Black carbon controls in California: emissions, abatement, and knowledge gaps

Dr. Alberto Ayala\textsuperscript{1,2}, Dr. Jianjun Chen\textsuperscript{1}, and Dr. Nehzat Motallebi\textsuperscript{1}

\textsuperscript{1}Research Division, California Air Resources Board
\textsuperscript{2}Mechanical Engineering, West Virginia University

Picture courtesy of Dr. D. Su, Fritz-Haber Institute
The case for BC abatement is well made in the scientific/policy mainstream

**Air Quality and Health**


American Clean Energy and Security Act 2009 (House)
Carper’s Amendment to Interior Appropriations Bill (Senate)
– direct EPA to find the most cost-effective ways to reduce BC emissions
First, the caveats

- You can’t manage it if you can’t measure it
  - Optical and thermal methods (to measure BC and EC) in contradiction
  - No single universally accepted standard (yet!) for BC or EC measurement
  - Separation of organic carbon (OC) from EC is difficult
  - Discrepancies due to local aerosol characteristics and meteorology

- Properties most relevant to climate
  - Optical (absorption), mixing state (aged aerosol), size distribution not yet measured consistently

- BC climate impacts differ at global, regional, and local scales

- Principal uncertainties: projection of future emissions and indirect BC effects*

- Preferred inventories are bottom-up approaches
  - Experimental data scant for specific emission factors and activities

- California-specific emission factors account for
  - Unique mix of fuels, combustion technology, operating conditions, and aggressive emission control programs

References:
3) CARB study (04-307) by Chow et al. (2008).
California BC emissions

- Wildfire: 29%
- Managed Burning: 14%
- Residential: 8%
- Miscellaneous: 6%
- On-Road Transportation: 20%
- Off-Road Transportation: 23%


- PM2.5, from emissions inventory
- PM2.5, X [BC/EC and OC],
- BC/EC and OC for source, (i.e., source profile)
Transportation emissions are key focus for air quality and climate
Trends in gasoline car emissions

1965
- CO: 87.0 g/m
- HC: 8.8 g/m
- NOx: 3.6 g/m
- PM: 0.2 g/m
- BC: 0.04 g/m

1975
- CO: 9.0 g/m
- NOx: 2.0 g/m
- PM: 0.08 g/m
- BC: 0.02 g/m

2003
- CO: 1.4 g/m
- NOx: 0.1 g/m
- PM: 0.003 g/m
- BC: 0.6 mg/m

2009
- CO: 1.4 g/m
- NOx: 0.05 g/m
- PM: 0.003 g/m
- BC: 0.6 mg/m

Source: PM emission factors from US EPA Kansas City Study
Trends in diesel truck emissions

Data source: CARB’s EMFAC model
Research confirms progress on PM reductions

SULEV limit = 10mg/mi

Fleet averaged emission rates of OC and EC for SULEVs, not corrected with background.


GASOLINE

DIESEL

Diesel Soot Emissions/Fuel Consumed
(Estimated)

Engine diesel soot ~18 fold
Fuel usage ~6 fold
Ambient diesel soot ~3 fold
Diesel control
Health = #1 policy driver for diesel PM/BC control

Air pollution and premature death*
California estimates for 2005

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Annual Deaths*</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM2.5</td>
<td>18,000</td>
</tr>
<tr>
<td>Ozone</td>
<td>540</td>
</tr>
<tr>
<td>Toxic Air Contaminants</td>
<td>400</td>
</tr>
</tbody>
</table>

* At least a factor of two uncertainty.

Relative cancer risk by inhalation from airborne toxics

Impact of diesel PM on California*

Premature death (3500 per year*)
Lung cancer (250 per year)
Decreased lung function in children
Chronic bronchitis
Increased hospitalizations
Aggravated asthma
Increased respiratory symptoms
Lost work days
Reduction in visibility (10-75% of total)

* www.arb.ca.gov/research/health/pm-mort/pm-mort.htm

CARB’s Diesel Risk Reduction Plan (DRRP) (Diesel PM 85% below 2000 in 2020)

New engines 90% NOx & PM reduction

Low sulfur Fuels 15 ppm S content (2006)

In-use engines* (2000-2018)

Trucks (2007-2010)

Off-road (2011-2015)

Diesel GHG Reduction

EPA SmartWay Standards

Idling limits

Replace

Repower

Retire

Retrofit

Urban bus

Trash trucks

Portable equipment

Stationary engines

Cargo handling equip.

