U.S. Department of Energy (DOE) - Arctic Black Carbon Project

Using Science to Inform Black Carbon Mitigation Potential

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The impact of emissions on the Arctic

"…reductions in the emissions of long-lived greenhouse gases, particularly carbon dioxide, are urgently needed. However, the Arctic may also benefit more than other regions from reductions in the emissions of short-lived climate agents. In particular, reducing BC emissions could slow atmospheric warming and the melting of snow and ice, and reducing tropospheric ozone concentrations could slow the increase in Arctic surface air temperatures. Increases in emissions of BC and ozone precursors in the Arctic itself should be strictly avoided." [1]

[1] ***"Arctic Air Pollution: Origins and Impacts,"*** *K. Law & A. Stohl, Science, Volume 315, March 16, 2007*

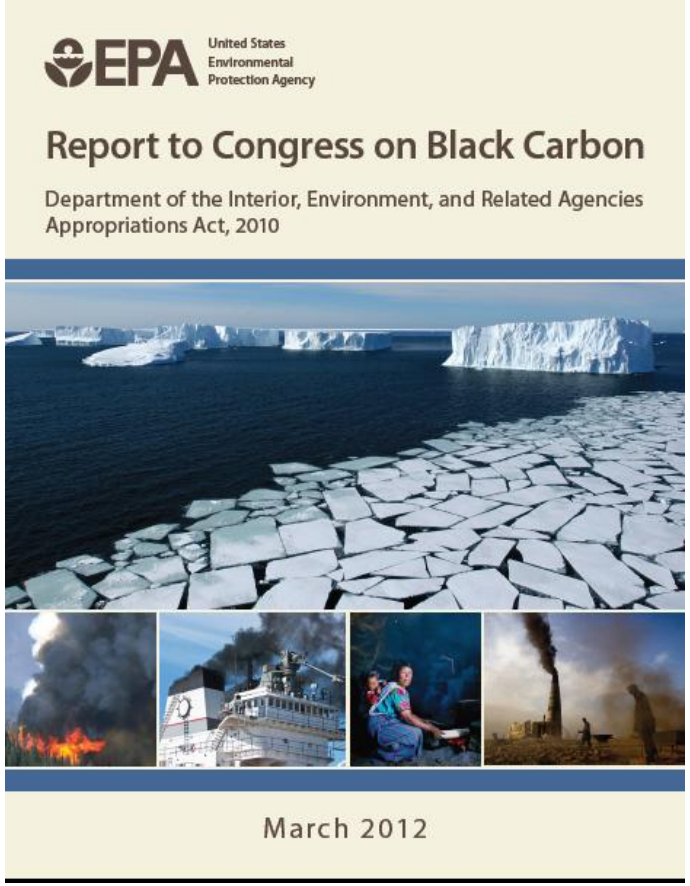
Concern has evolved into action

For example:

2011 – *"Integrated Assessment of Black Carbon and Tropospheric Ozone,"* UNEP

2012 – Climate and Clean Air Coalition (CCAP) consisting of 20 countries and 17 NGOs.

"BC has been linked to a range of climate impacts, including increased temperatures, accelerated ice and snow melt, and disruptions to precipitation patterns. Importantly, reducing current emissions of BC may help slow the near-term rate of climate change, particularly in sensitive regions such as the Arctic." [2]



[2] ***Report to Congress on Black Carbon,"*** *US Environmental Protection Agency, March 2012*

Arctic Black Carbon Initiative

- **On December 17, 2009, the US Government (USG) announced at the Copenhagen climate meeting a $5M commitment towards international cooperation to reduce black carbon (BC) emissions in and around the Arctic.**

- **Arctic BC Initiative goals:**
  1) Fill information gaps
  2) Identify implementation barriers and develop approaches to overcome them
  3) Demonstrate and evaluate technological and non-technological mitigation options
  4) Where possible, to lay the groundwork to quantify the climate and public health benefits of black carbon mitigation strategies

- **In 2011, the U.S. Department of State initiated the following projects at three U.S. government agencies:**
  1) U.S. Environmental Protection Agency – BC emissions from diesel & transportation
  2) U.S. Department of Agriculture – BC emissions from agriculture burning
  3) U.S. Department of Energy – black carbon emissions from heating, power generation, and industrial applications

Working assumptions about Arctic black carbon when project started.

- Emissions sources north of 40°N latitude are primarily responsible for the presence of black carbon in the Arctic [*Bond, 2004; Stohl, 2006].*

- Modeling and empirical evidence suggest that Russia's share of world BC emissions in this zone is 10-15% [*Bond et al., 2004; Quinn et al., 2007],* a figure which rises above 50% north of 60°N [*Bond et al., 2004; Klimont, 2008].*

- Some studies have suggested that most of the BC in the Arctic is from fuel combustion – for transportation, heating, and industry – rather than from open biomass burning (i.e. forest fires and controlled burning of crop residues) [*Zender,* 2007].

- Russia does not use ultra low-sulfur diesel (ULSD) fuel and has older diesel-fueled machinery and vehicle fleets [*Bond et al., 2004*]. Russia's small scale residential and industrial facilities are aged and inefficient. Industrial facilities and practices of waste disposal and agricultural burning generate very heavy particulate air pollution, including BC.

BC emissions in or near the arctic have a disproportionate warming effect

Examples of the types of questions we are considering

- What is the geographic origin of BC emissions transported and deposited to the Russian Arctic?
- What is the effect of seasonal variability on BC emissions and deposition in the Russian Arctic?
- What is the fraction of industrial sources in Arctic BC emissions?
- Which fuel sources are the major BC emitters in the Russian Arctic?
- Does Arctic BC stem mainly from BC transported from population centers or other localized sources?

Inform mitigation priorities

How are we addressing the problem: U.S. Department of Energy Project Activities

- **Identify probable sources of BC:**

  Identify the location of Russian emissions sources by back-trajectory modeling. Analyze BC data (or proxy) in a receptor-oriented framework: Potential Source Contribution Function. (Work is underway).

- **Establish Emissions Inventory of BC in the Russian Arctic:**

  Improve estimates of BC emissions in Russia through use of atmospheric transport models with an emphasis on industrial, power, CHP & DHC sources – and work with local and other experts to fill in the gaps of the available emissions inventory. (Work is underway).

