Certification of Combined Heat and Power Systems: Establishing Emissions Standards

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September 2001

Report Number IE014

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ACKNOWLEDGEMENTS

The authors would like to thank The Energy Foundation and Oak Ridge National Laboratory for the support that made the preparation of this report possible. Special thanks are extended to Cheryl Carter, of the Natural Resources Defense Council (NRDC), who provided insights on the California regulatory process. We are grateful to Joel Bluestein, of Energy and Environmental Analysis, Inc., for providing technical input regarding CHP system treatment and the emissions characteristics of various technologies. We would also like to thank NRDC, the Center for Clean Air Policy (CCAP), The Energy Foundation, and the other organizations for participating in the working group that provided the forum for the development of the ideas set forth in this report. The authors thank all these, and others unnamed, for their help.

SUMMARY OF KEY RECOMMENDATIONS

Combined heat and power (CHP) is more energy efficient than the separate generation of electricity and thermal energy. CHP systems generate electricity (and/or mechanical energy) and thermal energy in a single, integrated system. Heat that is normally wasted in conventional power generation is recovered as useful energy for satisfying a thermal demand, thus avoiding the losses that would otherwise be incurred from separate generation of power. CHP systems are highly efficient (and thus emit less carbon dioxide [CO_2]) and reliable. Modeling analysis has demonstrated that clean CHP technologies have significant air emissions, transmission, and price benefits (Morris 2001). Despite these benefits, CHP remains an underutilized technology hindered by a number of disincentives. According to Elliott and Spurr (1999), the main barriers to the implementation of CHP are

- complicated permitting systems that are complex, time consuming, and varied;
- regulations that do not account accurately for the overall system efficiency of CHP or credit displaced emissions and grid losses;
- difficult and frequently prohibitive interconnection arrangements with utilities; and
- depreciation schedules that do not reflect the true life of CHP assets.

To encourage the market to recognize the benefits of CHP, we recommend the following measures:

1. Establish output-based regulations—Output-based regulation encourage efficiency;
2. Calculate compliance based on displaced emissions— CHP units produce two types of energy, but thoughtful regulations can encourage the most economically and environmentally beneficial configuration for each system .We recommend calculating a CHP unit's compliance with electric emissions rates by subtracting the emissions that would have occurred at a stand-alone boiler;
3. Continue a proper accounting for the emissions benefits of CHP beyond 2007 indefinitely;
4. Establish efficiency requirements and a timetable for improvement:

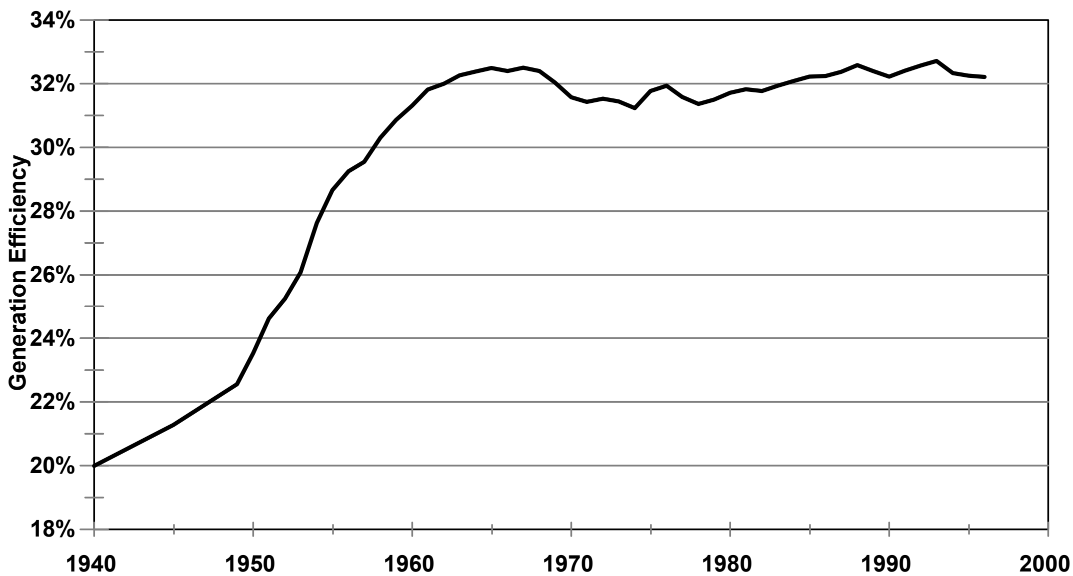
   2003: minimum 55% system efficiency
   2008: minimum 60% system efficiency
   2012: minimum 65% system efficiency

5. Establish operational requirements—At least 20% of a system's output should be thermal and at least 20% electrical to ensure that they are proper CHP units; and,
6. Ensure that labeling and certification strategies include CHP—All the reasons to develop labeling and certification of other DG technologies also apply to CHP.