Municipal fleets

TRUs

Locomotive & rail yard (under study)

School bus

Port trucks

Stationary agri. engines

Off-road non-agri.

Aux. engine OGV

Private trucks

Ag. equip. (2010)

*With millions $ per year in incentive funding provided

www.arb.ca.gov/diesel/dieselrrp.htm
Diesel engine applications covered by DRRP

On-road Vehicles
- On-road Truck
- Passenger Bus
- Concrete Mixer
- Hay Squeeze
- Water Truck
- Fuel Tank Truck
- Reefer Van
- Drill Rig
- Dump Truck
- Tow Truck

Off-road Vehicles
- Aerial Lift
- Loader
- Backhoe Loader
- Ground support equipment
- Skid Steer
- Belt Loader
- Mast Forklift
- Dozer
- Telescopic Forklift
### BC fraction in PM vehicle emissions

#### Gasoline Car

<table>
<thead>
<tr>
<th>Conventional</th>
<th>Direct injection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organic carbon</td>
<td>Elemental carbon</td>
</tr>
</tbody>
</table>

- **Conventional**
  - PM emissions $< 1$ mg/mile
  - $<<$ current SULEV PM standard of 10 mg/mile
  - Most PM is OC
  - BC increases for high PM emitters

- **Direct injection**
  - Very good for CO$_2$ reduction
  - still $<$ current SULEV PM standard
  - But PM $>$ conventional gasoline
  - Also $>$ particle counts
  - Most PM is BC or soot like diesel

#### Diesel Truck

<table>
<thead>
<tr>
<th>Pre-2007</th>
<th>2010</th>
</tr>
</thead>
</table>

- **Pre-2007**
  - PM standard at 100 mg/bhp-hr
  - Most PM is EC or soot

- **2010**
  - PM emissions $<<$ standard 10mg/bhp-hr
  - Little BC (EC or soot)

---

**CARB evaluating LEV III (more stringent PM standard)**

DPF (for retrofit or OE installation) is a game changing solution.

Pre-DPF soot agglomerates

Post-DPF clean sample

SEM images courtesy of Dr. D. Su, Fritz-Haber Institute
Significant PM(BC) reductions by various types of DPFs

Clean diesel exhaust (Post-DPF particles)

EC(soot or BC) is eliminated; if particles present, they are mostly very small sulfate


Global warming emissions

**Diesel w/o DPF**

- CO\(_2\): 2074
- BC: 142
- N\(_2\)O: 7

**2010 Prototype Diesel Retrofit (DPF+SCR)**

- CO\(_2\): 2075
- BC: 1
- N\(_2\)O: 223

[Diagram showing CO\(_2\) Equivalent Emissions for Diesel w/o DPF and 2010 Prototype Diesel Retrofit (DPF+SCR)]
Other BC sources

Southern California Wildfire

Managed Burning

Residential - Fireplace
- **Residential wood burning**
  - Mandatory wood burning curtailment when air quality is poor in winter (e.g., in Bay Area, Sacramento, San Joaquin Valley, South Coast)
  - Wood stoves & fireplace change out incentive program to replace older polluting units with cleaner units (e.g., $150-750 voucher in the Sacramento County)

- **Managed burning**
  - ARB Smoke Management Program provides guidelines for agricultural and prescribed burning operations in California (effective in 2001)
  - Agricultural burning prohibited unless no economically feasible alternatives available (e.g., in San Joaquin Valley)
  - Working groups involving different stakeholders to find alternatives to burning (e.g., use as a fuel in biomass plants)
Closing remarks

- Science supports co-benefits of BC reductions for air quality and climate protection
- California implementing clear policies
- Taking aggressive action for reducing PM (and BC)
  - Major programs in place for mobile sources (gasoline, diesel, etc.)
  - Tangible progress
  - Diesel PM reductions is key focus for air quality and health
  - Concurrent climate benefit from BC reductions
- New policies will emerge
  - California’s LEVIII program
  - US Congress directs EPA to look into BC