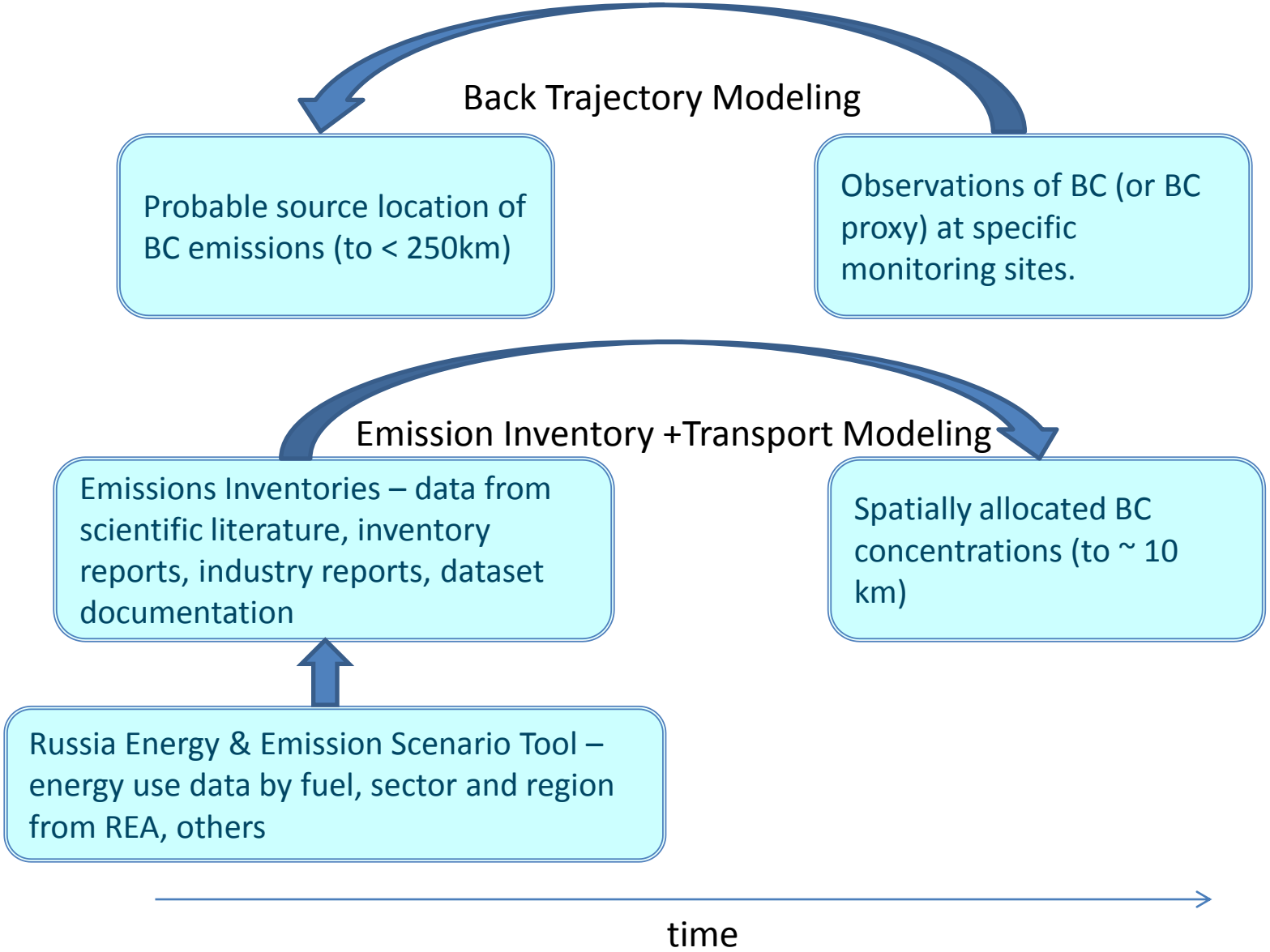
- **Demonstration of BC Emissions Reduction Technologies:**

  Demonstrate the best-available emissions reduction technologies available for a subset of the identified sources in Russia. (Work is starting.)

- **Information Sharing:**

  Initiate information sharing; e.g. a global network of energy and BC experts for the purposes of sharing best practices and leading educational outreach and hands-on projects to encourage the adoption of highly-efficient, low-emissions technologies. (Future work).

