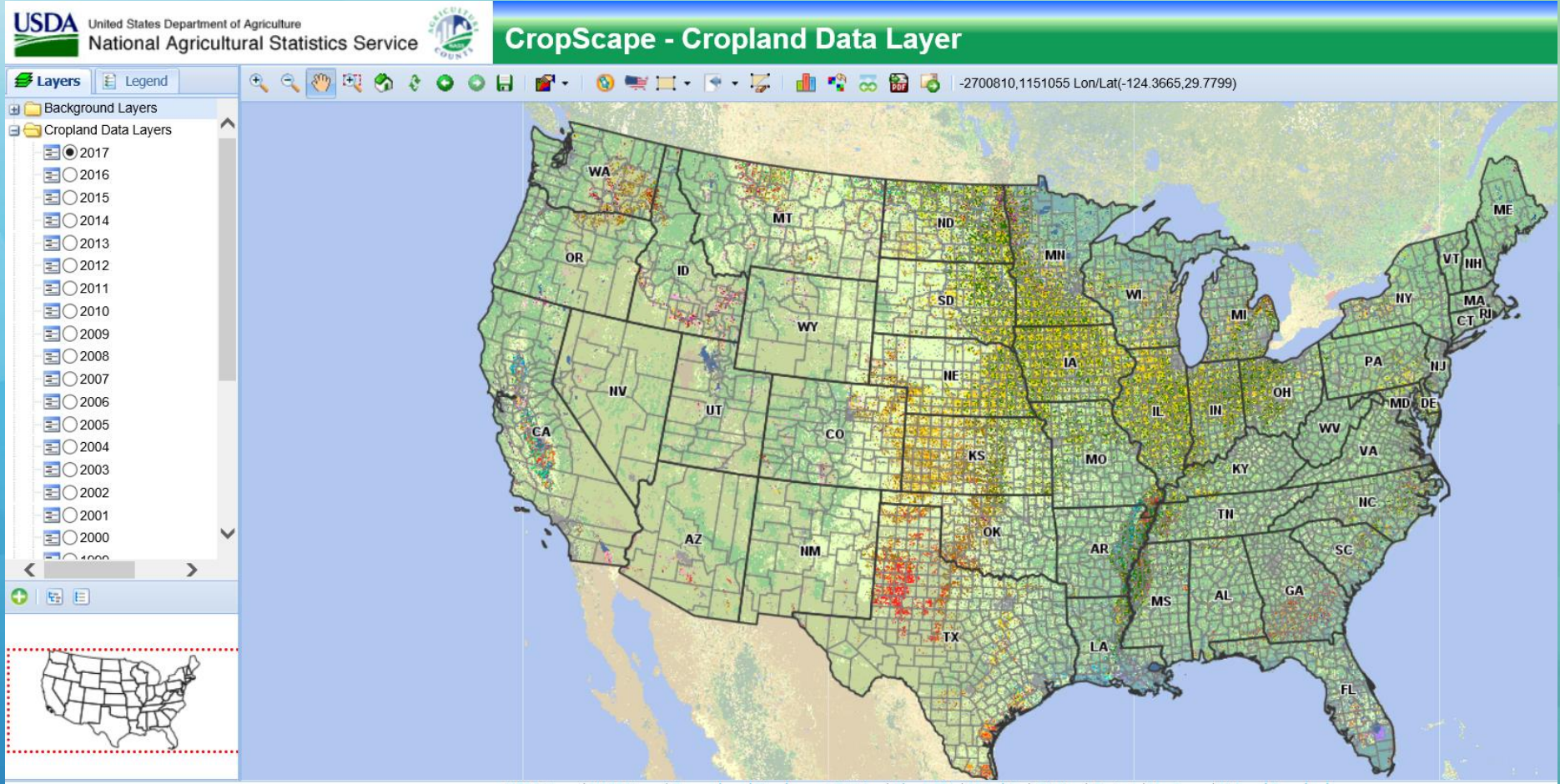


Thailand-Vietnam area – Aug 24, 2022





USDA CropScape



<https://nassgeodata.gmu.edu/CropScape/demo/demo.htm>

Land Cover Categories (by decreasing acreage)

