Energy efficiency as a compliance pathway for industry environmental regulation in the United States

Nate Aden
Climate and Energy Program
World Resources Institute
10 G St, NE
Washington, DC 20002
USA
naden@wri.org

Keywords
boilers, combined heat and power (CHP), industrial energy saving, air pollutants, output-based emissions standards, maximum achievable control technology (MACT)

Abstract
Industry is the largest energy-using and greenhouse-gas-emitting sector in the U.S. in end-use terms. The Clean Air Act is the primary driver of federal laws governing industry emissions, though it has not, to date, been used directly for industrial greenhouse gas emissions. In 2012 the U.S. Environmental Protection Agency is expected to finalize boiler air toxic emissions standards that include an output-based efficiency compliance pathway. While the boiler standards are focused on reducing emissions of toxics including mercury, they also impact industry sector greenhouse gas emissions. Compliance assessment of these standards indicates that boiler efficiency improvements through installation of combined heat and power (CHP) technologies can reduce greenhouse emissions as much as fuel switching from coal to natural gas and more than utilization of end-of-pipe air toxic emission controls. Simultaneous installation of CHP with fuel switching to natural gas is the most beneficial boiler standard compliance pathway from a greenhouse gas emissions reduction perspective. The inclusion of output-based emissions standards in new Clean Air Act regulations can help the U.S. achieve its 17 percent greenhouse gas emissions reduction target by 2020.

Introduction
Energy use and greenhouse gas emissions from U.S. industry declined intermittently starting in the 1990's. This decline was related to structural change in the economy and resulting reductions of industrial activity as well as fuel switching and ongoing efficiency improvements. Industrial activity rebounded in 2010, bringing industry to 31 % of total U.S. energy use (32 out of 103 exajoules) and 30 % of U.S. greenhouse gas emissions (2.0 out of 6.8 billion tonnes CO_2e) (U.S. EIA, 2011; U.S. EPA, 2012a). Although transportation, residential, and commercial-sector energy use and greenhouse gas emissions have grown since 1980, industry remains the largest sector in end-use terms for both. Looking forward, both the U.S. Department of Energy and the International Energy Agency forecast that U.S. industry energy use will grow through 2035 at an average annual growth rate of 0.4 % (U.S. EIA, 2012; IEA, 2011). These demand growth forecasts underscore the importance of policies for improving efficiency and mitigating greenhouse gas emissions from U.S. industry.

In the wake of unsuccessful cap-and-trade legislation, the Clean Air Act (CAA) has emerged as the primary mechanism for federal energy-related environment and climate policy in the United States. This role was formalized in 2007 when the U.S. Supreme Court confirmed the authority of the Environmental Protection Agency (EPA) to regulate greenhouse gases (GHGs) as pollutants under the CAA in *Massachusetts v. EPA* (U.S. Supreme Court, 2007). Since the promulgation of the EPA's "endangerment finding," finalized GHG-emissions and fuel-efficiency standards for cars and trucks have been the most significant government policy for emissions mitigation (U.S. EPA, 2010a).

For stationary emissions sources, the CAA includes permitting and standards-based tools for GHG mitigation. The EPA reined in the scope of stationary-source GHG permitting with its proposed "tailoring rule," which sets a 100,000-ton-per-year CO_2e emissions threshold for identifying top emitters that would be subject to new permitting requirements.[1] Meanwhile on the standards side, the EPA released proposed New Source Performance Standards (NSPS) in March 2012 limiting CO_2 emissions from new fossil-fired electricity generation units under Section 111(b) of the CAA. The EPA published its electricity sector NSPS proposal in the Federal Register and is developing a final rule based on public comments received during the solicitation period, which closed on June 25, 2012.

The U.S. has debated and implemented three types of policies for improving energy efficiency and reducing emissions: market-based carbon tax or cap and trade programs (most recently for GHGs in the American Clean Energy and Security Act, or Waxman-Markey Bill, that passed the House of Representatives in 2009, but not the Senate), voluntary programs, and mandatory regulations. The majority of existing federal, industry-focused energy policies in the U.S. are voluntary. The Department of Energy's Better Buildings, Better Plants program (formerly known as Save Energy Now), Superior Energy Performance (part of the ISO 50001 energy management system standard), and the EPA's Energy Star Program for Industry are examples of voluntary U.S. industry energy policies. Beyond these voluntary programs, the CAA is the vehicle for new mandatory, industry-focused standards expected to be finalized in 2012. Whereas the proposed NSPS mitigate electric sector GHG emissions under Section 111 (b) of the CAA, Boiler Maximum Achievable Control Technology (MACT) standards are focused on limiting hazardous air pollutant emissions through Section 112 of the CAA.

Boiler MACT rules directly target industry energy users and are notable for their inclusion of output-based emissions standards (OBES) as an efficiency compliance pathway for achieving toxic emissions reductions. As described below, OBES allow energy efficiency to serve as a compliance pathway while also reducing costs. Although Boiler MACT standards regulate air toxic emissions, meeting compliance will impact U.S. boiler energy use and GHG emissions. The following three sections of this paper explore potential energy and carbon emissions impacts of the OBES compliance pathway for Boiler MACT implementation. The next section traces the development of Boiler MACT standards, describes the boilers that would be affected by new standards, and discusses the method and implementation of output-based emissions standards. The third section presents an assessment of the energy and carbon emissions impact of OBES under Boiler MACT. Finally, the concluding section discusses implications of the boiler type assessment and suggests areas for further research.

