Benefits of Combined Heat and Power Systems

In Reducing Criteria Pollutant Emissions

In MANE-VU States

Last Updated: September 4, 2015

Executive Summary

CHP, or cogeneration, is a general term that refers to setting up systems that produce either heat or electricity to instead produce both. A traditional system with separate power and heat production can achieve an efficiency of 45%, whereas CHP can achieve efficiencies of 80%. A more advanced type of system called trigeneration also uses the system for heating and electricity, but also cooling. Further, transmission losses are decreased since electricity is now produced closer to the end user. This report looked at the benefits of installing cogeneration or trigeneration systems for different applications in the MANE-VU states.

We relied on an analysis conducted by ICF international that examined the potential, both technical and economic, nationally for CHP installations. We then used the ERTAC EGU tool to estimate criteria pollutant benefits from reduced generation in the power sector.

With the CHP technologies discussed in the paper increases in CHP penetration would lead to strong decreases in SO_2 pollution in MANE-VU due to displacement of current base load generation. The same is not true for NO_X emissions given the increase in onsite NO_X emissions from CHP systems in the vast majority of the scenarios examined. When looking at smaller systems the replacement need to meet the NO_X standards outlined in the OTC Stationary Generator Model Rule to have a benefit. Larger systems do not appear to have a NO_X benefit until they are adopted widely, which is concerning since small scale adoption is what is current economically feasible.

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Last Updated: August 25, 2015

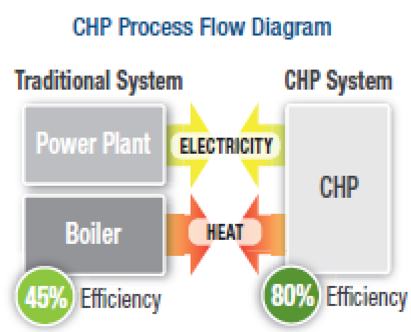
Overview

In November 2012, the Mid-Atlantic North East Visibility Union (MANE-VU) members charged the Technical Support Committee (TSC) with evaluating the potential for combined heat and power strategies to reduce ozone and fine particulate matter levels in MANE-VU states, and recommending an appropriate strategy or strategies. In February 2013, the TSC launched the Combined Heat & Power (CHP) Workgroup to fulfill MANE-VU's charge. The workgroup decided to initially focus on the reduction potential for installations and retrofits commercial and industrial system with CHP.

Purpose of this report: This report estimates the magnitude of oxides of Nitrogen (NO_X) and Sulfur Dioxide (SO_2) emission reductions possible in MANE-VU from installation and retrofit commercial and industrial systems with CHP.

Background

CHP, or cogeneration, is a general term that refers to setting up systems that produce either heat or electricity to instead produce both. A traditional system with separate power and heat production can achieve an efficiency of 45%, whereas CHP can achieve efficiencies of 80%. A more advanced type of system called trigeneration also uses the system for heating and electricity, but also cooling. Further, transmission losses are decreased since electricity is now produced closer to the end user.



Since CHP systems use the same fuel to produce heat and electricity rather than the traditional separated power plant/boiler system, they also produce fewer emissions. One way to look at it is that an institution would be producing relatively the same level of emissions as they would with just a boiler used for heating, but now the power plant no longer needs to generate a portion of the electricity to meet the institution's needs so the overall system does not emit the same level of criteria, toxic, and greenhouse pollutants.

There are other benefits to the installation of CHP systems. CHP systems can be set up to provide versatility to the electric grid as distributed generation by being called on during times of peak energy needs, times which often require the lowest need for heat production. CHP systems can also continue to function to provide power locally at times when the grid fails due to acts of nature, voltage problems or during blackouts allowing the organization with the CHP system to remain electrified.

There are also challenges to implementation of CHP systems. In a report on CHP produced by Oak Ridge National Laboratory it was stated that "challenges include unfamiliarity with CHP, technology limitations, utility business practices, regulatory ambiguity, environmental permitting approaches that do not acknowledge and reward the energy efficiency and emissions benefits, uneven tax treatment, and interconnection requirements, processes, and enforcement.[1]" Additionally, since CHP systems are smaller than a conventional EGU, emissions from these systems could sometimes outweigh the benefits of reduced electricity production, especially in situations when the onsite steam generation did not exist prior.

