An Assessment of the Feasibility of Retrofits for the Mercury and Air Toxics Standards Rule

U.S. Environmental Protection Agency
Office of Air and Radiation

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Abbreviations and Glossary

ACI	Activated Carbon Injection – controls mercury
APC	Air Pollution Control(s) – ACI, DSI, FGD, etc
CAIR	Clean Air Interstate Rule
CSAPR	Cross State Air Pollution Rule
DSI	Dry Sorbent Injection – controls acid gasses
ESP	Electrostatic Precipitator – controls particulates
FF	Fabric Filter (baghouse) – controls particulates
FGD	Flue Gas Desulfurization – controls SO_2 and acid gasses
GW	Gigawatt(s) – one thousand MW
GWeq	GW(s) of WetFGDeq
HAPS	Hazardous Air Pollutants
IPM	Integrated Planning Model
MATS	Mercury and Air Toxics Standards
MW	Megawatt(s) – one million watts (1000 kilowatts)
NEEDS	National Electric Energy Data System
SCR	Selective Catalytic Reduction – controls nitrogen oxides
WetFGDeq	Wet FGD equivalent - The amount of an APC technology expressed as its GW equivalent in wet FGD technology

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PREFACE

This paper summarizes an EPA assessment of the feasibility of retrofitting various air pollution control (APC) technologies to coal-fired power plant units in the U.S. for power sector compliance with EPA's Mercury and Air Toxics Standards Rule (MATS). Following are key dates associated with the Rule:

- December 2011 – Final
- February 2015 – Statutory Compliance Deadline
- February 2016 – Compliance Deadline with extension from permitting authorities

EPA has projected the quantity of each APC technology that may need to be newly retrofitted and in service by the compliance date(s). EPA used the latest version of its IPM model to analyze which APC technologies would likely be used, and in what quantities, to achieve compliance with MATS.

Result: **EPA's assessment shows that a reasonable, moderately paced effort of the power sector and supporting industry, including some early starts, would result in the majority of the needed retrofits being installed by February 2015 with the possibility of some installations needing up to an additional year for completion. In order for all retrofits to be completed by February 2015, more projects would have to start early and the sector would have to engage in a more aggressive deployment program. In the event that individual projects cannot be completed by the February 2015 statutory deadline for compliance, the Clean Air Act offers affected sources the opportunity to apply for a one-year extension.**

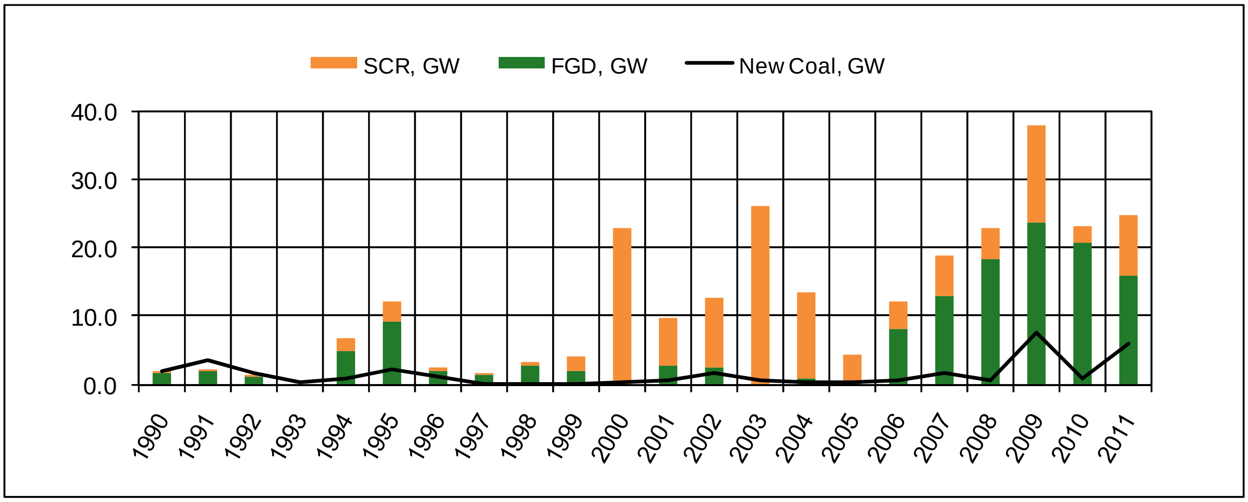
ANALYTICAL APPROACH

Site-specific feasibility studies are typically performed before owners commit to an APC retrofit plan for a unit or plant. However, an assessment of the feasibility of retrofitting a sector-wide aggregation of APC systems to achieve timely compliance with MATS on a *national scale* cannot replicate the same level of detailed analysis of either specific plants or of individual components of the APC "supply chain." Various detailed analyses of the supply chain have been conducted for past rules, usually resulting in a significant underestimate of what was ultimately achieved in practice[1]. Aside from the difficulties of making detailed "bottom-up" analyses of either plants or supply chains on a national scale, such analyses miss the mark because no single planner can be responsible for the strategies of competitive participants in the supply chain, much less for owner compliance strategies at all affected units. In reality, the sector will benefit from the creative interaction of a multitude of actors in the marketplace developing routes to compliance. For the purposes of this Rule, this assessment adopts a broad-scale, order-of-magnitude estimate of what appears reasonably feasible nationwide based on the pattern of power sector deployment activity in the recent past. EPA recognizes that a wide range of site-specific conditions will result in a range of “better-than-average” and “worse-than-average” project outcomes as regards cost and schedule. In developing a broad-scale estimate, the influence of differences in local factors and in past, current, and future circumstances has been considered at an appropriate level of detail.