INTRODUCTION TO THE BENEFITS OF CHP

Combined heat and power (CHP) systems, also known as cogeneration, generate electricity and thermal energy in a single, integrated system (Elliott and Spurr 1999). CHP is more energy efficient than separate generation of electricity and thermal energy. Heat that is normally wasted in conventional power generation is recovered as useful energy for satisfying an existing thermal demand, thus avoiding the losses that would otherwise be incurred from separate generation of power. The average efficiency of U.S. electric generation has been stagnant since the 1960s at about 32 percent (see Figure 1), while overall efficiencies of greater than 80 percent are being achieved today by CHP systems. By utilizing high-efficiency heat and power systems, we can extract a greater amount of the available energy from our natural resources. Increased fuel efficiency translates directly into reduced emissions of greenhouse gases (GHG) and other pollutants. CHP systems can be employed in many commercial and industrial facilities where there is a relatively constant thermal need. This thermal demand can take the form of hot water, steam, space heating, cooling, and refrigeration. (For more information on the benefits of CHP, refer to Appendix A, and for more information relating to the environmental impact of CHP, refer to Appendix B).

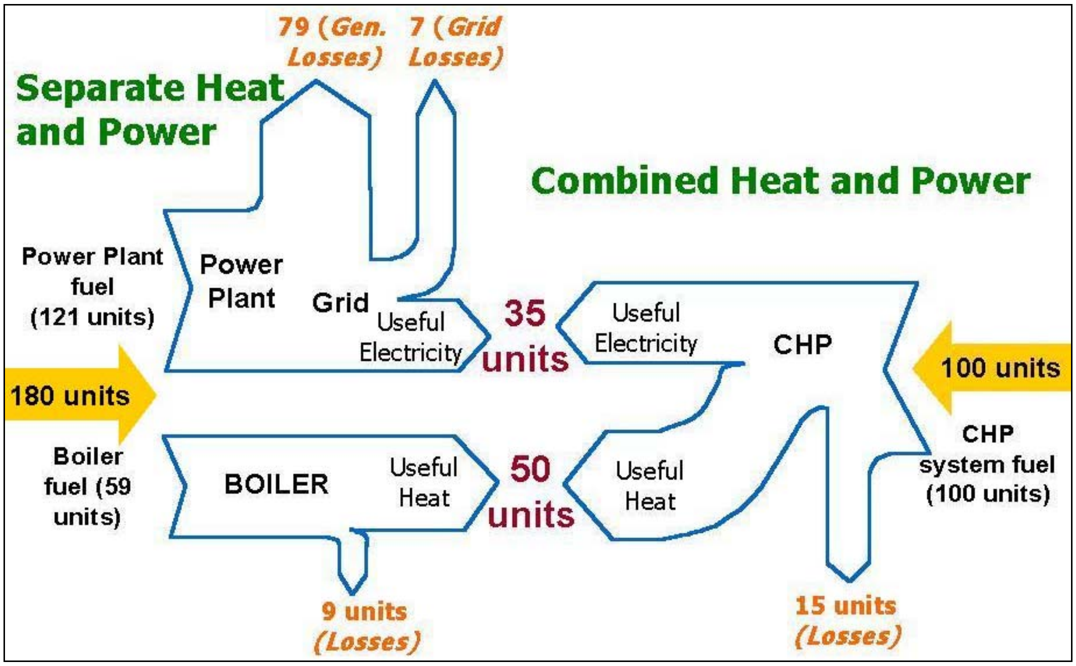
Figure 1. Efficiency of Electricity Generation in the United States



Source: Hall (1998)

Figure 2 displays how a CHP system compares to a system in which heat and power are separately obtained. In the system shown below, it requires 180 units of fuel input in a separate heat and power system to achieve the same usable electrical and thermal energy output as a CHP system that requires only 100 units of fuel input. The graphic displays how much greater the losses are in separate heat and power systems.