Criteria Pollutant Reduction Potential from Commercial and Industrial Installation & Retrofits of Heating Systems with CHP

Potential for CHP Installation in MANE-VU States

The first step in determining potential emission reductions from CHP installations is to determine how much potential there is for such installations, especially since many states in MANE-VU have existing installed CHP. A report conduct by ICF International that looked at the technical potential for CHP systems beyond current installations to be installed nationally will be relied on for determining the technical potential in our region.

There are also many economic factors that could prevent CHP from being feasible. The interactions between fuel prices, electricity prices, potential capacity, physical constraints, and available capital, among other factors, could prevent some of this capacity from being realized. Regulations also play a role in reducing the amount of economically feasible CHP. However, to begin our examination of the benefits of CHP systems we first look at the emission estimates on all technically feasible CHP in MANE-VU as listed in Table 2.

[1] Oak Ridge National Laboratory. "COMBINED HEAT AND POWER Effective Energy Solutions for a Sustainable Future." http://www1.eere.energy.gov/manufacturing/distributedenergy/pdfs/chp_report_12-08.pdf. Accessed March 23, 2013.

Table 1: Existing and technical potential (MW) for CHP systems in the U.S. by capacity and application[2]

Sector		Load Factor	Application	Technical Potential (MW)					
				.05-1 MW	1-5 MW	5-20 MW	>20 MW	Total	Class
Cogeneration	Industrial	High	Food & Beverage	2,744	3,250	1,330	697	8,021	63,823
			Textiles	586	751	726	176	2,239	
			Lumber and Wood	1,413	854	332	164	2,763	
			Paper	1,230	1,869	3,601	7,597	14,297	
			Printing/Publishing	2,306	5,875	8,165	8,223	24,569	
			Chemicals	424	897	697	1,941	3,959	
			Petroleum Refining	1,023	314	120	28	1,485	
			Rubber/Misc Plastics	88	122	53	0	263	
			Stone/Clay/Glass	406	532	953	1,214	3,105	
			Fabricated Metals	254	21	6	0	281	
			Transportation Equip.	681	469	725	304	2,179	
			Furniture	44	2	0	0	46	
			Chemicals	173	23	5	0	201	
			Machinery/Cptr Equip	74	62	17	0	153	
			Instruments	76	23	24	0	123	
			Misc Manufacturing	85	20	34	0	139	
	Comm/Inst	High	Waste Water Treatment	111	66	0	0	177	3,242
			Prisons	318	1,343	850	554	3,065	
		Low	Laundries	116	13	0	0	129	612
			Health Clubs	125	26	8	0	159	
			Golf/Country Clubs	235	28	15	0	278	
			Carwashes	43	3	0	0	46	
Trigeneration	Comm/Inst	High	Refrig Warehouses	67	33	9	7	116	21,188
			Data Centers	272	380	339	46	1,037	
			Nursing Homes	765	159	13	0	937	
			Hospitals	892	3,179	769	345	5,185	
			Colleges/Universities	641	1,648	1,669	1,471	5,429	
			Multi-Family Buildings	3,774	1,325	0	0	5,099	
			Hotels	1,330	1,386	460	209	3,385	
		Low	Airports	125	261	290	0	676	43,014
			Post Offices	29	11	0	0	40	
			Food Sales	1,079	65	41	0	1,185	
			Restaurants	1,179	62	15	0	1,256	
			Commercial Buildings	20,378	12,842	0	0	33,220	
			Movie Theaters	3	1	0	0	4	
			Schools	789	87	0	0	876	
			Museums	41	13	0	0	54	
			Government Facilities	1,276	1,334	955	170	3,735	
			Big Box Retail	1,662	251	25	30	1,968	

[2] ICF International. "Effect of a 30 Percent Investment Tax Credit on the Economic Market Potential for Combined Heat and Power." October 2010. Accessed October 29, 2014.