RECENTLY DEMONSTRATED DEPLOYMENT CAPABILITIES OF THE APC SUPPLY CHAIN

Annual GW capacity additions are plotted in Figure 1 for the two most resource intensive APC systems: flue gas desulfurization (FGD) and selective catalytic reduction (SCR). Figure 1 data reflect the year that systems went into service. These data are from the National Electric Energy Data System (NEEDS)[2], as provided by plant owners and updated by EPA. They include both retrofitted APC and systems installed as part of new coal plant construction. The FGD component is a sum of wet and dry FGD technologies. Dry FGD comprises about 12% of total 1990-2011 FGD additions. Annual installations of new coal-fired power plant capacity are also plotted to indicate the size of its role in contributing to APC additions. Although there have been no new coal power projects ordered in the past two years, several are still in construction. The supply chain for coal power plants is thus an active and applicable set of resources (including engineers, manufacturers, fabrication shops, craft labor, construction managers, etc.) that could be tapped to rapidly enlarge the APC supply chain.

Figure 1: FGD, SCR, and Coal Plant Annual GW Additions, New and Retrofit



Source: EPA, NEEDSv4.10PTR

The large, rather abrupt peaks in annual SCR additions (2000 and 2003) for compliance with the NOx SIP Call are apparent in Figure 1. A more gradual build up to the historic 2009 peak for annual FGD additions in anticipation of the Clean Air Interstate Rule (CAIR) is also apparent. These data depict a recent major ramp-up in the APC deployment capabilities of all industry participants, including plant owners, the APC supply chain, and state and local permitting agencies. These expanded APC capabilities are still active today, even if not fully utilized. EPA believes that in today's post-recession economy it is reasonable to expect that these experienced capabilities can be quickly re-engaged, can quickly return to production at historic rates, and can be quickly augmented by additional available resources to increase production rates beyond historic levels.

RETROFIT PROJECTIONS FOR MATS

Table 1 shows the types and quantities of APC retrofits that EPA has projected the sector to adopt for MATS compliance. "Retrofit GW" refers to the total generating capacity of coal-fired units that are projected to receive each APC technology. For example, the table shows that the Rule may require the retrofitting of dry FGD systems to 20 GW of coal-fired generating capacity. A sum of the Retrofit GW capacities across the categories in Table 1 would be greater than the amount of generating capacity affected by retrofits because many generating units will elect to install more than one APC technology.

Table 1: MATS Retrofit Technologies and GW Capacity required by 2015 for Coal-fired Units

APC Technology	Wet FGD	Dry FGD w/ FF*	SCR	FF	DSI	ACI	FGD upgrades**	ESP upgrades***
Retrofit GW	0	20	0	85	44	99	63	34

Source: EPA, derived from IPMv4.10_MATS
*17 GW of FF included with DryFGD is in addition to the 85 GW of FF installed for PM control or in conjunction with DSI or ACI.
**63 GW of existing FGDs are assumed to be upgraded to achieve adequate HCl removal
***34 GW of existing ESPs are assumed to be upgraded to achieve adequate PM removal

At any particular coal-fired power plant it is possible that none or several of these APC technologies might be retrofitted for MATS compliance. Depending on the plant, they might be retrofitted to each individual unit, or some to one unit but not others, and some might be sized to serve multiple units at a plant. Under MATS, plant operators have the flexibility to design for plant-wide compliance with the rule's emission rates, rather than requiring each unit to meet the specified standards exactly, which further increases the likely diversity of compliance strategies that may reduce cost and time for implementation. These and many other site- and owner-specific factors that cannot be fully considered in IPM modeling would influence plant owner decisions on how to apply any of these systems on individual units. Therefore, although IPM projections based on "model plants" have proven to be excellent predictors of economic technology deployments on a state-wide, regional, and national basis, they are not intended and should not be interpreted as authoritative projections for any single plant or unit.

METRIC FOR TOTAL RETROFIT DEPLOYMENTS (GW WetFGDeq)

EPA has adopted a single metric to represent all APC technologies in this analysis. Use of a single metric facilitates an extrapolation of historic deployment rate data for wet and dry FGD and SCR to assess feasible future deployment rates needed for the retrofit technologies projected for MATS. Such a single metric permits assessment of the overall combined feasibility of all APC retrofits projected. This metric should be regarded as "average," not capturing the specifics of any particular site, but representing average difficulty across many projects.

As shown in Table 2, EPA converted the projected Retrofit GW capacities of each technology from Table 1 into an "equivalent wet FGD capacity" (WetFGDeq). The total (64 GW WetFGDeq) is the future APC deployment goal for this retrofit feasibility analysis. One example of this conversion is that retrofitting 20 GW of dry FGD systems is considered roughly equivalent in terms of cost and resources to the retrofitting of 16 GW of wet FGD systems.

The equivalence factors are computed as the ratio of the capital cost of each technology to that of a wet FGD system. Capital cost includes the installed and commissioned retrofit project elements (engineering, equipment, construction labor, project management, etc.), excluding only financing costs and owner's "home office" costs. The capital costs are derived from IPMv4.10_MATS technology assumptions for single-unit systems.