The Atmospheric Research Component

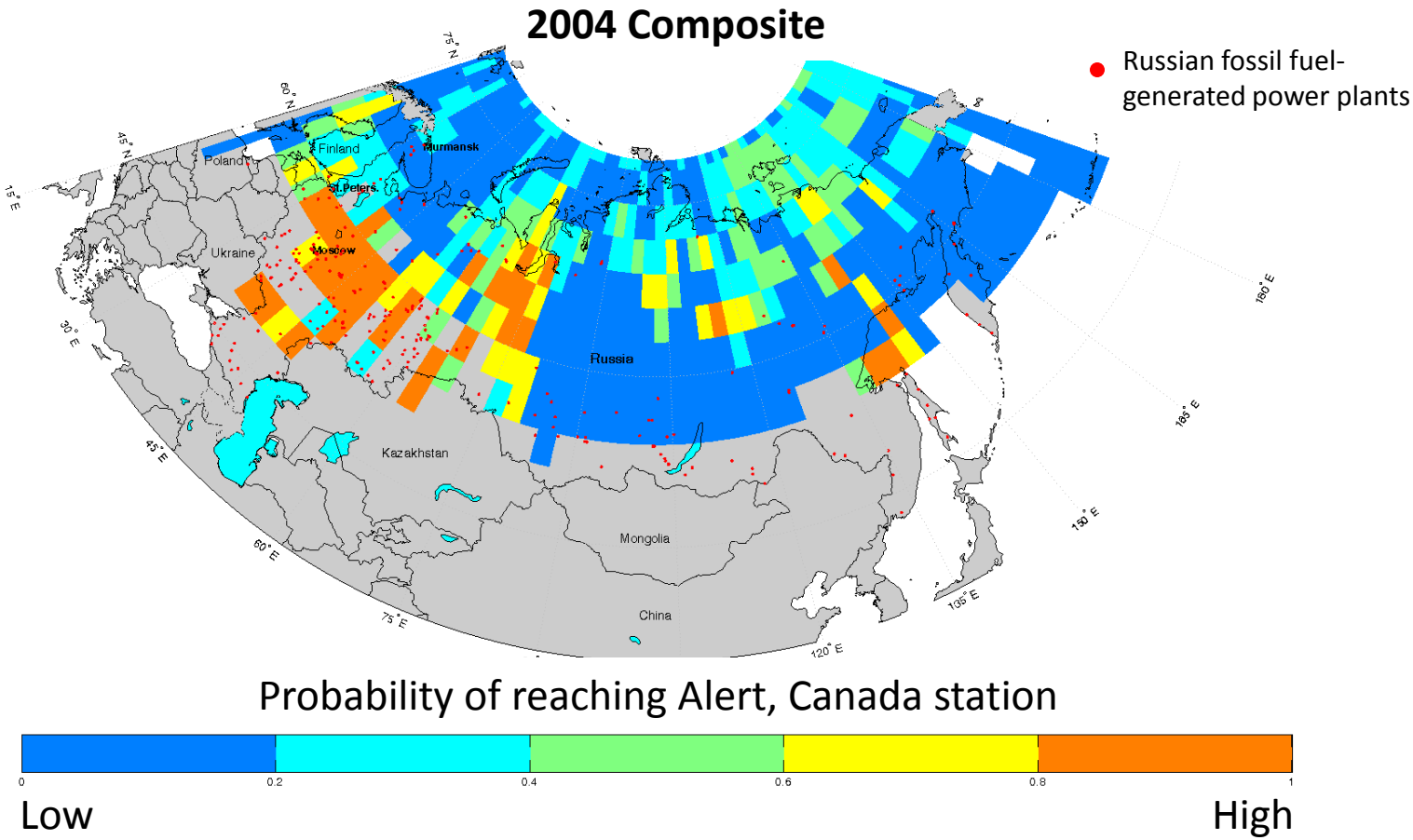


Monitoring Stations for Back Trajectory Modeling

Environmental data observation sites

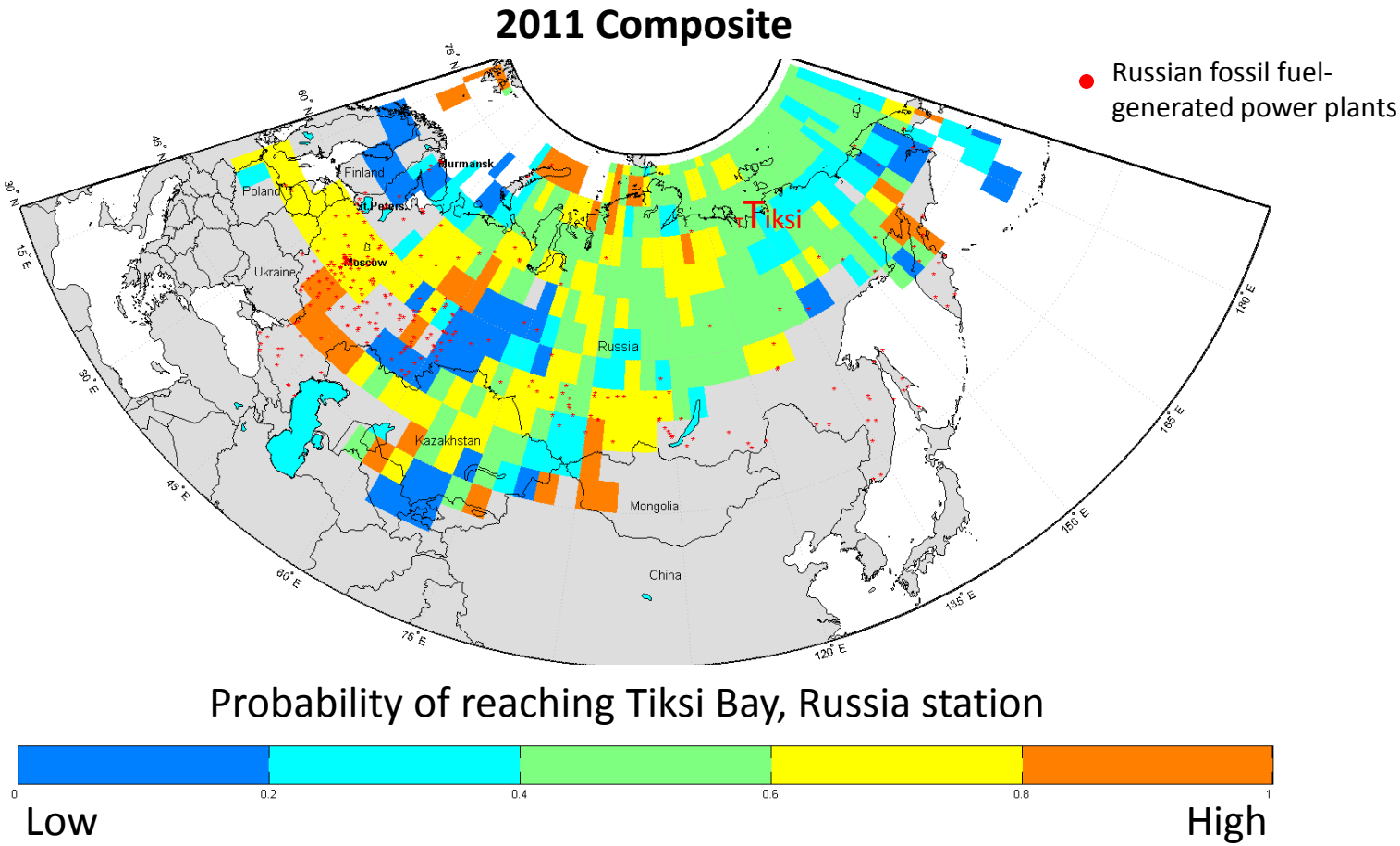
wikipedia.com

Geographical Locations of Black Carbon Emission Sources in Russia
Example 1: Data from Alert, Canada



- Significant presence of black carbon sources in Russia
- Possible sources include: power plants, biomass burning, industrial activities, oil and gas flaring

Geographical Locations of Black Carbon Emission Sources in Russia
Example 2: Data from Tiksi Bay, Russia



Observation of source locations from Tiksi is consistent with that observed with Alert data: Eurasia is a major source of black carbon which is transported to the Arctic.

Emissions Inventory—Identification of Missing Sources

Comparison of regional particulate matter (PM) emissions in the industrial sector from one Russian and one Global data set

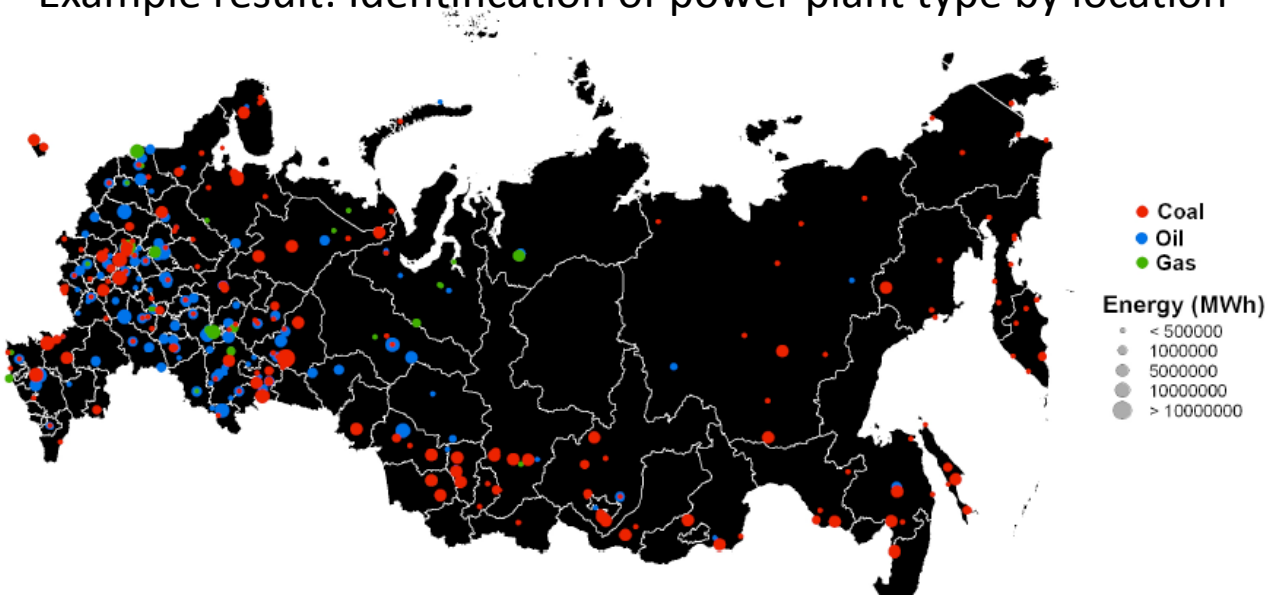
Ratio: Russian Energy Agency/Global data set (Yellow: ratio ≤ 1, Black: ratio >1)