Boiler MACT Development

In 1990 the U.S. Congress amended the Clean Air Act to require EPA regulation of air toxics through Section 112. Under the amendment, the EPA was required to identify sources of 187 hazardous air pollutants (HAPs) including particulate matter (PM), hydrogen chloride (HCl), carbon monoxide (CO), mercury (Hg), and dioxin/furan emissions. Major sources of these pollutants are those that emit at least 10 tons per year of a single HAP or 25 tons per year in aggregate of several HAPs; facilities with emissions below these thresholds are considered "area sources". Once new and existing sources are identified, the EPA promulgates technology-based standards for reducing HAP emissions using maximum achievable control technology (MACT). Emissions limits established by the MACT approach are calculated based primarily on performance of the best-performing 12 % of existing sources—the so-called "MACT floor". This approach was established by the U.S. Congress in its bipartisan Clean Air Act amendments of 1990.

The EPA has developed Boiler MACT standards based on data showing that industrial, commercial, and institutional (ICI) boilers and process heaters are major sources of HAP emissions. Because major source boilers are used as sources of power and heat throughout industry, there has been extensive public interest in the development of these standards. The U.S. Council of Industrial Boiler Owners highlights boiler diversity when they write that "There are two identically designed, constructed sided by side, stoker fired boilers in Indiana burning the same fuel that have very different performance characteristics" (U.S. CIBO, 2003). The broad usage of boilers and their diversity help to explain the protracted development of Boiler MACT standards.

On December 23, 2011, the EPA published proposed revisions to previous Boiler MACT standards that had been promulgated on March 21, 2011. Part of the widespread interest in Boiler MACT rules comes from the simultaneous promulgation on March 21, 2011 of three related standards on small (area source) boilers and boilers that use solid waste as fuel. The March 2011 standards were published in response to a court order from the D.C. Circuit Court of Appeals. The original Boiler MACT rule was promulgated on September 13, 2004, only to be vacated by the court and remanded to the EPA in 2007. Over the next three years the EPA engaged in a thorough reconsideration of the rule and related public comments that resulted in its June 2010 Proposed Rule. Industry submitted extensive comments on the 2010 Proposed Boiler MACT rules on the grounds that they were unreasonably stringent (McCarthy, 2012).

The Clean Air Act requires that MACT emissions levels be based solely on performance of existing facilities, with no consideration of the cost or economic impacts thereof. The EPA Administrator is only allowed to consider cost, health, energy, and environmental factors when standards go beyond the MACT floor (McCarthy, 2012). Nonetheless, the reconsideration rule released in December 2011 is significantly less stringent than the June 2010 proposal. Three key changes in the reconsideration rule were the addition of new subcategories for boiler technologies and standards, the easing of HAP emissions limits for existing subcategories, and the elimination of dioxin/furan emissions limits in favor of work practice standards. In addition to reducing potential litigation risks, these regulatory adjustments have been used by the EPA to address cost and implementation concerns.

Industry continues to express reservations about specific aspects of the Boiler MACT rules. For example, a coalition of U.S.

1. Previous analysis indicates that permitting requirements are not expected to yield significant GHG emissions reductions beyond business-as-usual projections (Bianco and Litz, 2010).

Table 1: Top Ten Subsectors in Terms of Major Source Boiler Units and Boiler Capacity.

	NAICS Code	Subsector Description	Number of Major Source Boilers	Aggregate Capacity (mmBtu/hr)
1	324	Petroleum & coal product mfg	2,099	246,070
2	325	Chemicals mfg	1,250	146,944
3	336	Transportation equipment mfg	558	28,661
4	322	Paper mfg	533	160,789
5	221	Utilities	445	84,176
6	331	Primary metal mfg	437	47,092
7	311	Food mfg	435	59,036
8	928	National security & international	414	13,309
9	321	Wood product mfg	382	28,287
10	326	Plastics & rubber products mfg	278	13,816
Total for all subsectors			8,300	1,718,779

Source: EPA ICR database- "Boiler Emissions Database (version 7).mdb", (U.S. EPA, 2011).

industry associations led by the American Forest and Paper Association submitted more than 100 pages of comments on February 21, 2012 (AFPA, 2012). The industry coalition agreed with the inclusion of output-based emissions standards, but expressed concern about the timing and scope of the standards as well as subsector technology-specific provisions. Within the steel subsector manufacturers are concerned that Boiler MACT standards could force integrated steel mills to flare coke oven gas that otherwise would be used to fuel plant boilers because of its treatment of coke oven process gases (AFPA, 2012). The protracted development of Boiler MACT rules exemplifies the technical and political complexity of regulating industry emissions in the United States.

Once the Boiler MACT rule is finalized, existing major source boilers will have three years to comply through adherence to emissions limits or work practice standards. All major source boilers would also be required to perform a one-time energy assessment to identify cost-effective energy conservation measures. There are three criteria for determining whether major source boilers are subject to emissions limits or work practice standards: boilers with capacity above 10 million Btu per hour, that are used more than 10 % of the year, and that burn fuels other than natural gas or refinery gas would be subject to emissions limits. Smaller, limited-use, or gas-fired boilers can comply with Boiler MACT standards through work practice standards. As a flexible alternative to numeric emissions limits, work practice standards require annual tune-ups with submission of informational reports back to the EPA. Some categories, including limited use boilers burning liquid fuels, would qualify for work practice standards through tune-ups every two years.