Table 2: MATS Retrofit Technologies and GW WetFGDeq Capacity

APC Technology	Retrofit GW	Equivalence Factor	WetFGDeq GW
Wet FGD	0	1	0
Dry FGD	20	0.8	16
SCR	0	0.4	0
FF	85	0.3	26
DSI	44	0.1	4
ACI	99	0.02	2
FGD Upgrade	63	0.2	13
ESP Upgrade	34	0.1	3
Total			**64**

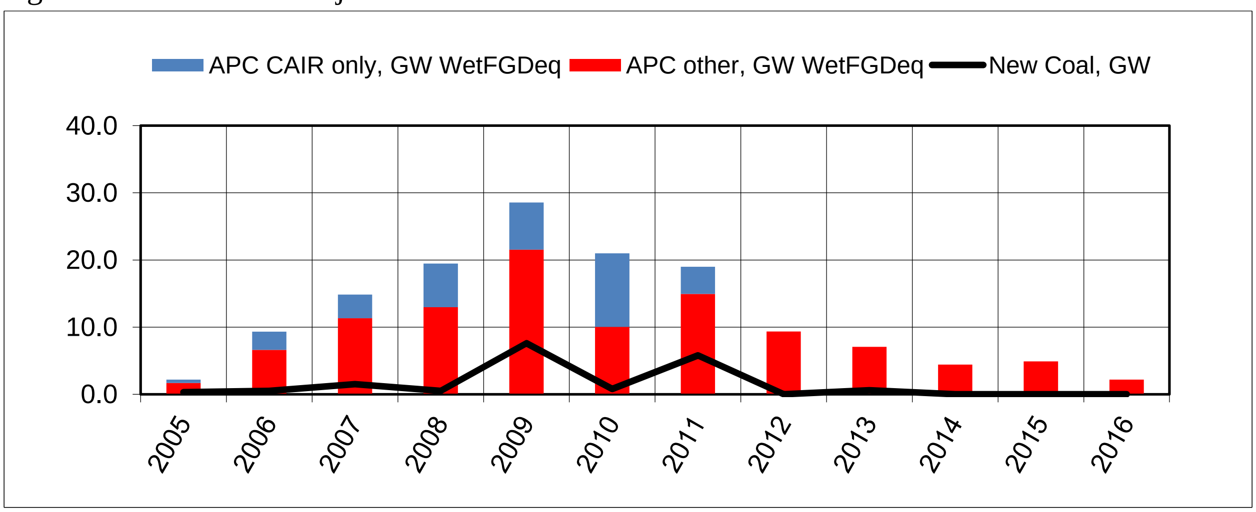
Source: EPA Note: Some values may not add exactly due to rounding.

WetFGDeq values are intended to approximately represent the relative GWeq capacity, capital cost, and supply chain deployment resources associated with APC technologies individually and in total, on the basis of current market conditions. They do not directly represent the relative calendar times required to install individual technologies. Wet FGD was selected as the "base" technology for this metric because it has been widely deployed, is familiar to the industry, has the highest capital cost, uses the most supply chain resources, and requires the longest schedule for deployment. Use of the single WetFGDeq metric is intended to allow the public to more readily visualize and consider a complex set of relationships among many factors (including site conditions, APC designs, and supply chains), and to consider the aggregate level of effort projected for the sector to reach overall MATS compliance.

TRENDS IN TOTAL RETROFIT DEPLOYMENT EFFORT (GW WetFGDeq)

Figure 2 shows the total annual historical APC additions from Figure 1 and current APC commitments for the future using the WetFGDeq metric. Figure 2 reveals the pattern of retrofit deployment driven *solely* by CAIR, showing separately the WetFGDeq of APC capacity installed for other reasons. Note that the retrofit capacity depicted as "other" in Figure 2 has separately identified drivers, but the portion of that "other" capacity deployed inside the CAIR region may have also been timed in coordination with that rule. Figures 1 and 2 both demonstrate the sector's early deployment of APC controls in advance of CAIR compliance deadlines of 2009 for NO_x and 2010 for SO_2. Solely CAIR-driven APC deployments of about 13 GW WetFGDeq occurred within two and a half years after CAIR's finalization in mid-2005, showing that at least 40% of total CAIR-only APC effort through 2010 was sufficiently planned for installation to start before or immediately upon finalization of the rule.