Agriculture

- Pasture/Grass
- Corn
- Soybeans
- All Wheat
- Other Hays
- Fallow/Idle Cropland
- Alfalfa
- Cotton
- Other Crops
- Sorghum

- Vegetables/Fruits/Nuts
- Other Small Grains
- Rice

Non-Agriculture

- Woodland
- Shrubland
- Urban/Developed
- Wetlands
- Water
- Barren
- Perennial Ice/Snow



Emission Factors ($PM_{2.5}$ lbs/ton)

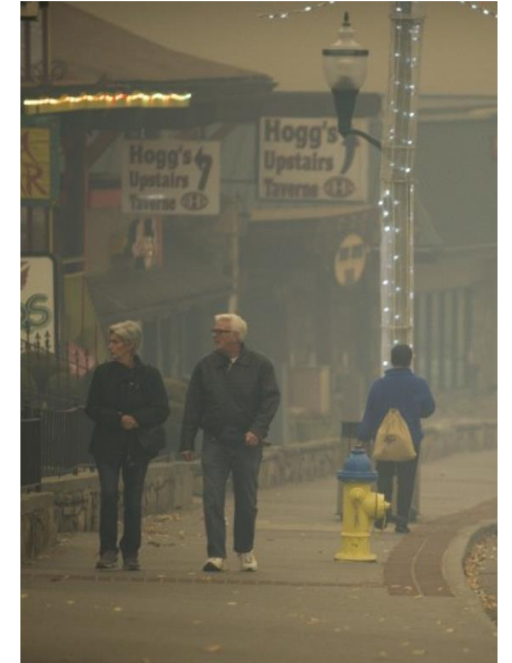
Crop Type	Fuel Loading (tons/acre)	Combustion Completeness	PM _{2.5} (lbs/ton)
Kentucky bluegrass	2.91	0.85	23.23
Corn	4.19	0.75	9.94
Cotton	1.70	0.65	12.38
Rice	2.99	0.75	4.72
Soybean	2.50	0.75	12.38
Sugarcane	4.46	0.65	8.69
Wheat	1.92	0.85	8.07
Other/fallow/le ntils	2.95	0.75	12.31



Factors derived from McCarty (2011). $PM_{2.5}$ adjusted based on consistent $PM_{2.5}/PM_{10}$ ratios applied to PM_{10} factors.

Public Education and Awareness

- Identify communities at risk (e.g., by using satellite-based methods)
- Develop public-health communication on health effects and actions to limit exposure to smoke (e.g., PSAs, social-media)
- Coordinate messages with local groups that are allowing agricultural burning
- Messages/Actions may include:
 - Use of a “visibility index” (e.g., Oregon’s 5-3-1 Index: visibility >5 miles good, under 1 mile unhealthy)
<https://www.oregon.gov/deq/wildfires/Pages/Using-Visibility-to-Estimate-Health-Effects.aspx>
 - Avoid activities that increase indoor or outdoor pollution (e.g., fireplaces, cook stoves, smoking, painting, diesel/gasoline equipment)
 - Reduce or delay outdoor physical activities
 - Do not rely on dust masks. Paper “comfort” or “dust” masks trap large particles, but do *not* provide protection from PM_{2.5}. Need HEPA filters
 - Consider evacuating from path of fires



But why burn crop residues?

Crop-residue burning is an inexpensive and effective method to remove excessive residue to facilitate timely planting and to control pests and weeds.

However ...