Much higher emissions estimated from REA data set

<u>Hypothesis</u>: Global data set underestimates black carbon emissions from Russia

Emissions Inventory—Improving Estimate of Black Carbon Emissions from the Industrial Sector

Example result: Identification of power plant type by location

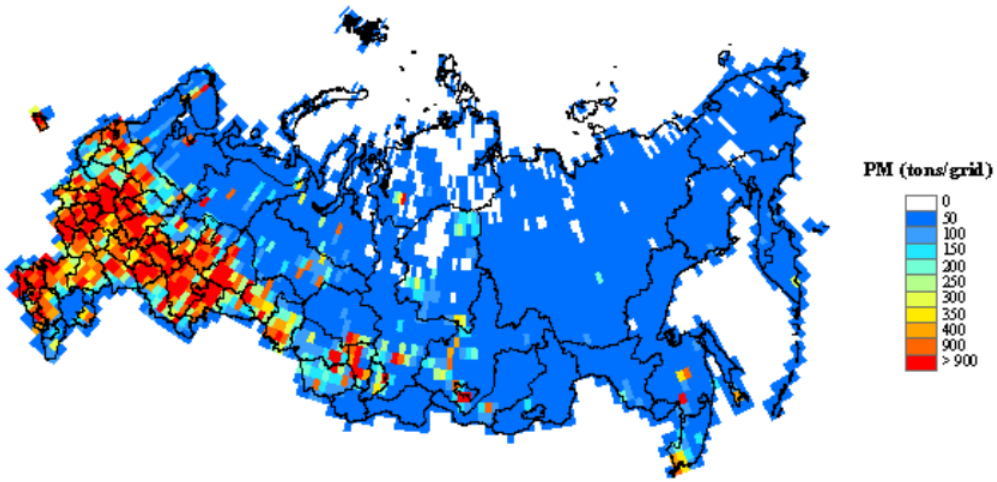


To better estimate industrial sector black carbon emissions, need improved information on:

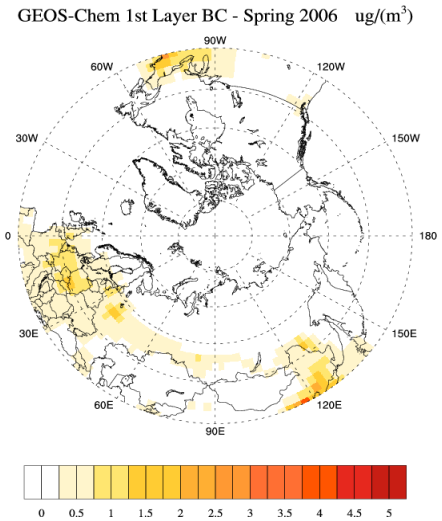
- Fuel type by power plant (e.g. coal, oil, natural gas fired)
- Ratio of PM/CO_2 emissions by power plant type and region (i.e. regional emission factors)

Modeling the Transport of Black Carbon (BC) to the Arctic

Global Atmospheric Transport Model



Example: Improved BC Emissions Estimate

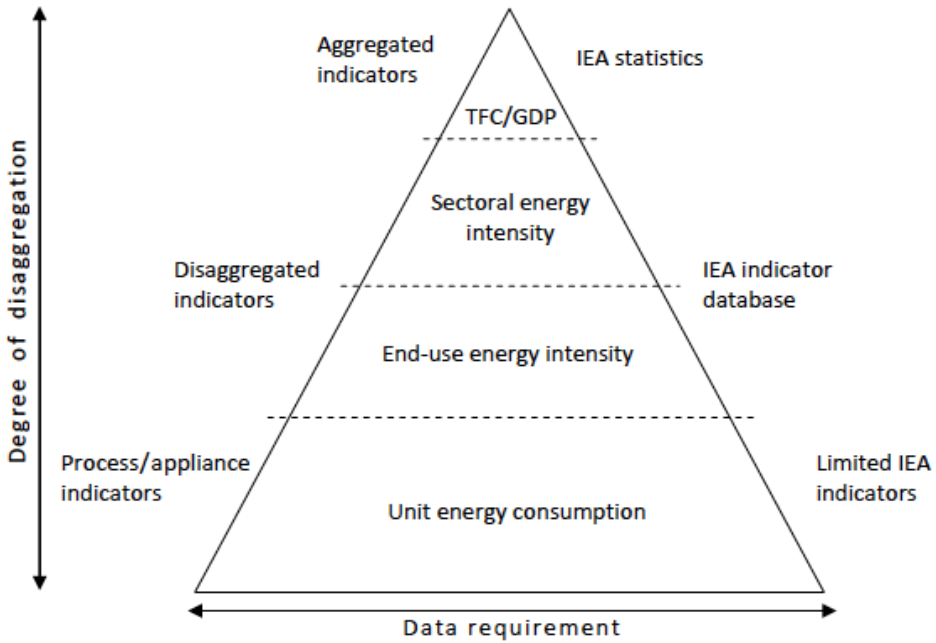


Example: Amount of BC which reaches the Arctic

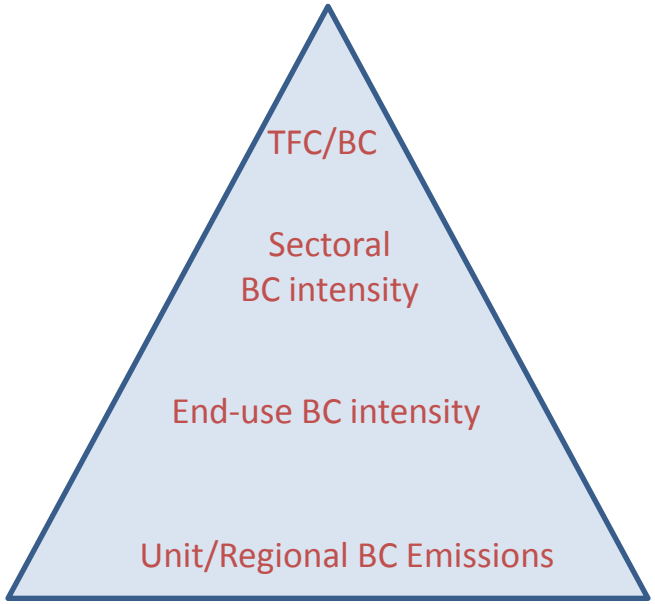
Question: Which regions contribute the most to BC deposited in the Arctic?