Figure 2: Historical / Projected APC and New Coal Annual Additions



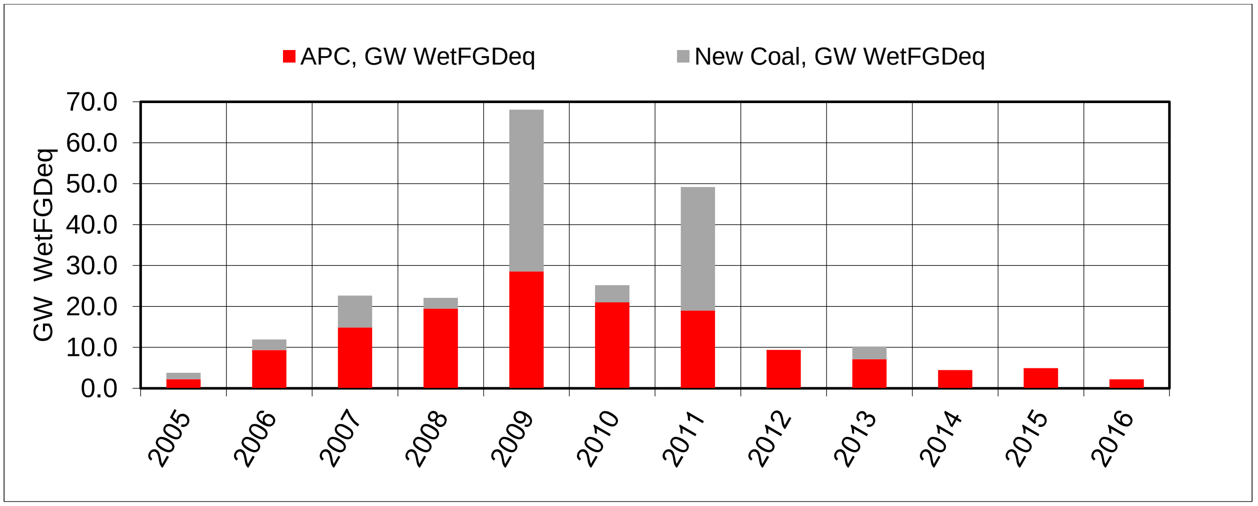
Source: EPA (NEEDS) through 2011; Data beyond 2011 derived with permission from IHS CERA "Announced Environmental Retrofit Project Database: November 2010 Update."

ADDITIONAL SUPPLY CHAIN RESOURCES

EPA estimates that on a GWeq basis, a new coal-fired plant would have at least 5 times more resources involved than a new retrofit wet FGD system. This is illustrated in Figure 3, which is similar to Figure 2 except that the actual GW values for New Coal have been converted to GW WetFGDeq. The comparable GWeq values indicate that there may now be as many underutilized and potentially available New Coal resources as were being used in the APC supply chain at its peak. The currently *available* APC resource pool might thus be up to twice as large as would otherwise be expected, and well able to support a major ramp-up of its deployment capabilities.

Although not quantified here, there is a similar, available, and to some extent transferrable resource pool that has until recently been supporting large annual deployments of the gas turbine combined-cycle power plant business line. NEEDSv4.10PTR shows gas combined-cycle capacity additions of 7 GW (actual) in 2009, 3 GW in 2010, and 7 GW for 2011.

Figure 3: Historical / Projected APC and New Coal Annual Additions



Source: EPA

SCHEDULE OUTLOOK FOR RETROFIT INSTALLATIONS

APC Retrofit Planning EPA thinks it likely that the majority of coal-fired power plant owners performed site-specific APC retrofit studies sometime prior to or in the seven years since CAIR was proposed in 2004. CAIR has remained in effect and will transition in 2012 to the recently finalized Cross State Air Pollution Rule (CSAPR), which continues to focus the industry on retrofit planning. All owners have long been aware that a MATS Rule would be forthcoming and that it would have a compliance date three years after the final rule is effective, as mandated by statutory language in the Clean Air Act. EPA therefore expects that many owners have already determined which of their units would eventually get some combination of APC systems. Such existing preparatory work should make it possible for many owners to quickly take steps toward making commitments for these systems. There is evidence that many such steps have already been taken. [3]

Early Movers CAIR was proposed in early 2004 and finalized in mid-2005. It established compliance dates in 2009 for NO_x and 2010 for SO_2. As discussed above, Figures 1 and 2 show that a significant fraction of "early mover" plant owners must have done their planning and made commitments well in advance of the CAIR final rule date. Southern Company's early 2003 commitment to a large program of APC retrofits, well in advance of CAIR's finalization, is one example of an "early mover" making major early APC deployment decisions, leading to 8,000

MW of installed wet FGD systems on 14 units.[4] Subsequent commitments from many more owners encouraged a continuing expansion of the supply chain, with further increases in annual deployments. EPA anticipates that this pattern will be repeated for the MATS Rule. “Early movers” making commitments in advance of the Rule are better positioned to avoid any potential increase in APC system costs when the supply chain ramps up to deploy a new peak in retrofit installations in a short period of time. EPA clearly saw this early mover advantage occur with CAIR, and early movers may have already triggered the beginning of a major new ramp-up of the APC supply chain for the MATS Rule.

Benchmarking to a New Coal Plant Schedule Actual schedule durations for APC retrofits have varied widely from plant to plant, as will be discussed later. There are many reasons for such variability, and for the fact that some retrofit projects apparently had lengthy schedules of 4 years or more. EPA believes that almost all future APC retrofits can be completed far more quickly than were historical APC projects. EPA’s perspective on this matter derives in part from a comparison of past APC schedules to the project schedule for an entire new coal-fired unit, including its APC systems. Springerville Unit 3, for example, is a 400 MW coal-fired unit that became operational in July 2006, some 33 months after the turnkey engineering-construction contractor was given a notice to proceed with engineering.[5] Springerville was clearly on an accelerated schedule, as its original planned schedule was about 38 months. The main point here is that typical schedules for large complex power projects can be significantly accelerated. Because the scope of the work involved for an entire new coal unit is at least five times that of a retrofit wet FGD system, EPA believes that even the most complex retrofit APC project can be significantly accelerated as well. EPA therefore also believes that its schedule assumptions used in CSAPR, 27 months for retrofitted wet FGD and 21 months for dry FGD, remain reasonable expectations for both CSAPR and MATS.