AFFECTED BOILERS

To inform development of MACT floor levels, the EPA compiled emissions and other data from existing U.S. boilers in a publically-available Information Collection Request (ICR) database. The Boiler MACT ICR database includes an inventory of 8,300 major source boilers throughout the U.S. The EPA has separately indicated that the U.S. has approximately 14,000 major source industrial, commercial, and institutional boilers, and more than 1.5 million boilers including electrical generating units and area source boilers (EPA, 2011b). In contrast, a contracted 2005 Oak Ridge National Laboratory Report estimated that the U.S. has 163,000 industrial and commercial boilers, of which 28 % had a unit capacity greater than 10 million Btu per hour (Energy and Environmental Analysis, Inc., 2005). Due to the ubiquity of boilers and the changing fortunes of industry, there is no definitive count of U.S. boiler units. While the ICR database has limited scope and is continually updated, it provides useful indicators on a sample of U.S. major source boilers; none of the ICR data suggest any systematic bias in the sample. Table 1 displays the number of listed boilers and their aggregate capacity for the ten subsectors with the most major source boilers.[2]

Manufacturing accounts for 81 % of listed U.S. major source ICI boilers. Oil refineries and coal processing operations are the largest subsector – accounting for 25 % of major source boiler units and 14 % of major source boiler capacity. Utilities are the most boiler-intensive non-manufacturing subsector in the ICR database; the importance of boilers for utilities is not surprising given that utilities provide electric power, natural gas, steam supply, water supply, and sewage removal.

The ICR database's combination of capacity, utilization, and fuel data enables the calculation of annual energy use by fuel for each boiler. Figure 1 shows the breakdown of aggregated annual energy use for listed major source boilers by fuel type.[3] Natural gas is the most prevalent fuel, followed by coal and biomass. The portion of listed major source boilers that use natural gas is 74% – this is more than the aggregate energy use portion due to the overall lower design capacity and utilization of gas-fired units.

BOILER MACT COMPLIANCE

High gas usage among major source boilers limits the impact of Boiler MACT standards in so far as gas-fired boilers can comply through work practice standards. Aside from gas-fired units, 88 % of boilers would be able to comply with Boiler MACT through work practice standards (EPA, 2011b). The EPA has estimated that major source boilers will achieve a 1 % improvement in efficiency by enacting work practice standards (EPA, 2011a). If they are not already in compliance with Boiler MACT standards, the estimated 12 % of major source boilers

2. The North American Industry Classification System (NAICS) is used by companies and governments to classify business establishments according to type of economic activity (process of production) in Canada, Mexico and the United States.

3. The fuel categories in this figure are aggregated. "Biomass" includes wet biomass, dry biomass, and bagasse; "natural gas" covers the EPA "Gas 1" and "Gas 1 – Metal Furnaces" categories; and heavy liquids and light liquids comprise the "Oil" category.

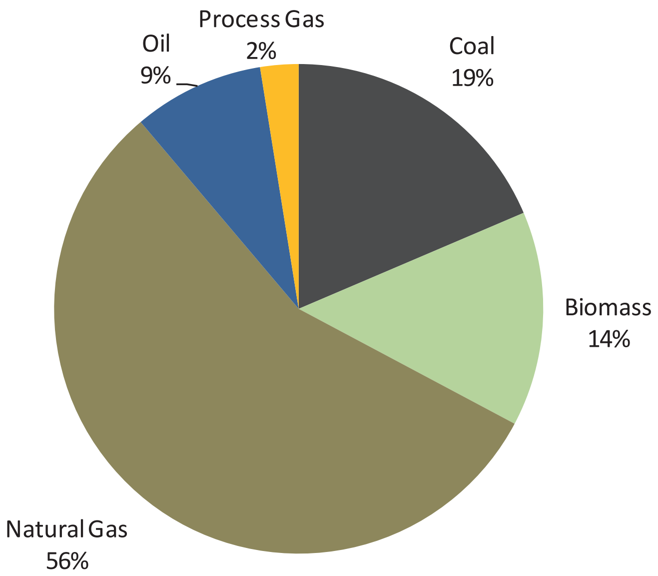

Figure 1: U.S. Major Source Boiler Energy Use by Fuel Type. Source: EPA ICR database – "Boiler Emissions Database (version 7).mdb", (U.S. EPA, 2011).

subject to emissions limits have three basic options for continuing to use their boilers:

- Switching input fuels to natural gas or refinery gas,
- Retrofitting existing affected boilers with pollution control equipment, or
- Improving boiler efficiency enough to comply with alternate output-based emissions standards.

Historically low U.S. natural gas prices, rising coal prices, and low capital costs for natural gas fired boilers suggest that fuel switching will be the preferred option for most existing units (Cuttica, 2012). The energy and GHG emissions impact of Boiler MACT standards depends on the compliance pathway used by affected facilities. Fuel switching from coal or oil to natural gas will reduce combustion-related carbon emissions and is likely to lower boiler energy use as a result of the comparatively high efficiency of new gas-fired units. In its assessment of expected energy impacts, the EPA estimates that affected boiler operation of pollution control devices, such as wet scrubbers, electrostatic precipitators, and fabric filters, would require an additional 1.4 billion kWh per year of electricity use (U.S. EPA, 2011a). As such the pollution control retrofit compliance option is likely to cause increased energy use and carbon emissions due to associated increases in parasitic power usage. On the other hand, facilities that use increased efficiency to comply with OBES are likely to reduce both energy use and emissions.

Boilers subject to MACT emissions limits are generally larger than facilities that can achieve compliance through work practice standards. Figure 2 shows a scatter plot of major source boilers included in the ICR database ordered by their design capacity. The density of data points makes the overall distribution appear as a solid line, but the inset box of the 100 largest capacity boilers shows that each unit is displayed as a single marker in the figure. The section in the lower left of the overall figure labelled "smaller boilers" illustrates the 1,600 boilers that have a design capacity of less than 10 million Btu per hour and therefore can comply through work practice standards. The largest, outlying boiler in the ICR database has a design capacity of more than 3,700 million Btu per hour; it is a coal-fired unit located at a coal mining and processing facility in Wyoming.