Table 2: Existing and technical potential (MW) for CHP systems in MANE-VU states by capacity

State	Existing (MW)[3]	Technical Potential (MW)[2]				
		.05-1 MW	1-5 MW	5-20 MW	>20 MW	Total
CT	741	492	396	78	0	966
DE	231	104	59	21	0	184
ME	936	176	142	0	6	324
MD	705	682	457	0	75	1,214
MA	1,576	976	755	0	140	1,871
NH	47	184	130	9	0	323
NJ	3,049	1,133	875	421	28	2,457
NY	5,775	2,851	2,671	820	259	6,601
PA	3,269	1,631	1,442	233	155	3,461
RI	126	159	117	22	0	298
VT	24	85	61	19	0	165
Total	**16,479**	**8,473**	**7,105**	**1,623**	**663**	**17,864**

Table 1 examines various CHP applications and whether they 1) would produce electricity, heating, and cooling (trigeneration) or just electricity and heating (cogeneration), 2) would be used for industrial purposes or commercial/institutional purposes, 3) run only during business hours (low load factor) or closer to 24 hours a day (high load factor). Data from the ICF analyses was also used to estimate annual operating hours from for systems in each class.

Table 2 includes state level totals of both existing and technical potential by system capacity as found in the ICF report. The technical potential will be the basis for the capacity estimates throughout this report. Since the ICF did not analyze Washington, DC it will not be included in the analysis although they do have 14 MW of existing CHP capacity.

Equation 1: State/Class/Size Technical Potential

$$PercentageTechPotential_{Class/\,Size} = (TechPotential_{Class/Size}/TechPotential_{National/Size})$$

Table 3: Percentage of technical potential for each class by capacity in the U.S.

Class	Op. Hours[2Error! Bookmark not defined.]	System Capacity			
		.05-1 MW	1-5 MW	5-20 MW	>20 MW
Cogen/Industrial/High Load	7,000	24.77%	38.09%	75.47%	87.78%
Cogen/Commercial/High Load	7,000	0.92%	3.56%	3.82%	2.39%
Cogen/Commercial/Low Load	4,000	1.11%	0.18%	0.10%	0.00%
Trigen/Commercial/High Load	7,000	16.52%	20.48%	14.65%	8.97%
Trigen/Commercial/Low Load	5,000	56.69%	37.69%	5.96%	0.86%

[3] https://doe.icfwebservices.com/chpdb/. Accessed September 4, 2015.

Since no information was available for technical potential for each class at the state level we assumed that all each state had the same distribution of classes as was found nationally. To estimate the technical potential for each class/state/capacity possibility Equation 1 was used. The resulting distribution that was used through the rest of the paper can be found in Table 3.

Additionally, we want to examine only the CHP systems that are economically feasible. ICF produced three scenarios looking at differing levels of the Investment Tax Credit (ITC) to determine what could be economically feasible (Table 4). Since this information was not available at the state level we assumed that all each state had the same distribution of classes as was found nationally. The percentage of each size that was found to be economically feasible was applied to each state's technical feasibility for these scenarios.

Table 4: Economic feasibility of CHP at three levels of the ITC in the U.S.[2]

Class	National Capacity (MW)								
	.05-1 MW		1-5 MW		5-20 MW		>20 MW		Total
0% ITC	125	0.27%	371	0.94%	567	2.55%	1,547	6.68%	2,610
Expanded ITC (10% up to 25 MW)	181	0.39%	500	1.26%	674	3.03%	1,802	7.78%	3,157
30% ITC (30% up to 25 MW)	258	0.55%	681	1.72%	973	4.37%	2,284	9.86%	4,196
Technical Potential	**46,857**		**39,600**		**22,246**		**23,176**		**131,879**

Potential Emission Reductions

There are two ways in which installation of CHP will change emissions levels, onsite and through replacement of electricity production elsewhere. The onsite emission changes would be due to retrofits and repowering necessary to convert a system to CHP that would result in an onsite boiler that produces differing emissions from the previous levels and the offsite emission reductions would be due to a lessened need for electricity production.

Estimating Onsite Emission Calculations

Breakouts by capacity and the class of facility as seen in Table 3 were available to calculate different emission reductions by these two traits. Emission reductions were calculated for both NO_X and SO_2 for each state.

An assessment conducted by NYSERDA contained emission reductions from replacing a subset of their boilers along the same capacity breakout with natural gas fired CHP systems[4]. Average annual emission rates for existing and replacement systems were calculated on a per MW basis for NO_X and SO_2 using the base case scenario found in the NYSERDA report; however the emission rates for NO_X for replacement systems was not used in the analysis. Since emission

[4] NYSERDA. "Combined Heat and Power Market Potential for New York State." October 2002.

rates are not available for systems sized .05-.5 MW in the NYSERDA report we assumed that they had the same emission rates as systems sized .5-1 MW.