What level of disaggregation is important?

Figure A.1: The IEA indicator pyramid



Note: Indicators shown are just on example among those available.

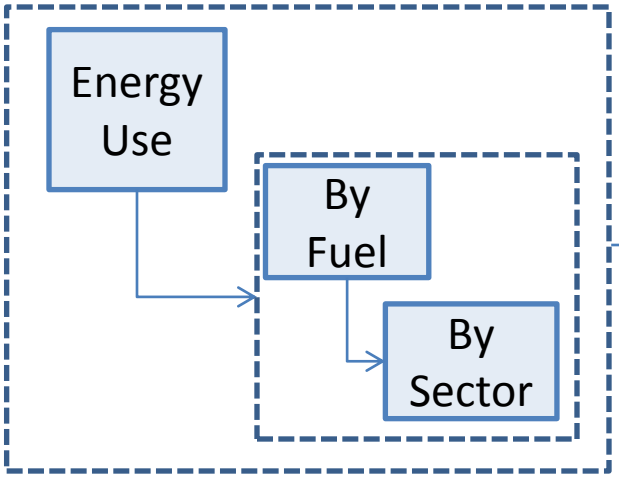


IEA Energy Indicators → Black Carbon Indicators ? *

How far is it necessary to disaggregate to the regional level?

*Can this team develop a protocol?

Black Carbon (BC) Sources, Transport in Context with Energy Use

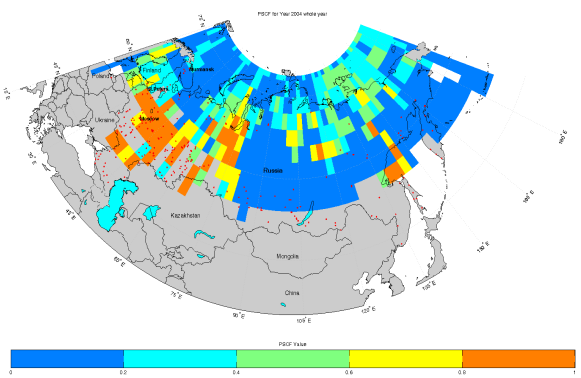


Data

Σ BC

Σ BC by region

Atmospheric research



Probable BC sources;
Infer types of sources

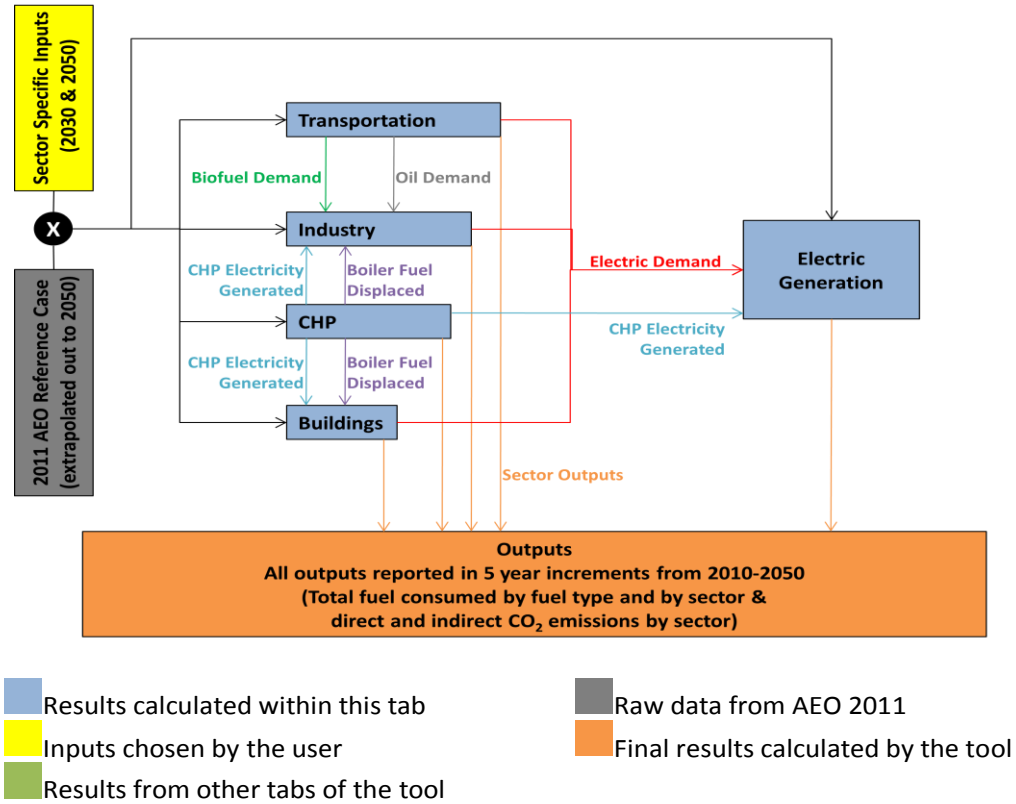
Emissions and Energy Model – calculate impacts of efficiency and technology

National energy and BC reduction potential

We are developing a Russian Energy & Emissions model. It is based on an approach used to assess U.S. energy and CO_2 emissions reductions, but will require spatial aspect to address BC.

- Originally developed to compute Greenhouse Gas (GHG) emissions for the U.S. (the Low Carbon Scenario Tool)
- The user inputs a scenario such as an efficiency improvement, increase in CHP, and/or fuel switch and the model shows the change in GHG emissions over the base case out to 2050.
- It is insufficient for BC modeling, (no regional aspect)
- We plan to adapt the model approach to predict BC emissions for various scenarios
- Our goal is to run scenarios to prioritize BC emission reductions that can be achieved through energy efficiency, emissions control measures, and/or fuel switching