Within the ICR dataset, 21 % of listed units would be subject to emissions limits. Figure 3 illustrates the geographic distribution of listed major source boilers that would be subject to emissions limits. The boiler markers in the map are scaled to design capacity and shaded according to whether they have air pollution control equipment installed.

The boilers shown in the map in Figure 3 are a small and influential subset of the more than 1.5 million boilers in the U.S. (U.S. EPA, 2011b). According to the three criteria outlined above, the 1,752 boilers displayed in the map would be subject to emissions limits under the December 2011 revised Boiler MACT language; this amounts to 21 % of the major source boilers listed in the ICR database. The entire fleet of industrial, commercial, and institutional boilers is estimated to account for 20 % of U.S. greenhouse gas emissions (Burtraw, et al., 2011). The impact of Boiler MACT on these GHG emissions will depend on the final rule's scope and stringency, the extent to which existing boilers are already in compliance, and the compliance pathway selected by existing units with excessive HAP emissions. Two key points from the map are that boilers are not evenly distributed across the U.S. and that the majority of listed boilers subject to emissions limits already have hazardous air pollution control equipment installed. Indiana is the state with the most installed boiler capacity that would be subject to emissions limits, and the South is the census region with the most affected boilers, followed by the Midwest. The cluster of large boilers in Maine may help to explain why the Senator from that state, Susan Collins, introduced an unsuccessful amendment to block the Boiler MACT rule in March 2012 (SA 1660 to S.1813). The high utilization of pollution control equipment among affected boilers – 62 % currently have devices installed – suggests that many units may already have emissions below MACT limits; current ICR data indicate the presence and type of HAP APCD rather than actual utilization or effectiveness.

OUTPUT-BASED EMISSIONS STANDARDS

Output-based emissions standards recognize the pollution prevention benefits of efficient energy generation and provide compliance flexibility to regulated combustion sources. In contrast with commonly-used input based emissions standards, OBES relate emissions to the productive output of a given process including electrical, thermal, and mechanical energy. OBES use measurement units such as kg emission/MWh of electricity generated or kg emission/MJ of steam generated, rather than heat input (kg emission/MJ input) or pollutant concentration (ppm). By focusing on useful energy output, OBES require specific levels of performance rather than any particular technology and they do not increase emissions. OBES account for the emissions benefits of efficiency measures such as increased combustion efficiency, increased turbine efficiency, recovery of useful heat, and reduction of parasitic losses associated with operation of the affected unit (e.g., operation of fans, pumps, motors) (U.S. EPA, 2004). In its Best Available Control Technology (BACT) guidance document for greenhouse gases, the EPA has identified more than a dozen efficiency improvement measures for ICI boilers aside from CHP. Those measures are

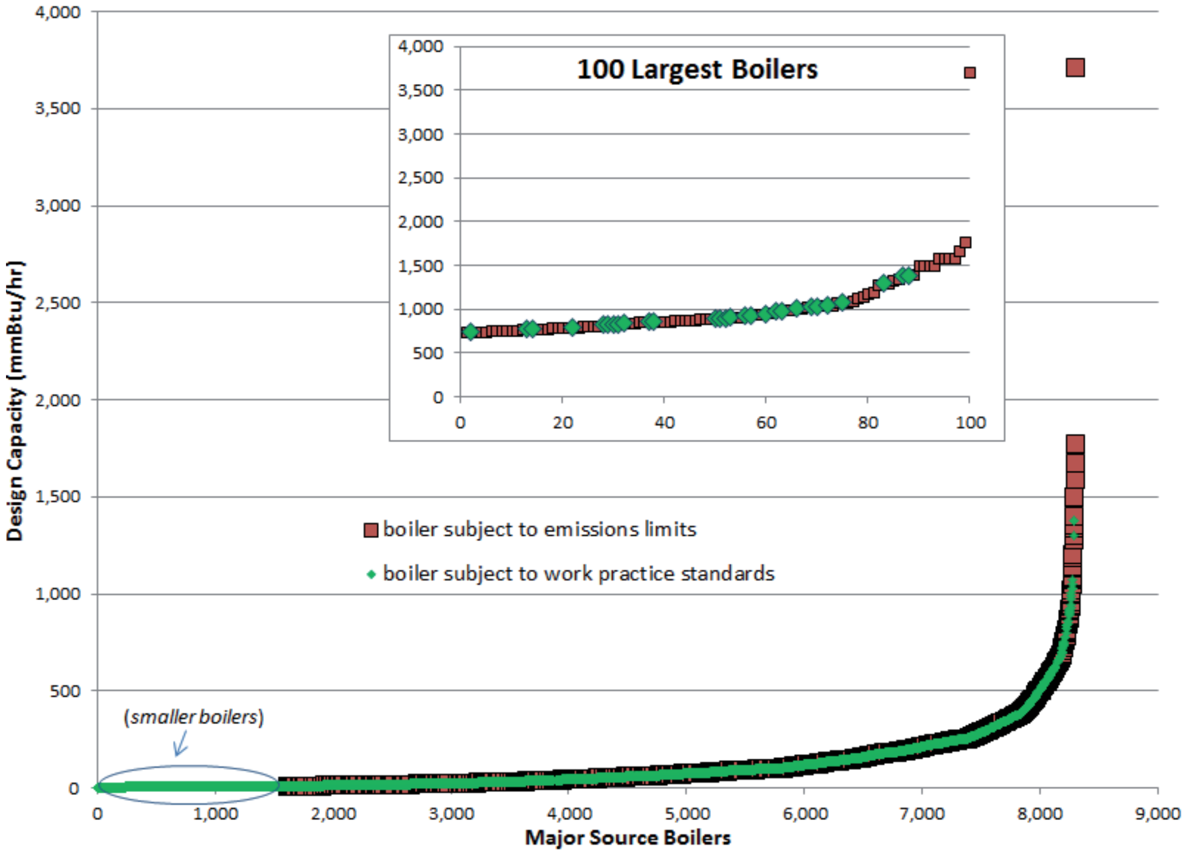

Figure 2: Capacity of U.S. Major Source Boilers. Source: EPA ICR database- "Boiler Emissions Database (version 7).mdb", (U.S. EPA, 2011).