- Burning often destroys humus (organic matter) and soil structure, and destroys a potential resource – the residues
- Burning reduces water retention and soil fertility by 25-30%, and thus requires farmers to invest in expensive fertilizers and irrigation systems to compensate.
- Without residue on soil surface, the ground is susceptible to erosion.
- PM and black carbon (BC) emissions impact local and regional air quality and visibility, and contribute to climate change (e.g., CO₂ and BC emissions, deposition of BC on snow and ice)
- *Question of long-term sustainability*
 - Prolonged burning (>15 years) results in significant loss of soil health and function (and nutrients - see next slide)



https://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=1800&context=extension_curall

<https://www.unep.org/news-and-stories/story/toxic-blaze-true-cost-crop-burning>

Benefits of not burning

- Improves air quality
- Promotes healthy soils. Crop residue:
 - Provide protective layer against soil erosion by wind or water
 - Increases organic matter and water-holding capacity of soil
 - Provides “feed and forage” for earth worms.
- Short-term benefits to burning (ease of tillage, seeding, weed and pest control, cost-savings) are lost in long term to reduction in soil health (microbial activity, carbon and nitrogen pools, soil physical conditions) that cannot be overcome by adding fertilizer.
- Creates new markets for agricultural residues
- Climate benefits:
 - During dry periods: greater moisture retention as seeding occurs through non-plowed stubble
 - During heavy rains: decreased erosion because remaining stubble holds soil in place
 - Fixes more soil carbon

https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs144p2_050272.pdf

<https://www.sciencedirect.com/science/article/pii/S0301479722006776>



Nutrients lost burning 2,000 lbs of wheat straw

	Element/ Nutrient	Amount
Nutrients present in 2,000 lbs of wheat straw	N	22 lbs
	P	6.2 lbs
	K	3.5 lbs
	S	2.2 lbs
	Carbon	826 lbs
Nutrients lost in burn	N	22 lbs
	P	0.7 lbs
	K	0.6 lbs
	S	1.5 lbs
	Carbon	749 lbs
Percent Loss	N	98%
	P	11%
	K	17%
	S	68%
	Carbon	91%
Value of lost fertilizer and straw	N @ \$0.60/lb	\$12.96
	P @ \$0.50/lb	\$0.35
	K @ \$0.52/lb	\$0.31
	S @ \$0.91/lb	\$1.37
	Straw \$/ton	\$40.00
	Total	\$54.99

https://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=1800&context=extension_curall

https://openprairie.sdstate.edu/cgi/viewcontent.cgi?article=1365&context=extension_extra