Instead of relying on the NYSERDA report several estimates of NO_X emission rates were used when calculating emissions from replacement systems. Systems smaller than 5 MW were assumed to rely on combustion from Reciprocating Internal Combustion Engines (RICE) and systems larger than that assumed to rely on combustion from Combustion Turbines (CT). Emission rates from Delaware's stationary generator rule were used in Delaware for the systems under 5 MW. The OTC 2010 stationary generator model rule was applied in New Jersey for systems under 5 MW. For all other states the RICE NSPS was used for systems sized less than 5MW. For systems in the 5-15 MW range we assumed the emission rates applicable in the OTC Model Rule for Additional NO_X Control Measures regardless of state. All systems greater than 20 MW regardless of state used the CT New Source Performance Standard. Additionally, average emission rates for the 5-20 MW category were calculated by averaging regulatory values for systems sized 5-15 MW (given 2/3 weight) and 15-20 MW (given 1/3 weight).

Table 5: Annual average emission rates (lb/MWh) for CHP replacement and existing heating only boilers

Capacity	**NO_X**				**SO_2**		***CHP Heat Rate (Btu/kWh)*** [2]
	CHP - DE [5]	***CHP – OTC M.R.*** [6]	***CHP – Fed.*** [7]	***Existing***	***CHP***	***Existing***	
.05-.5 MW	0.60	0.88	2.96	-	-	-	10,800
.5-1 MW	0.60	0.88	2.96	0.6355	0.0062	0.0031	10,800
1-5 MW	0.60	0.88	2.96	0.8246	0.0070	0.0028	9,492
5-20 MW [89]	1.87	1.87	1.87	0.7750	0.0069	0.0027	11,765
> 20 MW [9]	1.20	1.20	1.20	0.5546	0.0055	0.0022	9,220

A second set of calculations were made showing what would be the case if all MANE-VU states adopted the 2010 stationary generator rule for the replacement systems. This meant that all states, except Delaware, had NO_X emission rates equivalent to those used for New Jersey in the first scenario.

The systems were assumed to run according the annual operating hours listed in Table 3. One should note that the replacement systems themselves produce more emissions than the original systems.

Estimating Offsite Emission Calculations

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[5] DE 7 § 1144 3.2.2

[6] OTC Model Rule for Stationary Generator Control Measures.

[7] 40CFR60-JJJJ

[8] OTC Model Rule for Additional Nitrogen Oxides (NOx) Control Measures

[9] 40CFR60-KKKK

The other way in which CHP systems can reduce pollution is by reducing the amount of electricity that power plants need to produce.

Several assumptions were made in order to estimate the emission reductions from the power sector due to implementation of CHP:

- CHP systems would replace base load coal generation in the ERTAC region in which the state was predominately located. In regions where coal generation does not occur, the system would replace Combined Cycle Natural Gas units. The coal assumption in particular could lead the benefits to be overstated.
- Transmission loss would be based on the average in the Eastern Interconnection of 5.82%.
- CHP systems would undertake routine maintenance during shoulder months and would result in negligible emission misestimates.
- CHP systems will be completed by the modeled future year of 2018, which was chosen due to its importance for Ozone and Regional Haze planning.

Table 6: Average annual heating and cooling degree days, last and first date of heating season, and calculated hours for heating by state from 2004-2013[10]

State	**Annual Average Degree Days**		**Heating Season**		**Heating Hours**
	Heating	***Cooling***	**Last Day**	**First Day**	
CT	5,780	625	6/7	9/14	6,386
DE	4,414	1,210	5/17	9/27	5,545
MA	6,043	534	6/14	9/12	6,622
MD	4,497	1200	5/17	9/27	5,568
ME	7,622	236	7/22	9/10	7,563
NH	7,327	310	6/20	8/21	7,268
NJ	5,045	913	5/23	9/19	5,900
NY	5,909	647	6/7	9/14	6,405
PA	5,623	734	5/24	9/7	6,208
RI	5,682	585	6/15	9/18	6,488
VT	7,778	249	6/22	8/13	7,498

To calculate the number of hours the low load factor cogeneration CHP systems would run during the year, the number of heating degree days and cooling degree days were averaged from 2004-2013 for each of month of the year. The ratio of heating degree days to total degree days was used to approximate the number of hours in the month the heating system would run (heating hours).

