Technical Support Document
for the Final
Clean Air Interstate Rule

Cogeneration Unit Efficiency Calculations

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In the CAIR rule, certain cogeneration units may qualify for an exemption from the CAIR. A cogeneration unit can qualify for the exemption if it meets EPA's definition of a cogeneration unit and sells 1/3 or less of its potential electric output capacity. For further discussion, see section VIII of the CAIR. To meet EPA's definition of cogeneration unit, a cogeneration unit must meet a minimum efficiency standard. EPA proposed and is finalizing a minimum efficiency standard of 42.5% as calculated by using the efficiency formula used under the Public Utilities Regulatory Policy Act ("PURPA"). As discussed in the proposal and this final rule, a cogeneration unit must meet this minimum efficiency standard regardless of the fuel it utilizes. The purpose of an efficiency standard in this rule is to prevent units with very low efficiencies from claiming the cogeneration exemption. Without a minimum efficiency standard, a potential loop hole would exist for units to claim the exemption by sending a nominal or insignificant amount of thermal energy to a process. For further discussion, see section VIII of the CAIR.

The minimum efficiency standard EPA proposed and is finalizing (42.5% using the PURPA efficiency formula applied to any fuel) is intended to be a standard that most cogeneration units can meet. To demonstrate this, EPA has calculated efficiencies of a range of cogeneration units. Some commenters expressed concern that applying an efficiency standard to coal-fired cogenerators may adversely impact coal-fired cogenerators because some may not meet the efficiency standard and therefore become affected units under the CAIR. This document shows that the efficiency standard chosen by EPA is one that most coal-fired cogenerators should be able to meet and therefore the standard should not have a significant adverse impact on coal-fired cogenerators.

EPA selected a range of coal-fired cogeneration units from 25 to 250 MWe output and calculated the efficiency of each system to determine whether they would meet the minimum efficiency required to qualify as a cogeneration unit. This range includes three different cogeneration units, two utilizing back pressure turbines and one utilizing an extraction /condensing turbine. Back pressure units larger than 100 MWe were not selected because generally the larger the back pressure unit the higher the efficiency. Therefore, if a 100 MWe unit meets the efficiency standard then EPA feels it is reasonable to assume that larger back pressure units would also meet the efficiency standard. A 250 MWe condensing extraction unit was chosen because condensing extraction units smaller than 250 MWe are not expected to be common due to the higher capital cost of these units compared to back pressure units. Similar to back pressure units, generally speaking, efficiency increases as the MW capacity increases and thus EPA believes it is reasonable to assume that most condensing extraction units larger than 250 MWe would also meet the efficiency standard if a 250 MWe condensing extraction unit meets the efficiency standard. Coal-fired units were selected, because EPA received no adverse comments regarding applying the proposed efficiency standard to oil or gas-fired cogeneration units.

Table 1 below describes each coal-fired cogeneration system selected as well as the assumptions used in the calculations. EPA considers these assumptions to be reasonable for the units described. In the condensing/extraction case, the greater the process steam flow the higher the PURPA thermal efficiency will be. To be conservative, EPA assumed approximately 30% of the turbine throttle steam flow is sent to process. Some condensing/extraction units such as those burning low-rank coal or biomass may need to send more than 30% of turbine throttle steam flow to process to meet the 42.5% PURPA thermal efficiency standard. EPA expects most back pressure units burning low-rank coal or biomass to meet the efficiency standard because 100% of the throttle steam is sent to process, which has the effect of increasing the unit's efficiency. See Table 2 which shows the higher efficiencies associated with back pressure units as compared to condensing/extraction.

The calculations and results for each representative cogeneration unit are shown in Table 2 below. The results show that in all cases, the efficiency of the coal-fired cogeneration unit meets the minimum efficiency standard for qualifying as a cogeneration unit. Based on this analysis, EPA expects most coal-fired cogeneration units will meet this minimum PURPA thermal efficiency standard.