High level structure of the U.S. Low Carbon Scenario (LCS) model

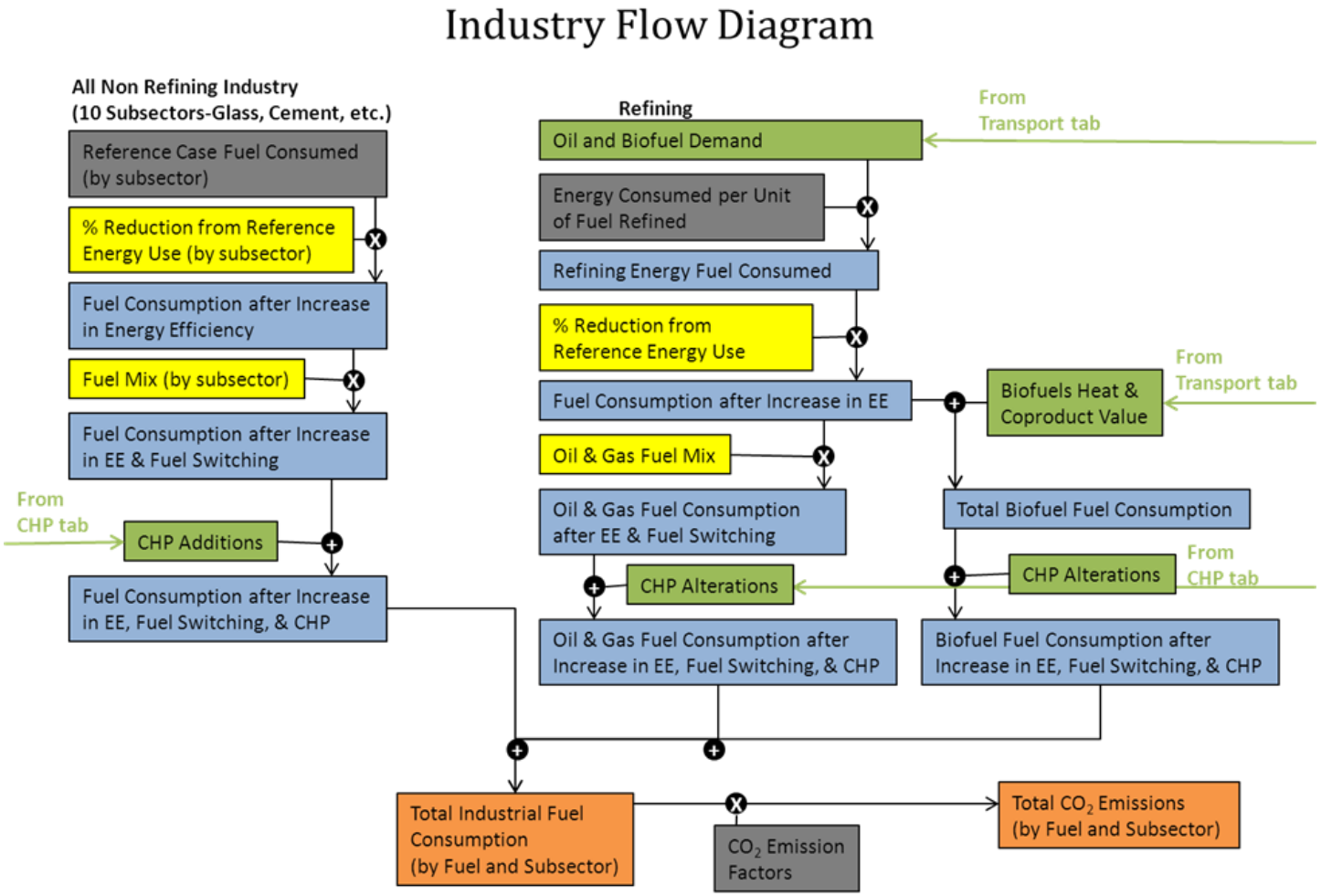


Results calculated within this tab
Inputs chosen by the user
Results from other tabs of the tool
Raw data from AEO 2011
Final results calculated by the tool

High level structure of the Low Carbon Scenario (LCS) tool for the U.S.

- Current estimates based on energy data and emissions factors
- Future estimates based on efficiency potential, fuel switching, control technologies.

LCS Tool - The Industrial sector



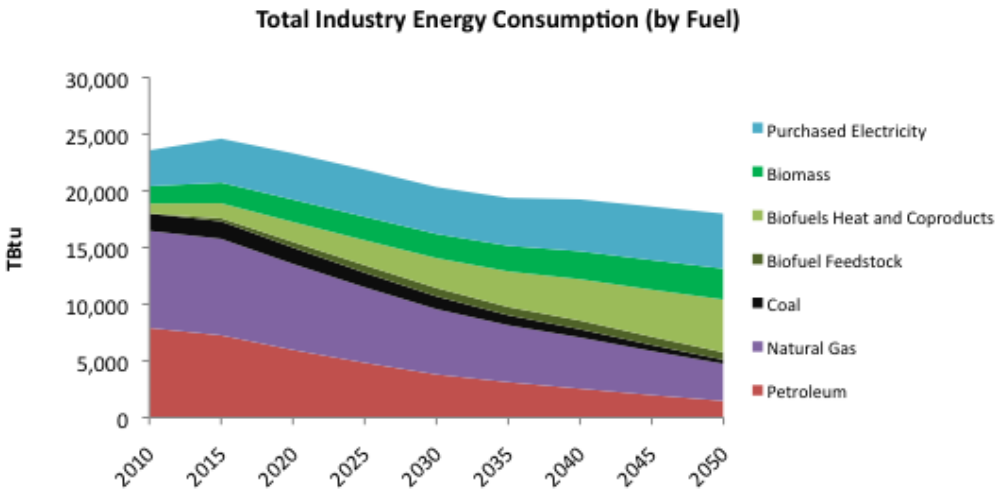
U.S. Low Carbon Scenarios (LCS) Tool – Example to illustrate concept