In order to estimate the start and end of the heating season the shoulder months were examined to determine which had the clearest end date was and then the average annual heating hours were

[10] NCDC Climate Indicators. http://www7.ncdc.noaa.gov/CDO/CDODivisionalSelect.jsp. Accessed April 11, 2014.

used to calculate the other date based on the assumption that the heating would run straight through. An overview of the heating/cooling degree days and heating hours are in Table 6, as well as the approximate dates used as the end and beginning of the heating season for each state.

The ERTAC EGU tool was then used to estimate the emission reductions from reduced need for generation in the power sector. Version 2.3 of the ERTAC inputs was used as the basis for the runs and the runs were conducted using a modified copy of version 1.01 of the software. The modifications were made to limit the number of hours that units could be run based on the utilization factor.

To use ERTAC EGU to project CHP's impacts on the grid a "virtual CHP plant" was created for each state (three in the case of New York), class of facilities, four tiers of capacities, and in the case of the class of low load factor cogeneration facilities seasonality, for a total of 364 "virtual CHP plants." This situation where all of the technically feasible CHP systems are built will be henceforth called "Technical Potential Scenario". We also looked at the benefits of only installing larger systems (those greater than or equal to 5 MW) and of only installing smaller systems (those less than 5 MW), henceforth called "Large Systems Scenario" and "Small Systems Scenario," respectively. Finally, we looked at the three economic options, "0% ITC Scenario," "10% ITC Scenario," and "30% ITC Scenario."

ERTAC EGU distributes generation using regions that are based on the regions the Energy Information Agency uses in their Annual Energy Outlook report. In most cases the entirety of the MANE-VU state is within the ERTAC region so 100% of the virtual CHP systems are allocated to that region. Even though part of western Pennsylvania, and to a lesser extent part of western Maryland, is in the RFCW region we allocated all of the CHP systems to the RFCE region since the RFCW region extends well beyond the MANE-VU region. New York has three regions. To allocate the CHP systems across those regions the percentage of the population from 2010 US Census data in each region was used as a surrogate[11]. The list of regions is in Table 7.

Table 7: List of ERTAC EGU regions analyzed and which states are allocated to the regions

ERTAC EGU Region	State Allocation
NEWE	100% of CT, ME, MA, ME, NH, RI, VT
NYCW	42% of NY
NYLI	15% of NY
NYUP	43% of NY
RFCE	100% of DE, MD, NJ, PA

Several traits are necessary to be included in the ERTAC EGU input files for the "virtual CHP plants" to be processed:

1. Capacity: calculated using Equation 2 using the distributions from Table 3.

[11] http://www.census.gov/popest/data/counties/totals/2014/CO-EST2014-01.html. Accessed August 6, 2015.

2. Annual heat rate: based on the capacity tier, obtained from the ICF report and listed in Table 5.
3. Utilization fraction (percentage of hours operating): The operating hours, based on the class obtained from the ICF report, are listed in Table 3. For the class of low load cogeneration facilities the utilization fraction was set the same as used for low load trigeneration facilities for the non-summer months and adjusted accordingly for the summer months using the length of the heating season defined in Table 6.
4. Maximum heat input: calculated using Equation 3.
5. NO_X and SO_2 emission rates: set to 0 since the onsite emissions were calculated separately.

Equation 2: "Virtual CHP plant" capacity

$$Capacity_{Virtual\ Plant} = PercentageTechPotential_{Class/Size}/TechPotential_{State/Size}/(1\text{-}TransLoss)$$

Equation 3: "Virtual CHP plant" maximum heat input

$$Maximum\ Heat\ Input = Annual\ Heat\ Rate * Capacity_{Class/State/Size}/1000$$

Additionally, to properly shutdown the "virtual CHP plants" during hours which they are not running the ERTAC EGU code was altered so that systems do not run after the maximum number of hours was met using the utilization fraction.

Results

When looking at the scenarios that examined technical potential only, the onsite increases from the replacement of boilers in MANE-VU with CHP systems would yield substantial increases in NO_X if the model rule is not adopted by all of the states. These emission increases outweigh the benefits of reduced power needed from the grid. Implementing the model rule leads to situations with NO_X benefits regionally. At the current emission limits the large systems, which are independent of the model rule, also have a negative impact on NO_X emissions. In all situations the implementation of CHP systems has a clear SO_2 benefit.