Retrofit Project Schedules The recently surveyed wet FGD project schedules shown in Table 3 are not all representative of the shorter project schedules that EPA expects to be prevalent under the MATS Rule. Some of these projects were conducted in a period of regulatory uncertainty without a strong driver for accelerated retrofit completion, tie-in, and subsequent operation – particularly where initiating such operation increases marginal operating costs without a certain regulatory benefit. Factors that will likely accelerate project schedules under MATS include the use of overtime and/or two-shift work schedules during construction, and 5- or 6-day work weeks, instead of the 4-day x10-hr schedules often used to minimize cost when time is not of the essence. Increased use of offsite modularization and pre-fabrication of APC components can also shorten schedules and reduce job hours. Also, many of the wet FGD projects performed in response to CAIR or to other legal actions in the same time frame took longer to perform than under normal market conditions due to the initial high demand for a large number of complex wet FGD systems in a short period of time. Extended lead times in the 2007/2008 time period, as high as 18 months for key wet FGD engineered equipment (such as large recycle pumps, large motors, and chimneys) contributed to extended wet FGD project durations. Increased lead times quickly subsided as the supply chain processed the initial influx of orders for this equipment. Neither CSAPR nor MATS, however, as shown in Table 1, is projected to require a significant number of large, complex wet FGD systems. The relatively much simpler dry FGD, fabric filter, and other even simpler dry sorbent injection (DSI) and ACI systems that may be required under the MATS rule will take significantly less time to plan, design, install, and commission than wet FGDs.

Table 3: Recent Wet FGD Project Deployment Schedules

Wet FGD Projects	Schedules (without planning)
13	26 – 35 months
8	37 – 52 months

Source: EPA (see Appendix A)

Motivation for MATS Rule Compliance There is a notable difference between CAIR and the MATS Rule as regards incentives for plant owners to be early movers - making retrofit commitments in advance of the final rule date. CAIR included provisions for the banking and trading of emission allowances, and thus offered unit owners the flexibility to deliberate over time varying compliance strategies that could be offset by allowance purchases if eventual emissions exceeded allowance allocations to that unit. The MATS Rule, on the other hand, does not offer trading flexibility and requires plant-level compliance as soon as the regulatory period begins. Compliance planning under MATS will involve assessment of the long-term differences between the costs of keeping in service an existing unit with newly retrofitted controls and the costs of building and operating a new generating unit that complies. In some cases, it may be possible for owners to delay a retrofit decision until after the MATS Rule is final and still be able to make the necessary deployments in good time. In some other cases, however, any delay in making a retrofit commitment may compromise a unit's ability to meet the statutory MATS Rule compliance deadline. Therefore, the rational expectation should be that affected unit owners would have been more motivated to move early on retrofit planning decisions in advance of the MATS Rule than they were to anticipate actions under previous trading-based regulations. Ultimately, affected plant owners should already have factored in the risk of noncompliance with the MATS Rule as they planned the futures of their coal units.

DEVELOPMENT OF APC DEPLOYMENT SCENARIOS

Current Supply Chain Activity Current activity levels for various participants in the supply chain depend on when their particular activity (engineering, manufacturing, fabrication, construction, etc) occurs in an APC project schedule. As shown in Figure 3, the deployment rate is currently in a second year of decline. Therefore, the activity level of front-end engineering and shop fabrication resources has by now decreased more than that of construction resources (relatively), and both have decreased very significantly. Overall, the current activity level of front-end resources is supporting committed projects that will likely come on-line in the 2013-2015 time frame, corresponding to an annual baseline deployment rate of 10 GW WetFGDeq or less. Not shown in Figure 3 are any additional deployments that may be made by 2014 in response to CSAPR. EPA's IPM analysis for CSAPR projected a need for at most 6 GW of FGD retrofits by 2014. This is an amount that has likely already accelerated a ramp-up in supply chain activity, but, as discussed below, is well within the previously demonstrated capabilities of the supply chain, even when added to retrofits that may be needed for MATS.

Moderate Future Deployment Historical peak annual APC deployments were nearly 30 GW WetFGDeq in 2009. Average year-on-year growth in annual deployments over the 3-year period from 2006 to the peak in 2009 was 45%. A renewed ramp-up in deployment capability, likely already started in early 2011, would have started from roughly the same reduced level of activity that preceded the sustained ramp-up for CAIR. With these observations EPA developed a "moderate" APC deployment scenario, as follows (see Table 4):

- Within three years (by early 2014) a *moderate* effort by the supply chain could put in service APC retrofits of at least 20 GW WetFGDeq for MATS. This is significantly less than the nearly 30 GWeq deployed in a similar time frame under CAIR, and leaves demonstrated capability for limited additional deployments under CSAPR as well. This initializing assumption is supported by EPA engineering staff interaction with the supply chain community and informal appraisals of the current activity and preparedness of the sector. The starting point assumption directly influences the computation of what proportion of retrofit effort is "on time" in 2015 and what proportion is "late" and would require the one-year extension to February 2016. This Moderate scenario expresses EPA's current expectation of what is reasonably achievable while recognizing that there is no definitive way to project how many controls will be on time and how many will require the extension. Completion of this scenario by 2016 seems a reasonable expectation since the MATS is not projected to require use of wet FGD, the most time- and resource-consuming APC technology. Note that although this WetFGDeq analytical concept appears to suggest that nothing is deployed until 2014; in reality there would likely be deployed increasing amounts of DSI, activated carbon injection (ACI), fabric filter (FF) technology, and upgrades of existing FGD and ESP starting in the earliest years, 2012 and 2013, and continuing throughout the program. Dry FGD retrofits could begin coming online sometime in 2013.