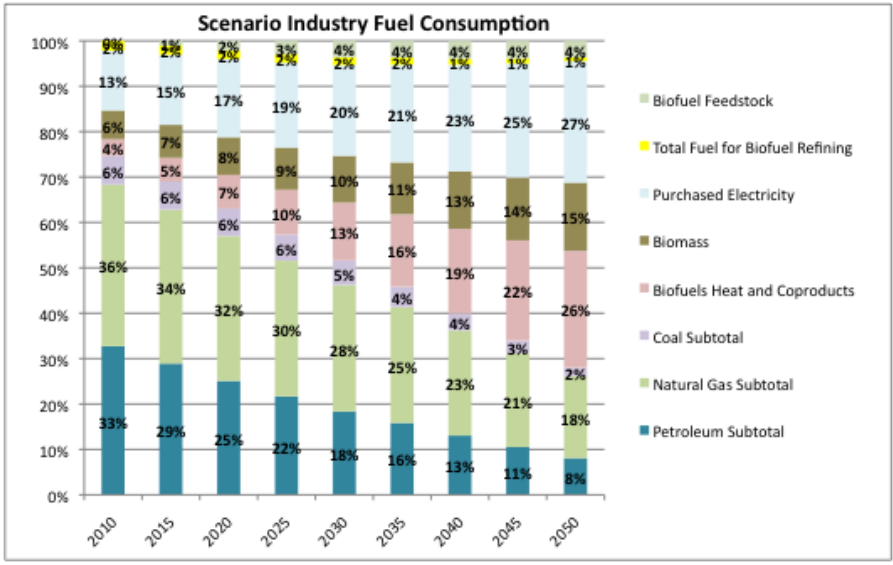
Bulk Chemical					Bulk Chemical	Fuel Consumption After Increase in EE, Fuel Switching, & CHP								
					TBtu	2010	2015	2020	2025	2030	2035	2040	2045	2050
2010 Fuel Mix		2030 Fuel M	2050 Fuel M	2030 BAU Fu	**Heat and Power**									
2.6%		0%	0%	2.5%	Residual Fuel Oil	68	50	30	13	0	0	0	0	0
0.8%		0%	0%	0.7%	Distillate Fuel Oil	20	14	9	4	0	0	0	0	0
2.4%		0%	0%	2.3%	Liquefied Petroleum Gases	63	46	28	12	0	0	0	0	0
0.0%		0%	0%	0.0%	Petroleum Coke	0	0	0	0	0	0	0	0	0
12.0%		5%	0%	11.4%	Other Petroleum	313	261	196	137	85	53	32	14	0
	17.8%	5%	0%	16.9%	Petroleum Subtotal	463	372	263	166	85	53	32	14	0
	60.1%	40%	40%	64.2%	Natural Gas	1,568	1,406	1,158	912	678	568	518	434	351
	3.9%	5%	0%	3.9%	Steam Coal	102	107	103	96	85	53	32	14	0
	0.0%	0%	0%	0.0%	Biomass	0	0	0	0	0	0	0	0	0
	18.3%	50%	60%	15.0%	Purchased Electricity	476	669	790	852	848	746	713	624	527
	100.0%	100%	100%	100.0%	Total Heat and Power	2,610	2,554	2,314	2,026	1,696	1,420	1,296	1,085	878
					Feedstock									
	52.2%	25%	15%	52.5%	Liquefied Petroleum Gas Feedstocks	1,923	1,644	1,282	936	619	467	384	284	198
	31.5%	25%	15%	34.1%	Petrochemical Feedstocks	1,161	1,082	938	784	619	467	384	284	198
	16.3%	20%	20%	13.4%	Natural Gas Feedstocks	599	623	602	561	496	415	384	324	264
	0.0%	30%	50%	0.0%	Biofuel Feedstock	0	271	498	662	743	726	768	730	661
	100.0%	100%	100%	100.0%	Total Feedstocks	3,684	3,620	3,320	2,943	2,478	2,076	1,920	1,622	1,322
					Total	**6,294**	**6,174**	**5,634**	**4,969**	**4,173**	**3,496**	**3,216**	**2,707**	**2,200**
					Before CHP Total	6,294	6,174	5,634	4,969	4,173	3,496	3,216	2,707	2,200

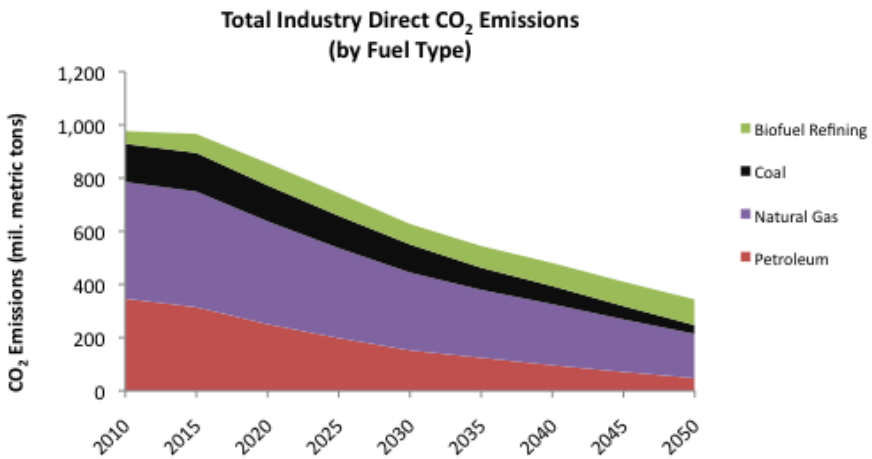
Snapshot of one subsector; user inputs fuel mix and efficiency targets for 2030 and 2050.

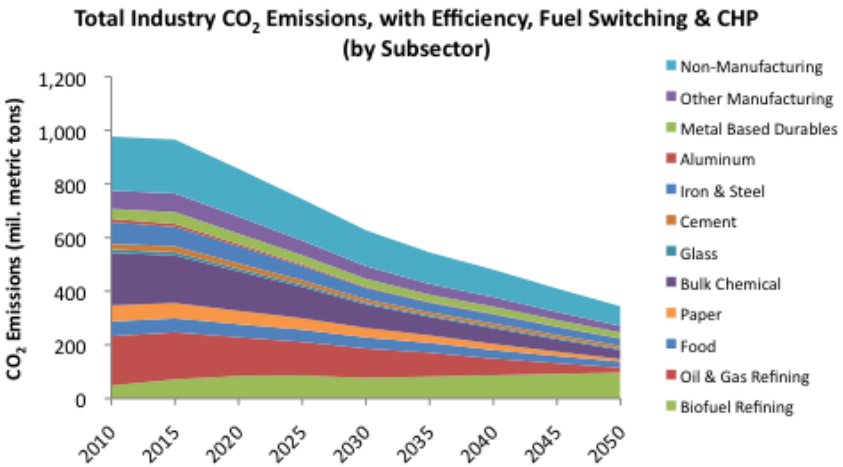
In the U.S.-based model, EIA's Annual Energy Outlook (AEO projections are used as the baseline; reductions are taken from the baseline. The tool characterizes all economic sectors (buildings, transport, industry and electric generation). Efficiency improvements beyond BAU reduce energy and emissions; fuel switching changes emissions.

U.S. Low Carbon Scenarios (LCS) model – Example to illustrate concept









Can we Connect Fuel Use to BC Emissions?

Industry:

- Fuel usage by fuel type by industrial subsector; and
- if possible further broken down by "region" ("region" defined as whatever might be available; unlikely to get to the "per plant" level, but might be able to get data at state, city or geographic level).

District Heating systems:

- Fuel usage by fuel type in district heating systems; and
- if possible statistics on district heating systems broken down by "region" ("region" defined as whatever might be available; unlikely to get to the number of buildings or building square footage served by individual district heating systems, but might be able to get data at state, city or geographic level); and if possible statistics on technology used, system size, vintage

Buildings (residential, commercial building separated by those served by district heating systems):