When looking at the systems that ICF found to be economical at the various ITC levels one finds what would be expected, the magnitude of the emission change the higher the ITC. At each level the NO_X increases from not having the model rule implemented throughout MANE-VU is about double, which is nowhere near the change in magnitude seen in the technical potential scenarios. On the downside since the larger units were found by ICF to be more economical, these scenarios result in increases in NO_X emissions. In all cases there was a benefit in reduced SO_2.

More details on the changes in emissions are in Table 9 .

Table 8: Changes in NO_X and SO_2 annual emissions (tons) in the MANE-VU region as a result of CHP replacement

Scenario		Pollutant	Total	Scenario		Pollutant	Total
"Technical Potential"	*Onsite*	*NO_X - no Model Rule*	*98,743*	"30% ITC"	*Onsite*	*NO_X - no Model Rule*	*1,400*
		NO_X - w/ Model Rule	*14,794*			*NO_X - w/ Model Rule*	*470*
		SO_2	*201*			*SO_2*	*4*
	Offsite	NO_X	-28,453		Offsite	NO_X	-288
		SO_2	-64,605			SO_2	-1,302
	Total	**NO_X - no Model Rule**	**70,291**		***Total***	**NO_X - no Model Rule**	**1,112**
		NO_X - w/ Model Rule	**-13,658**			**NO_X - w/ Model Rule**	**182**
		SO_2	**-64,404**			**SO_2**	**-1,298**
	CHP Capacity		**17,680**		**CHP Capacity**		**303**
"Large Units"	*Onsite*	*NO_X*	*7,661*	"10% ITC"	*Onsite*	*NO_X - no Model Rule*	*1,016*
						NO_X - w/ Model Rule	*341*
		SO_2	*31*			*SO_2*	*3*
	Offsite	NO_X	-1,856		Offsite	NO_X	-206
		SO_2	-9,648			SO_2	-946
	Total	**NO_X**	**5,805**		***Total***	**NO_X - no Model Rule**	**810**
						NO_X - w/ Model Rule	**135**
		SO_2	**-9,617**			**SO_2**	**-944**
	CHP Capacity		**2,265**		**CHP Capacity**		**221**
"Small Units"	*Onsite*	*NO_X - no Model Rule*	*91,082*	"0% ITC"	*Onsite*	*NO_X - no Model Rule*	*776*
		NO_X - w/ Model Rule	*7,133*			*NO_X - w/ Model Rule*	*284*
		SO_2	*170*			*SO_2*	*2*
	Offsite	NO_X	-12,598		Offsite	NO_X	-156
		SO_2	-58,043			SO_2	-737
	Total	**NO_X - no Model Rule**	**78,485**		***Total***	**NO_X - no Model Rule**	**620**
		NO_X - w/ Model Rule	**-5,464**			**NO_X - w/ Model Rule**	**128**
		SO_2	**-57,874**			**SO_2**	**-734**
	CHP Capacity		**15,415**		**CHP Capacity**		**173**

Conclusions

With the CHP technologies discussed in the paper increases in CHP penetration would lead to strong decreases in SO_2 pollution in MANE-VU due to displacement of current base load generation. The same is not true for NO_X emissions given the increase in onsite NO_X emissions from CHP systems in the vast majority of the scenarios examined. When looking at smaller systems the replacement need to meet the NO_X standards outlined in the OTC Stationary Generator Model Rule to have a benefit. Larger systems do not appear to have a NO_X benefit until they are adopted widely, which is concerning since small scale adoption is what is current economically feasible.

Although the report did not look into the issue, there is also likely a benefit from reduced CO_2 emissions as well, which needs to be examined in making decisions to pursue policies to encourage CHP installations. Finally, there is the potential from newer technologies on the horizon such as fuel cells to reduce the onsite emissions footprint further which would result in more emissions reductions, in particular from NO_X.

Recommendations for Future Work

One limitation of using the ERTAC EGU tool is that economics is not considered on a unit by unit basis, which creates a challenge in ensuring that the CHP systems replace generation from marginal units. Additionally, ERTAC EGU segregates generation by fuel further adding to the challenges of only reducing generation from marginal units. Although the technique of creating the "virtual CHP plant" attempted to solve this problem, it would be advisable to attempt using other more appropriate tools in any future analysis. Work is underway to explore incorporating ERTAC EGU projections into the EPA's AVERT (AVoided Emissions and geneRation Tool) model, which is designed to show the impact of renewables and other unconvential generation on the grid. It is recommended that once that work is complete examining the impact of CHP systems in MANE-VU on marginal units and peaking units using that tool.