Figure 2. Energy Flows in a Typical CHP System



Source: Kaarsberg and Elliott (1998)

STRATEGIES TO USE AS INCENTIVES FOR OVERCOMING BARRIERS TO CHP

Combined heat and power systems are highly efficient, reliable, and offer flexibility in fuel selection. Modeling analysis has demonstrated that clean CHP technologies have significant air emissions, transmission, and price benefits (Morris 2001). Despite these benefits, CHP remains an underutilized technology hindered by a number of disincentives. These barriers can be summarized as

- complicated permitting systems that are complex, time consuming, and varied;
- regulations that do not account accurately for the overall system efficiency of CHP or credit displaced emissions and grid losses;
- difficult and frequently prohibitive interconnection arrangements with utilities; and
- depreciation schedules that do not reflect the true life of CHP assets (Elliott and Spurr 1999).

One of the greatest barriers to the installation of CHP is the complicated and lengthy plant siting and permitting process. In nitrous oxide and ozone environmental quality non-attainment areas, major new emission sources are required to meet New Source Review (NSR) requirements to obtain operating and construction permits. NSR sets stringent emission rates for criteria pollutants and requires the installation of the best available control technology. New sources are also required to offset existing emissions in non-attainment areas. However, current emissions standards are generally based on fuel input, an approach that does not recognize the fuel efficiency of CHP technologies. Moreover, non-uniform interconnection standards and unfair utility tariffs inhibit the installation of CHP and other distributed generation (DG) resources.

The following paragraphs outline some of the strategies that can be employed on the state level to help make CHP an attractive option.

Output–Based Regulations

Current air regulations do not take into account the increased efficiency benefits that occur when heat is recovered in a generation system. Creating output-based standards for pollutants (in pounds per megawatt-hour [lbs/MWh] output or equivalent unit) for emissions would allow CHP to take credit for this increased fuel utilization. The creation of output-based standards is absolutely key in encouraging the adoption of the cleanest and most efficient electricity generation technologies. Several states have prepared rules for the adoption of output-based standards. For example, the Massachusetts restructuring legislation directs its Department of Environmental Protection (DEP) to develop an output-based standard for any pollutant determined to be of concern to public health and also to implement at least one standard by May 2003 (Massachusetts Department of Environmental Protection 1999). In a related effort, the Northeast States for Coordinated Air Use Management (NESCAUM) has devised a model Emission Performance Standard rule, on an output basis, for its member states (Northeast States for Coordinated Air Use Management 1999).

When devising output-based standards, it is important to understand the importance and value of thermal energy. There have been many debates over the value of recovered heat in a CHP system. It is difficult to imagine process steam or heated water output as being of the same value as electricity. However, one must consider how process heat is obtained in a separate heat and power arrangement. In typical industrial settings, boilers fueled by natural gas, fuel oil, or coal are required to provide steam and hot water needs. The combustion of a fuel to produce this heat has its own set of thermal losses and emissions. These losses are in addition to the losses and emissions inherent to grid-supplied electricity that must be purchased from the local utility. The value of heat must be considered in comparison to how it is obtained in a standard situation.

While many regulators and energy experts consider CHP to be primarily an electricity-generating technology, it is important to understand that industrial and commercial operators frequently think of CHP as a heat-generating technology with the added benefit of on-site power production. Therefore, while thermal energy may be considered to be lower-quality (based on its difficulty in being converted to other forms of energy) than electricity, it is nonetheless highly valued in both industrial and commercial settings.

Calculating Compliance of CHP Units with Emissions Standards

A first step in considering which systems are worthy of receiving incentives is ensuring that existing CHP systems comply with emissions standards. Obviously, CHP systems should not be encouraged if they are more polluting than stand-alone systems. The California Air Resources Board's (CARB) most recent draft would establish a standard of 0.5 lbs nitrogen oxides (NO_x) per MWh of electricity (California Air Resources Board 2001). However, to be fair to CHP, we need to recognize that CHP produces two outputs, power and heat (see Figure 2).

There are two common ways to give credit for CHP in an output-based system (Bluestein 2001). The first is temptingly simple. Under this approach, the steam output from a CHP system is added to electric output (using 3.412 million British thermal units (MMBtu) of steam per MWh of electricity). By increasing the output, the emissions rate goes down. This method is relatively simple; however, it does not directly address the avoided emissions in a CHP system. Also, it treats steam as if it can do the same amount of work as electricity, which is physically not true. For this reason, in the past, some regulations have discounted the thermal output before converting it. Recent trends have been to give full credit for the thermal output.