Table 1: Representative Cogeneration Units and Assumptions

Cogeneration units	Operating Assumptions
25 MW capacity back pressure steam turbine. Inlet steam conditions are 1250 psig, 900 deg F. Outlet steam conditions for process are 165 psia. All outlet steam is used by the process, i.e., no steam is condensed for additional power output. Assume boiler efficiency of 87% burning bituminous coal. No condensate is returned from the process.	Turbine Isentropic Efficiency - 80%. Turbine Mechanical Efficiency - 97%. The cycle includes a direct contact feedwater heater - there are no closed feedwater heaters. Lower Heating Value ("LHV") is 3% of Higher Heating Value ("HHV") for bituminous coal.
100 MW capacity back pressure steam turbine. Inlet steam conditions are 1800 psig, 900 deg F. Outlet steam conditions for process are 165 psia. All outlet steam is used by the process, i.e., no steam is condensed for additional power output. Assume boiler efficiency of 87% burning bituminous coal. No condensate is returned from the process.	Turbine Isentropic Efficiency - 84%. Turbine Mechanical Efficiency - 97%. The cycle includes a direct contact feedwater heater - there are no closed feedwater heaters. LHV is 3% of HHV for bituminous coal.
250 MW capacity condensing extraction steam turbine. Inlet steam conditions are 2400 psig, 1000 deg F. Outlet steam conditions for process is 165 psia. Assume boiler efficiency of 87% burning bituminous coal. No condensate is returned from the process.	The cycle is based on a system consisting of six closed feedwater heaters and a direct contact feedwater heater. An existing heat balance is used, which is modified by adding an automatic extraction point at 165 psia.[1] Boiler efficiency is assumed at 87%. Condenser cooling is provided via once

	through cooling.

1. R.C. Spencer, K.C. Cotton, and C. N. Cannon, “A Method for Predicting the Performance of Steam Turbine Generators - 16,500 kW and Larger,” ASME, Winter Annual Meeting, New York, Revised July 1974 version. Also, “Heat Rate Improvement Guidelines for Existing Fossil Power Plants,” EPRI CS-4554, May 1986.

Table 2: Cogeneration Unit Calculations

Cogeneration unit type	Backpressure	Backpressure	Condensing Extraction
Turbine Gross Electrical Output (MW)	25	100	250
Turbine Net Electrical Output (MW)	23	93	225
Turbine Net Electrical Output (BTU/hr)	79,332,023	317,328,090	767,818,307
Turbine Throttle Steam Flow, lb/hr	486,384	1,688,520	1,846,913
Turbine Throttle Steam Pressure (psig)	1,250	1,800	2,400
Turbine Throttle Steam Temperature (F)	900	900	1,000
Turbine Throttle Steam Enthalpy, (Btu/lbm	1,438	1,416	1,461
Reheat Steam Flow, lb/hr	NA	NA	1,619,929
Reheat Steam Enthalpy Gain in Boiler, Btu/lbm	NA	NA	212
Process Steam Flow (lb/hr)	400,000	1,385,000	539,000
Process Steam Pressure (psia)	165	165	100
Process Steam Enthalpy (Btu/lbm)	1,257	1,208	1,389
Condenser Pressure (in Hg abs)	NA	NA	1.0
Make-up Water Enthalpy (BTU/lbm)	58	58	58
Process Thermal Output (BTU/hr)	479,600,000	1,592,750,000	717,516,800
Power to Heat Ratio	0.17	0.20	1.07
Boiler Efficiency	0.87	0.87	0.87
Boiler Feedwater Temperature	305	300	400
Boiler Feedwater Enthalpy (BTU/lbm)	277	265	385
Fuel Heat Input HHV (BTU/hr)	648,847,437	2,234,474,800	2,678,593,275
Fuel Heat Input LHV BTU/hr	629,382,014	2,167,440,556	2,598,235,477
Thermal Efficiency (%)\	86.1%	85.5%	55.5%
PURPA Thermal Efficiency (%)	50.7%	51.4%	43.4%
PURPA Thermal Efficiency Standard (%)	42.50%	42.50%	42.50%
PURPA Thermal Efficiency = (Net Electric Output + Net Thermal Output/2)/Fuel Heat Input (LHV)			
Thermal Efficiency = (Net Electric Output + Net Thermal Output)/Fuel Heat Input (HHV)			