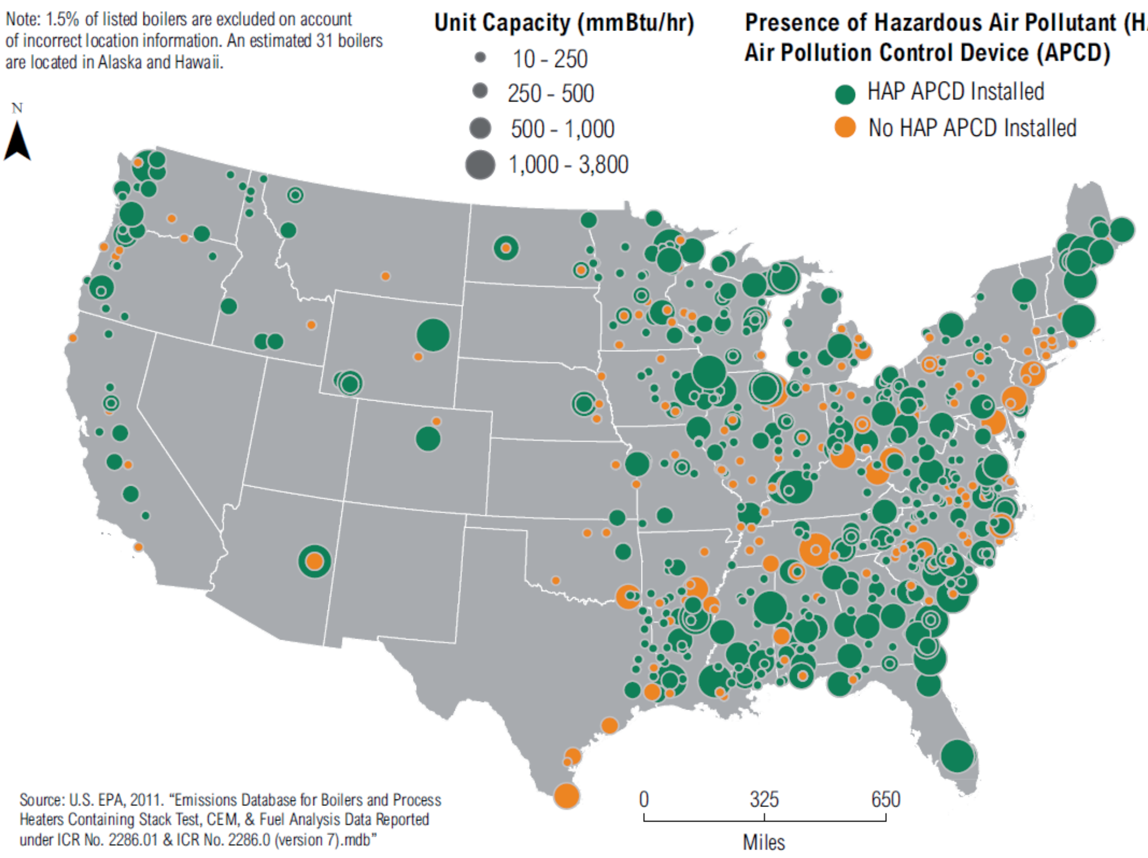

Figure 3: Major Source Boilers and Process Heaters Subject to Boiler MACT Emissions Limits.

oriented toward GHG permitting; they can also move units toward OBES compliance under the air toxics rule and raise efficiency by up to 40 % (U.S. EPA, 2010b). Because combined heat and power technology increases efficiency, use of output-based emissions standards can foster the introduction of CHP.

The output-based approach to setting emissions standards offers multiple benefits in comparison with other policy and technical approaches. Five key benefits of output-based emissions standards are incentive for pollution prevention, multi-pollutant emissions reductions, reduced fuel use, avoidance of upstream environmental impacts of fuel production and delivery, and lower compliance costs (U.S. EPA, 2004). From a policy perspective, research has found that OBES are more cost-effective and result in more total carbon abatement than other U.S. industry programs including energy portfolio standards, the Superior Energy Performance Program, tax-lien financing, and industrial motor rebates (Brown et al., 2011).

Several studies have found large potential for emissions mitigation in U.S. industry through expanded CHP utilization. In the chemicals and pulp and paper subsectors, Khrushch et al. found 32 GW and 18 GW of potential, respectively, for a total carbon emissions reduction of 44 % for those subsectors (Khrushch et al., 1999). In his analysis of U.S. industry in 2020, Lemar projected an advanced scenario with 76 GW of additional CHP units with resulting carbon emissions reductions of 40 MtC (Lemar PL, 2001). And finally in their assessment of industrial CHP technical potential by state Hedman and Hampson calculated a total of 64 GW of remaining potential for U.S. industry (Hedman and Hampson, 2010). The large potential for additional CHP usage in the U.S. is confirmed by international comparisons – Poland's CHP system accounts for twice the share of total national electricity production and Denmark's CHP system generates more than six times the portion of U.S. electricity from CHP (IEA, 2008). In line with these assessments, the U.S. Department of Energy's SEEAction program established a national CHP target of 40 GW of newly-installed, cost-effective capacity by 2020 (U.S. DOE, 2012).