- With a small further growth in the supply chain deployment rate, an additional 24 GWeq can be deployed by early 2015, making a cumulative deployment of 44 GWeq. A further 20 GWeq is completed by February 2016, thus meeting the MATS Rule cumulative projection of 64 GW WetFGDeq.

EPA views this moderate 5-year ramp-up as a reasonable and achievable deployment scenario, without anticipating that the sector may find more productive routes to effective and efficient compliance not yet reflected in the historic record.

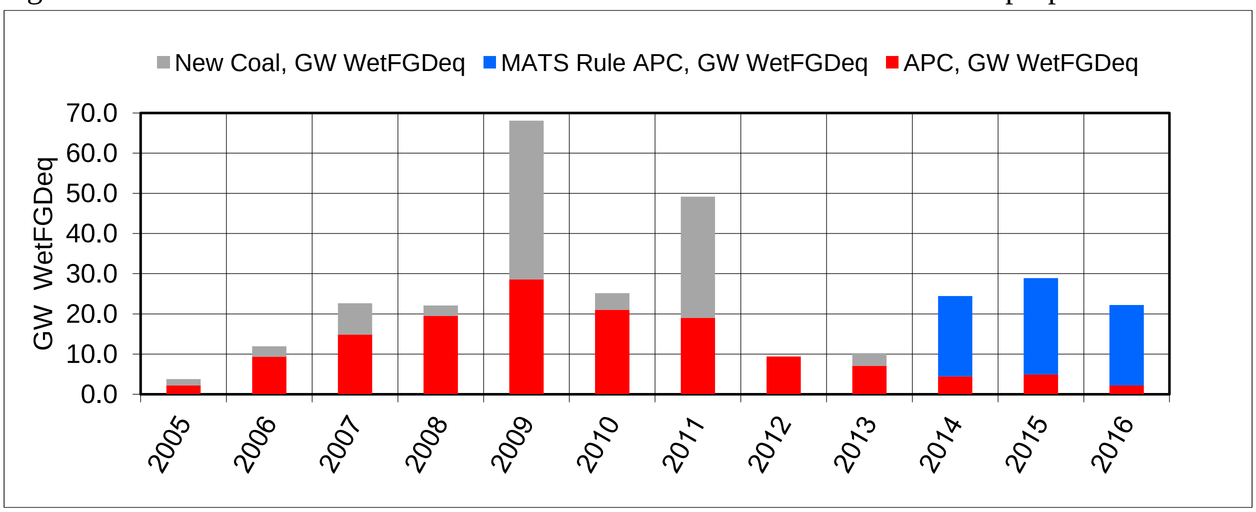
Table 4: APC Deployment Scenarios, Cumulative GW WetFGDeq

Cumulative GW WetFGDeq	Jan-11	Jan-12	Jan-13	Jan-14	Jan-15	Jan-16
5-year ramp-up	Moderate-paced increase in resources			20	44	64
4-year ramp-up	Aggressive increase in resources			28	64	

Source: EPA

The relative magnitudes of past and projected annual APC and New Coal deployments are depicted in Figure 4, where the incremental GWeq of APC for the MATS Rule under a moderate 5-year ramp-up are added to projected APC deployments without the Rule. This visual representation of the relative magnitudes of the resources involved supports the reasonableness of EPA's expectation that timely compliance is achievable in this moderately paced scenario.

Figure 4: Online Year for MATS Rule APC Annual Additions in 5-Year Ramp-up Scenario



Source: EPA

<u>More Aggressive Future Deployment</u> It is conceivable that the supply chain could begin immediately to ramp up its capabilities over three years to the same peak deployment rate achieved for CAIR, and to continue ramping up at an aggressive pace through a final year of APC deployments. Conceivably, it would not "throttle back" its resource growth; it would tap all available sources until all resources that are needed are in place to produce 64 GW WetFGDeq of deployments by early 2015. Under this more aggressive 4-year ramp-up scenario, 28 GWeq could be in service by early 2014 (40% more than in the moderate scenario, but about equal to the CAIR peak), with an additional 36 GWeq needing to be placed into service by early 2015.

EFFECT OF RETROFIT UNIT SIZES

It is useful to consider whether a difference in the past and future average *size* of the units involved, and thereby a difference in the *number* of unique units or projects involved, might significantly affect the feasibility results. NEEDS data indicate that the peak APC deployment of 38 actual GW in 2009 (Figure 1) involved a peak of 66 unique units. The average size unit built anew or retrofitted in 2009 with APC systems was therefore about 575 MW. Not all of those units were managed as unique projects, as some were part of continuing multi-unit projects at some plants, and a few shared an APC system with one or two other units at the same plant.

EPA projects that the future average unit size retrofitted for the MATS Rule will be about 300 MW. However, that does not necessarily mean that there will be proportionately more APC projects to be managed simultaneously. The limited time for compliance will likely necessitate parallel retrofitting activities at many multi-unit plants, with such plant-wide efforts managed most efficiently as single projects. Furthermore, with smaller average unit sizes being retrofitted in the future, there will likely be many plants (projects) where multiple smaller units share an APC system. Although it is not possible to accurately predict the future numbers of APC systems that will be uniquely deployed to single units, or to multiple units, it is clear that the sharing of APC systems by multiple smaller units, done to minimize resource needs and capital cost, could significantly limit the number of APC systems and projects involved. Shared APC systems will allow the overall effort to be more manageable than otherwise, and should require relatively fewer supply chain resources.