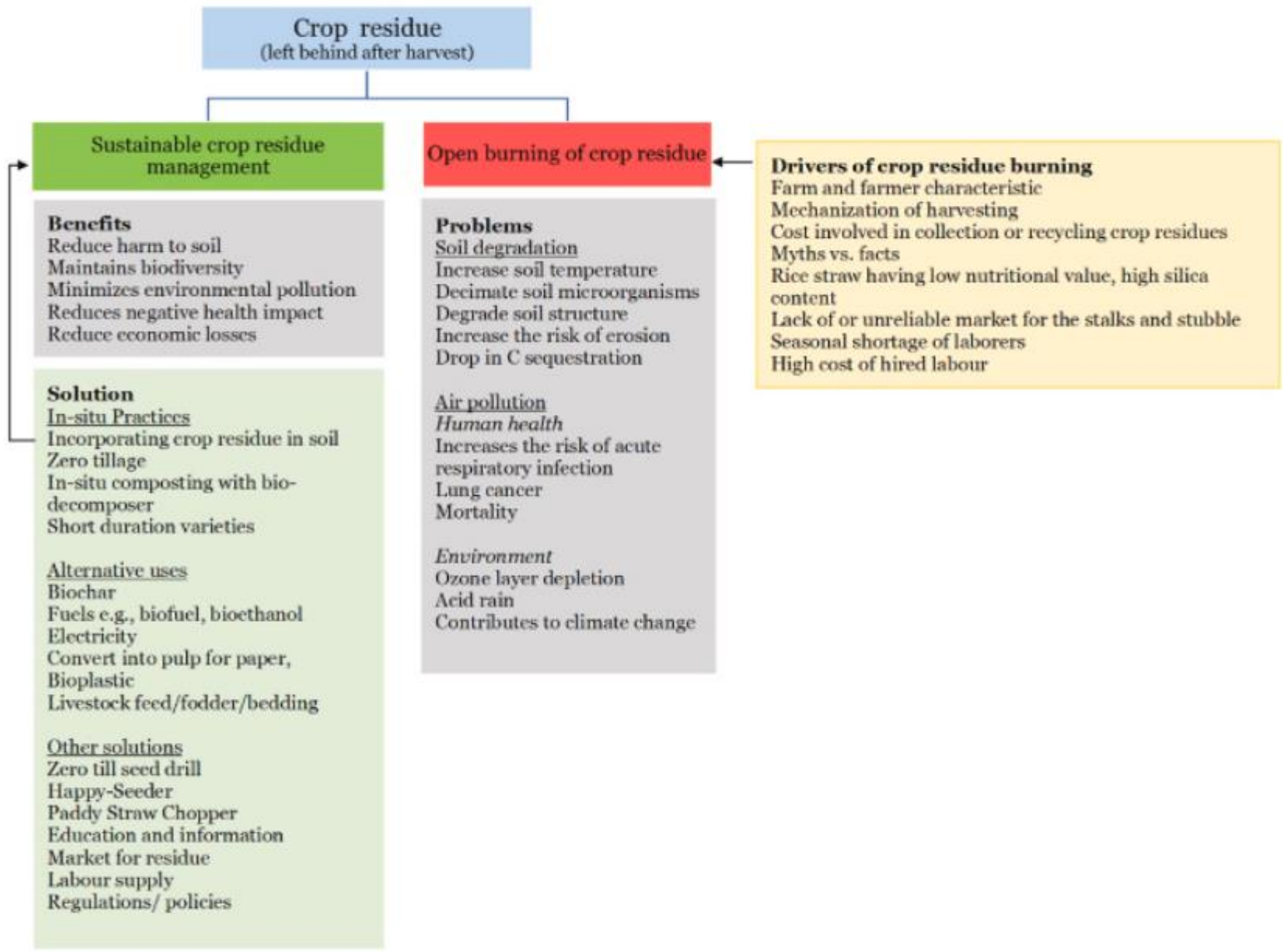
Alternatives to burning

- Chipping/grinding/shredding
- Use residue for animal bedding
- Use residue for ground cover (conservation agriculture)
- Low-Till: use machinery to incorporate/mix crop residue into soil
- No Till/Strip Till/Direct Seed: planting done through residues of previous plantings and weeds*
- Use chemicals to breakdown residue
- Remove by baling (e.g., grasses, winter wheat) and deliver to biomass plants. Can also use wood residue and animal waste as biomass fuels
- Mulching (spread across top of soil as protective cover and to prevent weeds)
- Composting (used beneath top layer of soil (feeds plants through their roots))

*Note controversy about increased use of herbicides for no-till farming

USDA-NRCS and USEPA: 2012, Agricultural Air Quality Conservation Measures Reference Guide

<https://www.epa.gov/afos-air/agricultural-air-quality-conservation-measures-reference-guide-cropping-systems-and>



Drivers, effects and solutions to crop residue burning

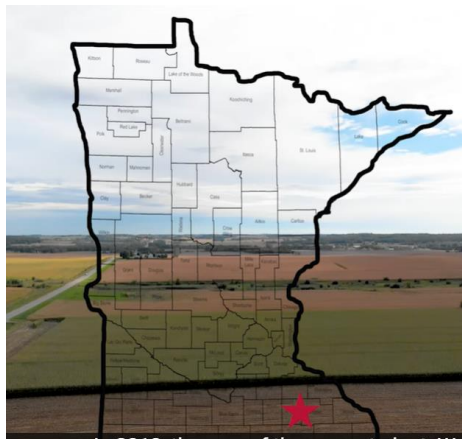
<https://www.sciencedirect.com/science/article/pii/S0301479722006776>