Within the U.S., OBES have been used at the state and federal level since the 1990's. Nine states use OBES for setting conventional emissions limits and emissions performance standards. On a federal level the Clean Air Act also uses an OBES approach in its new source performance standards (NSPS), national emissions standards for hazardous air pollutants (NESHAP), and for automotive emissions standards, which are expressed in grams/mile. Furthermore, the use of output-based emissions standards to promote efficiency has been endorsed by advocacy groups including the Natural Resources Defense Council, the American Council for an Energy Efficient Economy, and the Energy Foundation (EPA, 2004).

The only difference between input and output-based emissions standards is that the latter include the efficiency with which useful energy is produced or work is performed. For ICI boilers, input-based emissions standards can be converted to output-based emissions standards using the following equation:

$$OBES\ (\frac{kg}{MJ} heat\ output) = \frac{(\text{input based emissions limit}(\frac{\text{kg}}{\text{MJ}}\text{ heat input}))}{(\text{benchmark steam generator efficiency}(\%))}$$

For CHP units, there are two methods for calculating OBES: the equivalency approach and the avoided emissions approach. In the equivalency approach the thermal output of the steam is added to the electric output (in identical units) to calculate the compliance denominator. The second approach uses the amount of avoided emissions that a conventional boiler system would otherwise emit had it provided the same thermal output (i.e., purchasing electricity from the grid and generating steam onsite) to calculate the emissions actually avoided by the CHP system. The avoided emissions approach may be more accurate for a particular facility, but it also requires more data. Boiler MACT uses the equivalency approach to calculate output based emissions standards.

Assessment of OBES Impact under Boiler MACT

The ICR database provides a limited basis for assessing the energy and emissions impact of the output-based emissions standards compliance pathway under Boiler MACT. It lacks detailed boiler data (for example, on steam pressure and temperature, power-to-heat ratios, facility load duration curves, boiler efficiency, availability of net metering, local electricity and steam prices, and prior installation of CHP technology among existing boilers) required to complete a bottom-up evaluation of which boilers could potentially comply with MACT standards through efficiency improvements and installation of CHP. In addition to having limited boiler details, the ICR database lacks the comprehensive coverage needed to assess the aggregate impact of Boiler MACT rules. However, the database does include boiler capacity, utilization, and fuel data that can serve as the basis for an emissions assessment of average boiler types and potential compliance pathways.

Based on data from the ICR database and the academic literature, this study uses four boiler types to compare the carbon emissions impact of efficiency-improvement versus fuel-switching compliance pathways for units subject to Boiler MACT emissions limits. The first average boiler type shows the current carbon emissions from affected coal-fired boilers by combining ICR energy-use data with 2010 U.S. carbon emissions coefficients (U.S. EPA, 2012a). The average coal-fired boiler type does not assume current compliance or lack thereof from installed pollution control technology or CHP; rather, it calculates the carbon dioxide emissions related to average coal-fired major source boilers subject to emissions as described by the ICR database. The second type examines the impact of switching the average coal-fired boiler to natural gas ceteris paribus, i.e. without changing the design capacity, unit efficiency, or annual hours of operation. This fuel-switching boiler type misses important information on local fuel prices, equipment configurations, and facility loads, but the point is to perform an empirically-based hypothetical assessment for comparative purposes.

The "Average Coal CHP Boiler" type uses an exergy approach to estimate the carbon emissions savings from installing CHP on an average coal-fired boiler subject to emissions limits, again with all else being equal. Exergy is the amount of available energy to perform work in a system; in this case exergy is calculated assuming 45 % efficiency for existing units in combination with central station electricity (efficiency levels are based on data from Shipley et al., 2008). Assuming that the

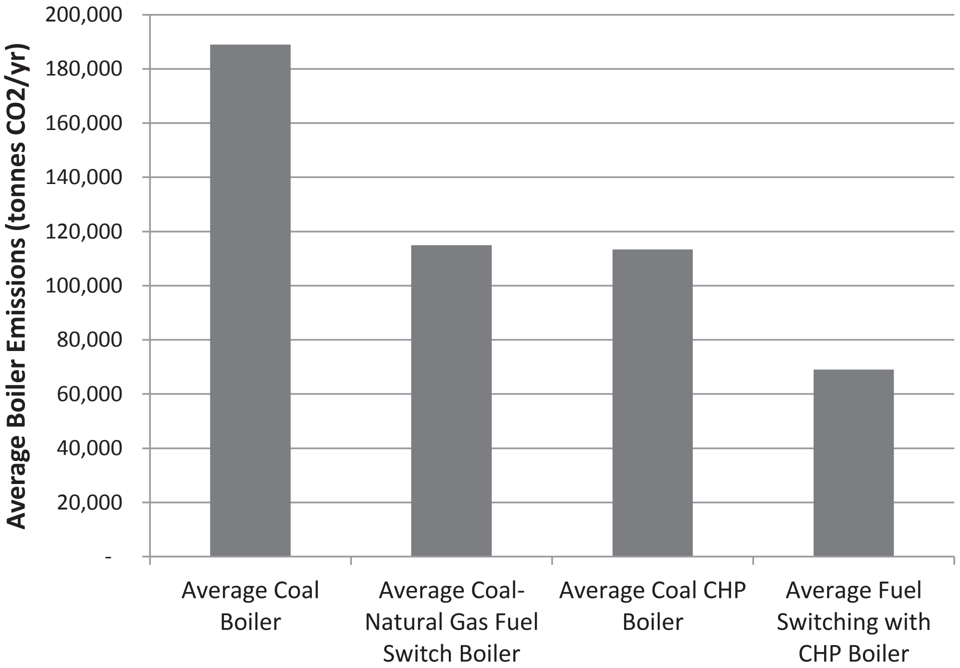

Figure 4: Annual Carbon Emissions for Average U.S. Major Source Boilers Subject to Emissions Limits.