A higher number of projects might be expected to impact project management and supervisory labor to some greater degree than craft labor. However, many of the projects will be upgrading existing systems and/or installing fabric filters and less complex technologies, any of which are far less complex than the wet FGD systems installed for CAIR. They will entail far fewer component suppliers, less process engineering effort, fewer technical specifications, etc. A typical upgrade or fabric filter project is therefore far less difficult to manage or supervise than a typical wet scrubber project. Likewise they are easier to construct and will require relatively less craft labor. Thus, although there may be more APC projects, they will be far easier to manage, and should require relatively fewer skilled personnel than CAIR experience and the WetFGDeq metric might suggest.

Referring again to Figure 4, EPA expects that the combined underutilized resources for the APC and New Coal supply chains, possibly supplemented with underutilized resources from the gas combined-cycle business line, will be adequate to support a moderately paced APC deployment scenario.

Appendix - Wet FGD Retrofit Timelines

Plant Name	Unit ID	Capacity (MW)	PROJ START (CAMD findings)	PROJ FINISH (CAMD Findings)	PROJ Duration (months)	Reference	CAMD SO_2 Control Start Date
Asheville	1	191	Sep-03	Nov-05	26	(web site: http://www.powergenworldwide.com/index/display/articledisplay/277709/articles/power-engineering/-/2006/11/best-coal-fired-projects.html) **Construction start Sept 2003. Unit #1 complete Nov 2005;** unit #2 complete 2006. Detail design to Start-up: 26 months. (web site: http://progress-energy.com/aboutus/news/article.asp?id=14282**)** unit 2 on-line May 25, 2006; **unit #1 on-line Nov 2005.**	11/6/2005
Killen Station	2	615	Mar-05	Jun-07	28	(web site: http://www.bv.com/News_3_Publications/News_Releases/2005/0503.aspx) **B&V announcement - alliance w DP&L for Killen & Stuart stations to utilize scrubber tecnology - May 3, 2005**. (web site: http://www.thefreelibrary.com/Black+%26+Veatch%27s+Largest+CT-121+Scrubber+Project+in+North+America+...-a0166786209) B&V **start-up of a CT-121 WFGD for Killen unit#2 - July 25, 2007**.	5/24/2007
Brandon Shores	1	643	Jun-07	Dec-09	29	(web site: http://www.highbeam.com/doc/1G1-165318616.html) **Construction start June 20, 2007**. (web site: http://www.constellation.com/vcmfiles/Constellation/Files/scrubber_factsheet.pdf) **Unit#1 connected Dec 2009;** unit #2 connected Mar 2010.	11/21/2009
Crist	7	472	May-07	Jan-10	32	(web site: http://www.bv.com/wcm/press_release/05072007_1374.aspx) B&V selected by Gulf Pwr Comp to provide EPC for CT-121 WFGD at Plant Crist station; all units will be scrubbed; unit 4,5,6,7 - **announ May 7, 2007**. NOTE: use CAMD SO2 control start date	1/1/2010
Brandon Shores	2	643	Jun-07	Mar-10	32	(web site: http://www.highbeam.com/doc/1G1-165318616.html) **Construction start June 20, 2007.** (web site: http://www.constellation.com/vcmfiles/Constellation/Files/scrubber_factsheet.pdf) Unit#1 connected Dec 2009; **unit #2 connected Mar 2010.**	1/1/2010
Asheville	2	185	Sep-03	May-06	33	(web site: http://www.powergenworldwide.com/index/display/articledisplay/277709/articles/power-engineering/-/2006/11/best-coal-fired-projects.html) **construction start Sept 2003;** unit#1 complete Nov 2005; **unit #2 complete 2006.** Detail design to Start-up: 26 months. (web site: http://progress-energy.com/aboutus/news/article.asp?id=14282**) unit 2 on-line May 25, 2006;** unit #1 on-line Nov 2005.	
Wansley	1	891	Jan-06	Oct-08	33	(web site: http://www.times-herald.com/Local/Scrubber-project-planned-at-Yates-596100) **Wansley constrction begin - Jan 2006**. (Meag Power Current vol.2: issue 1, 2009) **Wansley unit 1 scrubber completed Oct 2008;** unit #2 by next mid april).	10/1/2008
Mitchell	2	800	Mar-04	Jan-07	34	(web site: http://www.babcock.com/library/pdf/pch570.pdf) per B&W: **Project award mar 2004; unit 2 operational Jan 07,** unit 1 operational Apr 07. 2x800 Mw units	1/15/2007
Warrick	2	136	Jul-05	May-08	34	(web site: http://www.thefreelibrary.com/Alcoa+Investing+%24375+Million+for+Warrick%2c+IN+Facilities-a0134312217) **Alcoa announces investment in WFGDs for Warrick July 22, 2005**. (web site: https://www.alcoa.com/locations/usa_warrick/en/info_page/power_plant.asp) Dec 2008, all 4 units completed - WFGD'd installed - final scrubber installed in Dec 2008; **project start 2005.** (web site: https://www.insideindianabusiness.com/newsitem.asp?ID=29541) **the first scrubber went on-line 5/27/2008**. (web site: http://www.alcoa.com/locations/usa_warrick/en/news/newsletters/june08.asp#0) Unit #2 identified.	4/12/2008