No-till agricultural practices

- No-till farming methods result in low soil disturbance.
- With conventional plowing, the top layer is turned over before seeding. Tillage helps to aerate soil, incorporate manure and fertilizers, loosen earth for future fragile seedling roots, destroy pests, eradicate weeds.
 - Conventional plowing promotes soil erosion, removes cover matter, causes an imbalance in micro-communities, and releases soil carbon into the air, contributing to the greenhouse effect.
- No-till farming requires special equipment (disc seeders or agriculture drills) to make furrows, immediately plant seeds, firm them, and cover.
- But weeds are not destroyed by these mechanical methods. Therefore, farmers cover inter-rows with straw, dry hay, or mulches, which suppresses weeds due to lack of light and accumulates moisture and protects plant roots from sun.

<https://eos.com/blog/no-till-farming/>

US examples of no-till farming



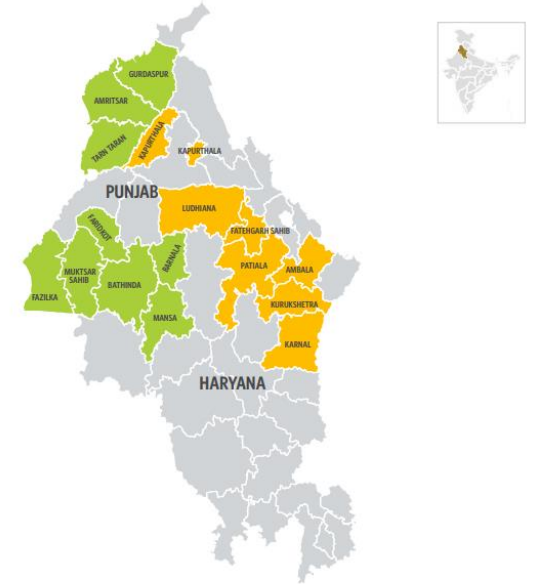
A no-till planter is used to plant soybeans into a terminated cover crop. Photo credit: Jason Johnson, NRCS-Iowa

<https://www.youtube.com/watch?v=pf0WJy5KzVQ>

<https://www.usda.gov/media/blog/2017/11/30/saving-money-time-and-soil-economics-no-till-farming>

Asian example of no-till farming: Happy Seeder

- “Happy Seeder” developed by Punjab Agricultural University PAU in collaboration with Australian Centre for International Agricultural Research (ACIAR)
- From 2019 – 2020, the Harnessing the power of Agricultural Residues through Innovative Technologies (HARIT) Initiative
- Supported 84 villages across 21 blocks in 7 districts of Punjab and Haryana
- Conducted field demonstrations with 83 Happy Seeders on 4,048 hectares of land.
- About 80% of farmers in Reviving Green Revolution (RGR) pilot villages did not burn crop residue and used alternate practices including use of Happy Seeder and zero tillage for sowing wheat



RGR (green) and HARIT (orange) initiative districts in Punjab and Haryana



<https://www.tncindia.in/content/dam/tnc/nature/en/documents/india/HARIT-FactSheet.pdf>

Potential uses of straw residue

Agricultural sector	Manufacturing industries	Construction sector	Renewable energy
Compost	Paper making	Building material	Biofuel
Vermicompost	Food packaging	Thermal insulation	(ethanol)
Nursery mats	Activated carbon materials	Erosion control	Electricity
Mulching	Pyroligneous acid	Grass growth medium	Biogas
Mushroom growth medium		Land reclamation	(domestic uses)
Livestock feed			
Animal bedding			
Thatching			

Source: Park et al., 2014; Qian et al., 2014; Department of Science, Technology and Environment, 2013; Kanokkanjana & Garivait, 2013; Nguyen et al., 2013; Thapat & Gheewala, 2013; Delivand et al., 2012; Indian Agricultural Research Institute, 2012; Li et al., 2012; Liu et al., 2010; Lal, 2005; Devendra & Sevilla, 2002; MADA, 2004.