boiler is replaced with a 75 % efficient CHP unit, the amount of input energy is then recalculated and carbon emissions are assessed as described above. This third type over-simplifies existing boiler efficiency and exaggerates the feasibility of installing CHP technology in all units – it is not intended to be a simulation of expected boiler CHP adoption so much as a hypothetical assessment of carbon emissions mitigation potential. Finally, the fourth type combines the second and third types to calculate the carbon emissions resulting from switching an average coal-fired boiler to CHP and natural gas without any other changes. Figure 4 shows the average annual carbon dioxide emissions for each of the boiler types.

The first point from the assessment results is that coal boiler conversion to CHP would reduce carbon emissions by roughly the same amount as switching from coal to natural gas. The "Average Coal CHP Boiler" type yields 40 % carbon dioxide emissions savings compared to calculated average coal boiler emissions, while the "Average Coal-Natural Gas Fuel Switch Boiler" type yields 39 % savings. If the fuel switch is accompanied by increased boiler efficiency then replacing coal with natural gas results in greater GHG emissions mitigation than stand-alone CHP retrofitting. This is further demonstrated with the "Average Fuel Switching with CHP Boiler" type, which reduces carbon dioxide emissions by 63 % compared with the average coal-fired boiler. The final type underscores the important point that these Boiler MACT compliance pathways are not exclusive and in fact can be complementary. The combined fuel-switching with CHP boiler type includes many benefits including reduced facility exposure to potential future gas price increases, HAP and GHG emissions reduction, improved overall efficiency, reliability, reduced electricity transmission congestion, and potential revenue related to surplus electricity sales. Insofar as facilities use CHP and other efficiency improvements or fuel switching to natural gas to comply with Boiler MACT standards, they can help the U.S. to move toward President Obama's Copenhagen pledge to reduce GHG emissions 17 percent below 2005 levels by 2020. As we look at the deeper emission reductions needed beyond 2020, the large capital requirements of CHP installation suggest that a large-scale shift in this direction may present infrastructure lock-in concerns that are inherent in manufacturing investment.

Unfortunately, the impact of OBES under Boiler MACT will likely be much smaller than those suggested by the "Average Coal CHP Boiler" type because of cost concerns, site space constraints, current HAP emissions compliance through installed pollution control technologies, the inability of many affected units to fully comply with emissions limits through CHP installation, and technical obstacles to large-scale CHP adoption given facility loads. In a contracted report, the Industrial Technologies Program of the U.S. Department of Energy conducted a bottom-up assessment and found that "heat recovery is not economical or even possible in many cases" (U.S. DOE, 2008). While the OBES will not result in total CHP adoption, they will help to incentivize facility-specific consideration of CHP and other efficiency improvement measures. Furthermore, the large savings associated with the last boiler type suggest that the OBES compliance pathway under Boiler MACT can help achieve GHG emissions mitigation by spurring facilities to adopt CHP while switching to natural gas.

Conclusions and Further Research

Over its twenty years of development, the yet-to-be-finalized Boiler MACT rule has evolved into a group of standards with mixed impact on boiler energy use and GHG emissions. Output-based emissions standards have the potential to beneficially reduce energy use and related emissions. This analysis shows that coal-fired facilities that pursue an OBES compliance pathway with installation of CHP technology could achieve emissions reductions comparable to facilities that comply through fuel switching to natural gas and exceeding those that comply through use of end-of-pipe pollution control devices. These findings suggest that efficiency can play a central role in mitigating U.S. industry emissions and achieving President Obama's target of reducing emissions 17 % below 2005 levels by 2020.

Output-based emissions standards have been promoted by environmental advocatess and industry associations as an acceptable way to regulate U.S. industry emissions (U.S. EPA, 2004; AFPA, 2012). Furthermore, academic analysis has found that OBES bring about more carbon abatement than other industry energy efficiency policies and have a higher social benefit-cost ratio (Brown et al., 2011). Within the framework of Boiler MACT standards, this analysis suggests that OBES can generate greater benefits than other compliance pathways.

Given the limitations of the existing data, this paper provided a theoretical assessment of output-based emissions standards for mitigating U.S. industry emissions through environmental regulation. Further research in four areas could help to facilitate U.S. industry emissions mitigation and development of integrated U.S. climate policy. On a general level, it would be useful to understand the interplay between efficiency and fuel switching in reducing industry GHG emissions. In terms of the policies discussed in this paper, an ex post assessment of the pathways used to achieve Boiler MACT compliance would assist in modeling expected impacts and guiding implementation. Likewise, an assessment of the actual impacts of OBES as deployed in Boiler MACT and other standards could validate the optimistic consensus between environmental groups, academics, and industry associations. Finally, research on the comparative efficacy of a regulatory approaches (as, for example, pursued by the Clean Air Act in the U.S.) for achieving deep long-term emissions reductions would usefully inform the development of more robust national and international climate policy.

References

American Forest and Paper Association. 2012. Comments on Docket ID No. EPA–HQ–OAR–2002-0058, National Emission Standards for Hazardous Air Pollutants for Major Sources: Industrial, Commercial, and Institutional Boilers and Process Heaters (76 Federal Register 80598, December 23, 2011). Online at: http://www.afandpa.org/temp/AFPA_et_al_Boiler_MACT_Comments_2_21_12.pdf (April 2012).