Fort Martin Power Station	1	552	Mar-07	Feb-10	35	(web site: http://findarticles.com/p/articles/mi_m0EIN/is_2007_March_15/ai_n27304049/) **Allegheny Pwr announces EPC contract w WGI for scrubber at Fort-Martin station - March 15, 2007**. (web site: http://newsblaze.com/story/2010020408561700001.bw/topstory.html) Allegheny Pwr **announce completion of scrubber project for Fort Martin station - Feb 04, 2010**.	10/31/2009
Fort Martin Power Station	2	555	Mar-07	Feb-10	35	(web site: http://findarticles.com/p/articles/mi_m0EIN/is_2007_March_15/ai_n27304049/) **Allegheny Pwr announces EPC contract w WGI for scrubber at Fort-Martin station - March 15, 2007**. (web site: http://newsblaze.com/story/2010020408561700001.bw/topstory.html) Allegheny Pwr **announce completion of scrubber project for Fort Martin station - Feb 04, 2010**.	8/26/2009
Miami Fort	7	500	Jun-04	Apr-07	35	(web site: http://www.mcilvainecompany.com/utility/subscriber/DefaultOLD.htm) McIlvaine #821 **(4/27/2007) Miami-Fort unit #7 WFGD operating;** (personal note: worked on proj, **proj start June 2004)**	4/1/2007
Monroe	4	775	Jul-06	Jun-09	35	(web site: http://www.redorbit.com/news/business/560181/washington_group_international_to_retrofit_scrubbers_at_detroit_edison_power/index.html) **WGI selected to provide EPC for WFGD's on Monroe units 3&4 - 5 july 2006.** (web site: http://www.tradingmarkets.com/.site/news/Stock%20News/2657108/) Monroe **unit #4 WFGD operational June 2009**. note: scrubber is a ceramic vessel (tile w concrete).	5/4/2009
Clay Boswell	3	351	Feb-07	Mar-10	37	(web site: http://www.redorbit.com/news/business/840682/minnesota_power_awards_boswell_energy_center_retrofit_contract/index.html); **Award 14 Feb 2007.** (http://hamon-researchcottrell.com/news_20100601) **Completed Mar 2010**	10/30/2009
Mitchell	1	800	Mar-04	Apr-07	37	(web site: http://www.babcock.com/library/pdf/pch570.pdf) per B&W: **Project award mar 2004;** unit 2 operational Jan 07, **unit 1 operational Apr 07**. Two 800 MW units.	1/1/2007
Warrick	1	136	Jul-05	Oct-08	39	(web site: http://www.thefreelibrary.com/Alcoa+Investing+%24375+Million+for+Warrick%2c+IN+Facilities-a0134312217) **Alcoa announces investment in WFGDs for Warrick July 22, 2005**. (use CAMD SO2 control start date)	10/15/2008
Wansley	2	892	Jan-06	Apr-09	39	(web site: http://www.times-herald.com/Local/Scrubber-project-planned-at-Yates-596100) **Wansley constrction begin - Jan 2006**. **(use CAMD SO2 control start date)**	4/1/2009
Bowen	3BLR	902	Jan-05	May-08	40	(web site: http://findarticles.com/p/articles/mi_m0EIN/is_2005_May_2/ai_n13664268/) **scrubber contract signed Jan 2005 - Chiyoda JBR.** (http://www.georgiapower.com/environment/air_quality.asp) Bowen scrubber **commercial operating May 2008**.	1/1/2008
Monroe	3	795	Jul-06	Nov-09	41	(web site: http://www.redorbit.com/news/business/560181/washington_group_international_to_retrofit_scrubbers_at_detroit_edison_power/index.html) **WGI selected to provide EPC for WFGD's on Monroe units 3&4 - 5 july 2006;** (web site: http://www.tradingmarkets.com/.site/news/Stock%20News/2657108/) **unit #3 WFGD operational 16 Nov 2009.** note - ceramic wfgd vessel (tile w concrete).	11/1/2009
E W Brown	1	94	Dec-05	Apr-10	52	(web site: http://www.corporatenews.net/_client/RL24592/Ghent-Brown%20FGD%20Final.pdf) contract award EPC (WFGD) Gent units 1,3,4 & EW Brown units 1,2,3 98% SO2 Removal. **Award Dec 2005.** [note: will use CAMD SO2 control date - 4/1/2010)	4/1/2010
E W Brown	2	160	Dec-05	Apr-10	52	(web site: http://www.corporatenews.net/_client/RL24592/Ghent-Brown%20FGD%20Final.pdf) contract award EPC (WFGD) Gent units 1,3,4 & EW Brown units 1,2,3 98% SO2 Removal. **Award Dec 2005.** [note: will use CAMD SO2 control date - 4/1/2010)	4/1/2010

[1] Staudt, *Availability of Resources for Clean Air Projects*, October 2010, http://www.andovertechnology.com/images/white%20paper%20-%20availability%20of%20resources%20for%20clean%20air%20projects_public.pdf

[2] National Electric Energy Data System

[3] Staudt, *U.S. Power Companies Actively Planning for Compliance with Clean Air Rules; Significant Work is Already Underway*, December 2011, http://www.andovertechnology.com/images/compliance_progress.pdf

[4] Huggins, et al, *Implementation Strategies for Southern Company FGD Projects*, 2010 Mega Symposium , Paper#68

[5]*Best Coal-fired Projects , Springerville Unit 3 Expansion Project*, Power Engineering, December 2006, http://www.powergenworldwide.com/index/display/articledisplay/277709/articles/power-engineering/-/2006/11/best-coal-fired-projects.html