Country	Rice straw utilization	Percent (%)
Bangladesh	Livestock feed, compost, biogas	74.4
Korea	Compost	46.0
	Biofuel	20.0
	Livestock feed	15.0
Thailand	Livestock feed	13.0
	Compost	5.0
	Raw material (sell)	1.5
	Biofuel	0.2
	Others activities	0.3
China	Rural energy (electricity)	53.6
	Livestock feed	28.0
	Fertilizer	15.0
	Paper making	2.1
	Reused on the farm and collected for other purposes	16.2
Japan	Livestock feed	11.6
	Compost	10.1
	Animal bedding	6.5
	Combustion	4.6
	Erosion control	4.2
	Mulching	4.0
	Incinerator	3.1
	Handicraft	1.3
	Processed	1.1
	Other activities	0.3
India	Biogas	28.0
	Other activities (livestock feed and roof)	49.0
Taiwan	Compos	56.9
	Livestock feed	11.0
	Biofuel	5.1
	Other activities	22.1
Philippines	Livestock feed, mulching, mushroom growth medium	5.0
Malaysia	Livestock feed, compos, erosion control, mushroom growth medium, paper making	1.0

Source: Devendra, 1989; Gadde et al., 2009; MADA, 2010; Matsumura et al., 2005; Su, 2009; Liu et al., 2010; Devendra & Sevilla, 2002; Li et al., 2012

Example: Repurposing rice straw in California

- Rice straw used for wattles would otherwise go into California landfills.
- Staked fiber rolls being used for erosion control on slopes of hillsides.



<https://www.usarice.com/news-and-events/publications/usa-rice-daily/article/usa-rice-daily/2020/05/28/repurposing-rice-straw>
<https://www.dailyrepublic.com/all-dr-news/solano-news/solano-county/seasonal-wetlands-best-success-story-of-repurposing-rice-straw/>

Examples of State Smoke Management/Crop Residue Programs

- Idaho Department of Environmental Quality(DEQ) <https://www.deq.idaho.gov/air-quality/smoke-and-burning/>
- California Air Resources Board <https://ww2.arb.ca.gov/smoke-management-programs-and-burn-decisions-other-air-districts>
- Georgia Department of Natural Resources <https://epd.georgia.gov/air-protection-branch/open-burning-rules-georgia/burn-types/prescribed-fire-smoke-management-plan>
- Oregon Department of Forestry <http://www.oregon.gov/ODF/Fire/pages/Burn.aspx>
- Nevada Division of Environmental Protection <https://ndep.nv.gov/air/air-pollutants/smoke-management>
- Washington Department of Natural Resources https://www.dnr.wa.gov/publications/rp_burn_smptoc.pdf
- Manitoba (Canada) Agriculture <https://www.gov.mb.ca/agriculture/crops/crop-residue-burning-program/index.html>

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<https://www.arb.ca.gov/research/resnotes/notes/95-16.htm>
- **CCAC Project Summary Report**, 2015, *Fire in the Fields: Moving Beyond the Damage of Open Agricultural Burning on Communities, Soil, and the Cryosphere* <http://www.ccacoalition.org/en/resources/fire-fields-moving-beyond-damage-open-agricultural-burning-communities-soil-and-cryosphere>
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- **Pouliot, George et al**, 2012, Development of a Crop Residue Burning Emission Inventory for Air Quality Modeling <https://www3.epa.gov/ttnchie1/conference/ei20/session1/gpouliot.pdf>

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- **USDA-NRCS and USEPA**: Agricultural Air Quality Conservation Measures Reference Guide for Cropping Systems and General Land Management, October 2012 <https://www.epa.gov/sites/production/files/2016-06/documents/agaqconsmeasures.pdf>
- **USDA**, 2003, Assessing Values of Air Quality and Visibility at Risk From Wildland Fires <https://www.fs.fed.us/pnw/pubs/rp550/rp550b.pdf>
- **US EPA, US Forest Service, US Centers for Disease Control and Prevention, California Air Resources Board**, revised May 2016, "Wildfire Smoke: A Guide for Public Health Officials https://www3.epa.gov/airnow/wildfire_may2016.pdf

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