Table 9: Changes in NO_X and SO_2 annual emissions (tons) in MANE-VU as a result of CHP replacement

Scenario		Pollutant	CT	DE	ME	MD	MA	NH	NJ	NY	PA	RI	VT	Total
		Emission Changes												
"Technical Potential"	*Onsite*	*NO_X - no Model Rule*	*6,271*	*28*	*2,153*	*7,838*	*11,963*	*2,148*	*2,622*	*40,825*	*21,900*	*1,941*	*1,055*	***98,743***
		NO_X - w/ Model Rule	*716*	*28*	*164*	*734*	*1,142*	*188*	*2,622*	*6,194*	*2,647*	*217*	*143*	***14,794***
		SO_2	*11*	*2*	*4*	*13*	*20*	*3*	*28*	*75*	*39*	*3*	*2*	***201***
	Offsite	NO_X	-388	-215	0	-6,230	-716	-2,677	-984	-4,380	-12,863	0	0	**-28,453**
		SO_2	-540	-561	0	-11,265	-1,508	-3,389	-1,309	-20,769	-25,262	0	0	**-64,605**
	Total	**NO_X - no Model Rule**	**5,883**	**-187**	**2,153**	**1,608**	**11,247**	**-529**	**1,638**	**36,445**	**9,037**	**1,941**	**1,055**	**70,291**
		NO_X - w/ Model Rule	**328**	**-187**	**163**	**-5,495**	**425**	**-2,489**	**1,638**	**1,814**	**-10,216**	**217**	**143**	**-13,658**
		SO_2	**-530**	**-559**	**4**	**-11,252**	**-1,488**	**-3,386**	**-1,281**	**-20,694**	**-25,223**	**3**	**2**	**-64,404**
		Capacity	**966**	**0**	**324**	**1,214**	**1,871**	**323**	**2,457**	**6,601**	**3,461**	**298**	**165**	**17,680**
"Large Units"	*Onsite*	*NO_X*	*296*	*80*	*14*	*169*	*315*	*34*	*1,663*	*3,699*	*1,235*	*84*	*72*	***7,661***
		SO_2	*1*	*0*	*0*	*1*	*2*	*0*	*6*	*15*	*5*	*0*	*0*	***31***
	Offsite	NO_X	9	-14	1	-285	-235	240	-71	-531	-970	0	0	**-1,856**
		SO_2	108	-76	0	-1,519	-1,394	491	-235	-4,758	-2,265	0	0	**-9,648**
	Total	**NO_X**	**306**	**66**	**14**	**-116**	**80**	**275**	**1,591**	**3,168**	**265**	**84**	**72**	**5,805**
		SO_2	**109**	**-75**	**0**	**-1,518**	**-1,392**	**491**	**-229**	**-4,743**	**-2,259**	**0**	**0**	**-9,617**
		Capacity	**78**	**0**	**6**	**75**	**140**	**9**	**449**	**1,079**	**388**	**22**	**19**	**2,265**
"Small Units"	*Onsite*	*NO_X - no Model Rule*	*5,974*	*-52*	*2,139*	*7,669*	*11,648*	*2,114*	*959*	*37,126*	*20,666*	*1,858*	*983*	***91,082***
		NO_X - w/ Model Rule	*419*	*-52*	*150*	*565*	*826*	*154*	*959*	*2,495*	*1,412*	*134*	*71*	***7,133***
		SO_2	*10*	*2*	*3*	*12*	*19*	*3*	*22*	*61*	*34*	*3*	*2*	***170***
	Offsite	NO_X	-191	-102	1	-2,004	-256	-782	-429	-2,090	-6,744	0	0	**-12,598**
		SO_2	-540	-491	0	-9,892	-1,508	-3,390	-1,152	-19,241	-21,831	0	0	**-58,043**
	Total	**NO_X - no Model Rule**	**5,783**	**-154**	**2,140**	**5,665**	**11,392**	**1,331**	**530**	**35,036**	**13,922**	**1,857**	**983**	**78,485**
		NO_X - w/ Model Rule	**228**	**-154**	**151**	**-1,439**	**570**	**-629**	**530**	**405**	**-5,331**	**134**	**71**	**-5,464**