Bianco NM, Litz FT. 2010. Reducing Greenhouse Gas Emissions in the United States Using Existing Federal Authorities and State Action. WRI Report. Washington, DC: World Resources Institute.

Brown MA, Jackson R, Cox M, Cortes R, Deitchman B, and Lapsa MV. 2011. Making Industry Part of the Climate Solution: Policy Options to Promote Energy Efficiency. Oak Ridge National Laboratory Report 2010/78. Online at: http://info.ornl.gov/sites/publications/Files/Pub23821.pdf (April 2012).

Burtraw D, Fraas AG, Richardson N. 2011.Greenhouse Gas Regulation under the Clean Air Act: A Guide for Economists. RFF DP 11-08. Washington, DC: Resources for the Future.

Cuttica J. 2012. "U.S. Department of Energy Boiler MACT Technical Assistance Pilot Program," Presentation to the Ohio Public Utility Commission. Online at: http://www.puco.ohio.gov/puco/assets/File/Cuttica%20Ohio%20PUC%20Workshop%20March%202012%20Rev%207.pdf (April, 2012)

Energy and Environmental Analysis, Inc. 2005. "Characterization of the U.S. Industrial /Commercial Boiler Population," Oak Ridge National Laboratory Report, May 2005.

Hedman B, Hampson A. (ICF International). 2010. 'Effect of a 30 Percent Investment Tax Credit on the Economic Market Potential for Combined Heat and Power.' Online at: http://www.uschpa.org/files/public/USCHPA%20WADE_ITC_Report_FINAL%20v4.pdf (April 2012).

International Energy Agency. 2008. Combined Heat and Power—Evaluating the Benefits of Greater Global Investment. Paris: IEA.

International Energy Agency. 2011. World Energy Outlook 2011. Paris: IEA.

Khrushch M, Worrell E, Price L, Martin N, Einstein D. 1999. "Carbon Emissions Reduction Potential in the US Chemicals and Pulp and Paper Industries by Applying CHP Technologies," Proceedings of the 1999 ACEEE Summer Study on Energy Efficiency in Industry. (Also published as LBNL Report number LBNL-43739.)

Lemar PL Jr. 2001."The potential impact of policies to promote combined heat and power in US industry," Energy Policy, 29 (2001) 1243–1254.

McCarthy JE. 2012. EPA's Boiler MACT: Controlling Emissions of Hazardous Air Pollutants. CRS Report R41459. Washington, DC: Congressional Research Service.

Shipley A, Hampson A, Hedman B, Garland P, and Bautista P. 2008. Combined Heat and Power: Effective Energy Solutions for a Sustainable Future. Oak Ridge National Laboratory Report ORNL/TM-2008/224.

U.S. Council of Industrial Boiler Owners (CIBO). 2003. Energy Efficiency & Industrial Boiler Efficiency: An Industry Perspective. CIBO White Paper. Online at: http://cibo.org/pubs/whitepaper1.pdf (April, 2012).

U.S. DOE (ITP). 2008. Waste Heat Recovery: Technology and Opportunities in U.S. Industry. Washington, DC: Department of Energy.

U.S. DOE. 2012. SEEAction Industrial Energy Efficiency and Combined Heat and Power Working Group. Online at: http://www1.eere.energy.gov/seeaction/combined_heat_power.html (June, 2012).

U.S. EIA. 2011. Annual Energy Review 2011. Washington, DC: Department of Energy.

U.S. EIA. 2012. Annual Energy Outlook Early Release 2012. Washington, DC: Department of Energy.

U.S. EPA. 2004. "Output-Based Regulations: A Handbook for Air Regulators." Washington, DC: EPA.

U.S. EPA. 2010a. "EPA and NHTSA Finalize Historic National Program to Reduce Greenhouse Gases and Improve Fuel Economy for Cars and Trucks," EPA Regulatory Announcement EPA-420-F-10-014. Washington, DC: EPA.

U.S. EPA. 2010b. Available and Emerging Technologies for Reducing Greenhouse Gas Emissions from Industrial, Commercial, and Institutional Boilers. Washington, DC: EPA.

U.S. EPA. 2011a. "National Emission Standards for Hazardous Air Pollutants for Major Sources: Industrial, Commercial, and Institutional Boilers and Process Heaters," Federal Register / Vol. 76, No. 247 / Friday, December 23, 2011 / Proposed Rules. Washington, DC: Government Printing Office. Online at: http://www.epa.gov/ttn/atw/boiler/boilerpg.html (April, 2012).

U.S. EPA. 2011b. "EPA's Air Toxics Standards, Major and Area Source Boilers and Certain Incinerators, Overview of Changes and Impacts," EPA Fact Sheet. Washington, DC: EPA.

U.S. EPA. 2012a. 2012 U.S. Greenhouse Gas Inventory Report. Washington, DC: EPA.

U.S. EPA. 2012b. "Prevention of Significant Deterioration and Title V Greenhouse Gas Tailoring Rule Step 3, GHG Plantwide Applicability Limitations and GHG Synthetic Minor Limitations," U.S. Federal Register, Vol. 77, No. 46 (March 8, 2012), Proposed Rules, p.14226. Online at: http://www.gpo.gov/fdsys/pkg/FR-2012-03-08/pdf/2012-5431.pdf.

U.S. Supreme Court. 2007. Massachusetts et al. v. Environmental Protection Agency et al. Online at: http://www.supremecourt.gov/opinions/06pdf/05-1120.pdf (April, 2012).

Acknowledgements

The author thanks Kevin Kennedy and James Bradbury for their review comments and Kristin Meek for her research assistance in producing the map for this paper.