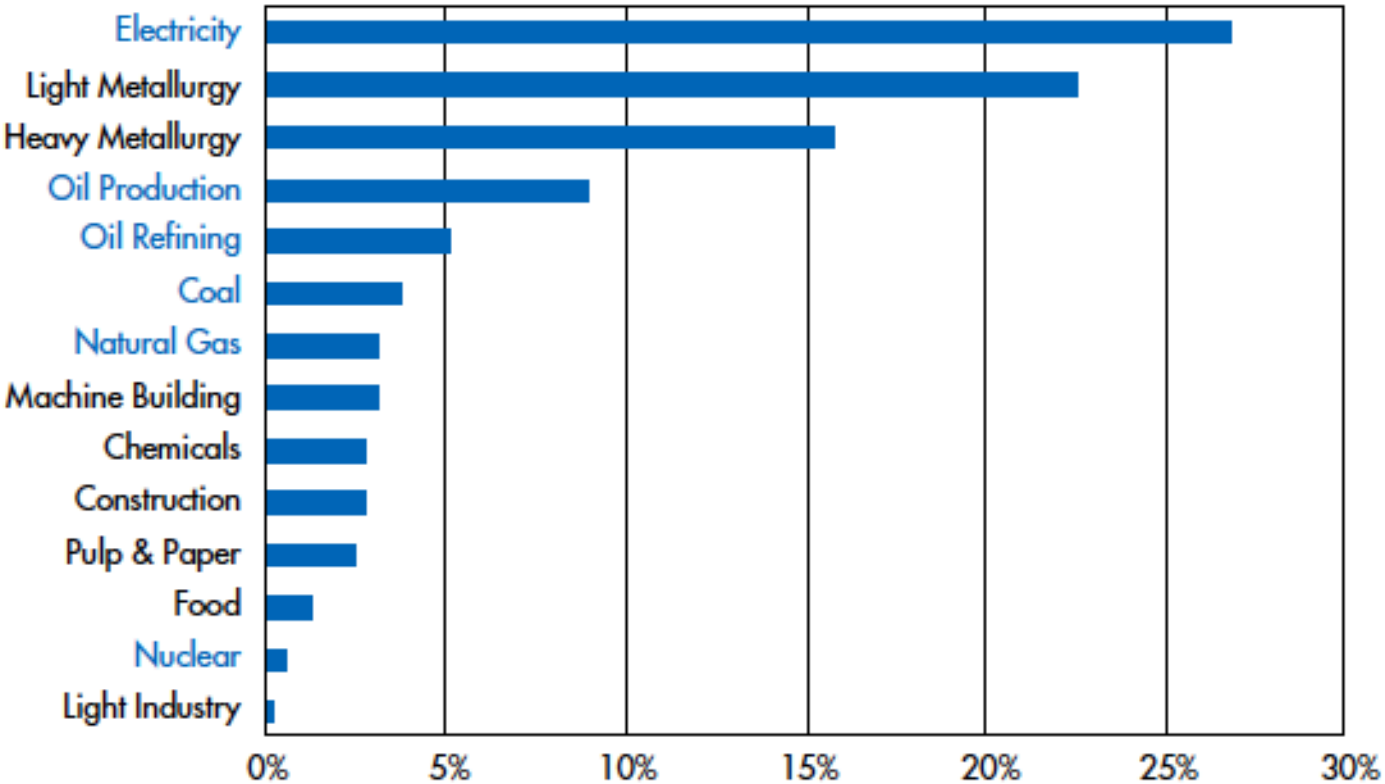
- Fuel usage by fuel type by building type; and
- if possible statistics on fuel usage by building type broken down by "region" ("region" defined as whatever might be available)

Combined Heat and Power:

- Fuel usage by CHP in industry and district heating systems; and
- if possible statistics on technology used, system size, vintage

Is it possible to characterize BC emissions to this level, by region, and connect with atmospheric transport?

Figure 23 Percentage Breakdown of Emissions* by Sector in 1999



** Emissions include: SOx, CO, NOx, Methane, VOCs and Particulate matter.*
Source: "State Report on the Ecology in 1999", Moscow 2000.

	Iron & Steel	Chemical & Petro-chemical	Non-Ferrous Metals	Non-metallic Minerals	Transport Equipment	Machinery	Mining & Quarrying	Food & Tobacco	Paper, Pulp & Print	Wood &Wood Products	Construction	Textiles & Leather	Non-Specified
Bituminous/ Anthracite		X		X		X		X		X	X	X	X
Lignite	X	X		X	X	X	X	X		X	X	X	
Coke/Tar		X		X	X	X	X				X		X
Coke Oven Gas	X			X		X				X			
Recovered Gasses	X	X											
Peat		X	X										
Natural Gas	X	X		X	X	X	X	X	X	X	X	X	X
Crude Oil	X				X			X			X		X
Refinery Gas	X	X											
LPG/Ethane	X	X		X	X	X	X	X	X	X	X		X
Gas/Diesel	X	X		X	X	X	X	X	X	X	X	X	X
Fuel oil	X	X		X	X	X	X	X	X	X	X	X	X
Petroleum Coke													X
Solid Biofuels	X	X			X	X	X	X	X	X	X		X
Waste/Other	X			X			X	X		X	X	X	X
Electricity	X	X	X	X	X	X	X	X	X	X	X	X	X
Heat	X	X		X	X	X	X	X	X	X	X	X	X

Table 1: 2008 Russian Industrial Fuel Consumption (IEA)

Demonstration of BC Emissions Reduction Technologies

Objective: Identify and assess BC emissions reductions. Examples of potential demonstration projects include:

- Use of cleaner fuel in centralized district heating plant
  - Availability of natural gas
  - Co-fire coal with biomass
- Improving combustion efficiency
  - Large-scale: burner design for DH plant
  - Small scale: wood stove catalyst deployment
- Emissions control devices
  - Example: PM control for coal- or oil-fired boiler
- Energy conservation practices
  - Replacement of long distance steam lines
- Deployment of combined heat & power

How do we leverage the science (What does a demonstration project look like)?

Types of Black Carbon (BC) Emissions

- Contained BC emissions sources - dominated by fossil fuel combustion (vehicles; industry; residences; etc.)
- Uncontained BC emissions sources - dominated by agriculture, forests, and savannah burning

Science

Global distribution of BC emissions

- By type
- By region
- By sector

Candidate Solutions

Assess the potential for energy & emissions reductions

- Efficiency
- Technology
- By sector, fuel, region

National Potential

Data,
Science,
Mitigation

Collaboration

Action

Demonstrate BC emissions reductions

- Technology
- Policy
- Public/Private Partnerships

Some Example Opportunities for Collaboration

1. Methodology and measurements of particulates (PM) - We would like information on the methods that are used to sample PM from both:
   - Point sources like smoke stacks or large generating engines, and
   - Transportation engines, like trucks.

2. Emission Factors - are BC or PM emissions factors (mass BC, PM/mass fuel) known for a variety of combustion sources?
   - Boilers used in district heating
   - CHP sources that use mazut as the fuel.

3. Compositional/Elemental analysis of different sources –
   - The amount of ash, sulfate, elemental carbon, volatile carbon in pm enables calculation of emissions factors from PM

4. Black Carbon Emission Factors - If PM composition information exists, what types of combustion sources and fuels were measured? In addition, are there any estimates black carbon as a function of either PM composition and/or fuel use. Our goal is to estimate black carbon emissions factors from the known PM emissions for a given fuel and combustion source.

5. PM Statistics - Is there published information on the statistics associated with the PM emissions? For instance, are there criteria in the regulations that repeated measurements of a source must meet a certain accuracy and precision?

Thank you!

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