		SO_2	**-531**	**-489**	**3**	**-9,880**	**-1,489**	**-3,386**	**-1,130**	**-19,180**	**-21,797**	**3**	**2**	**-57,874**
		Capacity	**888**	**0**	**318**	**1,139**	**1,731**	**314**	**2,008**	**5,522**	**3,073**	**276**	**146**	**15,415**
"30% ITC"	Onsite	*NO_X - no Model Rule*	*77*	*3*	*24*	*94*	*154*	*23*	*83*	*606*	*299*	*23*	*13*	***1,400***
		NO_X - w/ Model Rule	*16*	*3*	*2*	*21*	*37*	*3*	*83*	*213*	*84*	*5*	*4*	***470***
		SO_2	*0*	*0*	*0*	*0*	*0*	*0*	*1*	*2*	*1*	*0*	*0*	***4***
	Offsite	NO_X	-7	-1	1	-40	-11	-47	-6	-58	-119	0	0	**-288**
		SO_2	-28	-11	0	-209	-71	-149	-35	-546	-254	0	0	**-1,302**
	Total	**NO_X - no Model Rule**	**70**	**2**	**25**	**55**	**143**	**-23**	**77**	**548**	**180**	**23**	**13**	**1,112**
		NO_X - w/ Model Rule	**9**	**2**	**3**	**-19**	**26**	**-44**	**77**	**155**	**-35**	**5**	**4**	**182**
		SO_2	**-28**	**-10**	**0**	**-209**	**-71**	**-149**	**-34**	**-544**	**-253**	**0**	**0**	**-1,298**
		Capacity	**13**	**0**	**4**	**19**	**32**	**4**	**42**	**123**	**59**	**4**	**2**	**303**
"10% ITC"	Onsite	*NO_X - no Model Rule*	*55*	*2*	*18*	*69*	*114*	*17*	*58*	*439*	*218*	*17*	*10*	***1,016***
		NO_X - w/ Model Rule	*11*	*2*	*2*	*16*	*29*	*2*	*58*	*153*	*62*	*3*	*3*	***341***
		SO_2	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*1*	*1*	*0*	*0*	***3***
	Offsite	NO_X	-5	0	1	-29	-8	-34	-3	-42	-86	0	0	**-206**
		SO_2	-21	-8	0	-153	-51	-108	-25	-398	-183	0	0	**-946**
	Total	**NO_X - no Model Rule**	**50**	**2**	**18**	**40**	**106**	**-17**	**56**	**397**	**132**	**16**	**10**	**810**
		NO_X - w/ Model Rule	**6**	**2**	**2**	**-13**	**21**	**-32**	**56**	**112**	**-24**	**3**	**3**	**135**
		SO_2	**-21**	**-8**	**0**	**-152**	**-51**	**-108**	**-25**	**-397**	**-182**	**0**	**0**	**-944**
		Capacity	**9**	**0**	**3**	**14**	**24**	**3**	**30**	**90**	**44**	**3**	**2**	**221**
"0% ITC"	Onsite	*NO_X - no Model Rule*	*41*	*2*	*13*	*52*	*86*	*12*	*49*	*337*	*165*	*12*	*7*	***776***
		NO_X - w/ Model Rule	*9*	*2*	*1*	*13*	*24*	*1*	*49*	*128*	*51*	*3*	*2*	***284***
		SO_2	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*1*	*0*	*0*	*0*	***2***
	Offsite	NO_X	-3	0	1	-23	-6	-26	-1	-33	-66	0	0	**-156**
		SO_2	-16	-6	0	-119	-38	-82	-20	-314	-141	0	0	**-737**
	Total	**NO_X - no Model Rule**	**38**	**2**	**13**	**29**	**80**	**-13**	**48**	**304**	**99**	**12**	**7**	**620**
		NO_X - w/ Model Rule	**6**	**2**	**2**	**-9**	**18**	**-24**	**48**	**96**	**-15**	**3**	**2**	**128**
		SO_2	**-16**	**-6**	**0**	**-119**	**-38**	**-82**	**-20**	**-313**	**-141**	**0**	**0**	**-734**
		Capacity	**7**	**0**	**2**	**11**	**19**	**2**	**24**	**71**	**34**	**2**	**1**	**173**