Instead of this overly simplified approach, we recommend the following method for giving credit to CHP systems:

> When calculating compliance of an individual CHP unit with electric output-based emissions standards, the emissions from the unit should be discounted by the avoided emissions that a conventional system would have otherwise emitted had it provided the same thermal output. For example, a 35 megawatt electric (MW_e) CHP system with a power-to-heat ratio of 0.7 produces 50 megawatt thermal (MW_t). For this system, we assume that the CHP unit displaces a typical small industrial, commercial, or residential boiler with an efficiency of 80%. Using this assumption and the California emissions standard for boilers, we assume that the displaced boiler would emit as 0.036 lbs/MMBtu on an input basis, equivalent to 0.154 lbs NO_x/MWh_e on an output basis (California Clean Air Act 1998). Based on a power-to-heat ratio of 0.7, the emission credit on an electric basis would be 0.220 lbs NO_x/MWh_e. In other words, a CHP unit could emit 0.72 lbs NO_x/MWh_e and still comply with CARB's proposed 0.5 lbs/MWh standard (since 0.72 lbs NO_x/MWh_e - 0.220 lbs/MWh_e = 0.5 lbs/MWh_e). See the calculations on the next page for more details.

Using this approach, CARB could establish a single emissions standard in pounds per megawatt-hours of electricity for both stand-alone electric generators and CHP units. CARB would then have to establish guidelines for calculating compliance of CHP units based on CARB's own boiler emissions standards and the method outlined above.

Although the latest CARB draft does not propose continued preferred treatment for CHP after 2007, we encourage the board to consider crediting the displaced boiler emissions as an incentive (California Air Resources Board 2001). The approach presented here is the best way to merge the emission standards for electric generators and boilers. This approach reflects proper accounting and is not an incentive. Accordingly, we recommend that this approach be put in place indefinitely.

fictional CHP unit emission $rate_{electric}$ = 0.72 lbs NO_x/MWh_e
California boiler emission $rate_{boiler}$ standard = 0.036 lbs NO_x/MMBtu (input basis)
fictional unit power-to-heat ratio = 0.7

convert emission $rate_{boiler}$ from an input basis to an output basis:
assume: boiler efficiency (heat out/heat content of fuel in) = 80%

emission $rate_{boiler}$ (output basis) = emission $rate_{boiler}$ (input basis)/boiler efficiency
= 0.036 lbs NO_x/MMBtu / 0.8
= 0.045 lbs NO_x/MMBtu

convert emission $rate_{boiler}$ units from lbs/MMBtu to lbs/MWh_e:
emission $rate_{boiler}$ = 0.045 lbs NO_x/MMBtu * 3.412 MMBtu/MWh_t
= 0.154 lbs NO_x/MWh_t

convert emission $rate_{boiler}$ from lbs NO_x/MWh_t to lbs NO_x/MWh_e:
where: emission $rate_{boiler}$ = emission $rate_{boiler}$ (thermal basis) / 0.7
(based on power to heat ratio)
emission $rate_{boiler}$ = 0.154 lbs NO_x/MWh_t / 0.7
emission $rate_{boiler}$ = 0.220 lbs NO_x/MWh_e

calculate adjusted emission rate based on displaced boiler emissions:
adjusted emission rate = emission $rate_{electric}$ + emission $rate_{boiler}$
adjusted emission rate = 0.72 lbs NO_x/MWh_e - 0.220 lbs NO_x/MWh_e
= 0.5 lbs NO_x/MWh_e (CARB's draft standard)

Proposed Emission Standards

In comments filed on July 13, 2001, the Natural Resources Defense Council recommended the following schedule of emissions certification standards to the California Air Resources Board.

Standard Date	NO_x	CO	VOCs	PM
2003	0.50	6	1	tbd
2005	0.14	2	0.3	tbd
2006	technology review			
2008	0.05	0.08	0.02	tbd
2011 and then every 3 years thereafter, updated to latest California Best Available Control Technology level				

Note: VOCs = volatile organic compounds; PM = particulate matter; tbd = to be decided.

Using the approach outlined above and these recommended standards for NO_x emissions, the total emissions per megawatt-hour of electricity (i.e., before subtracting the displaced boiler emissions) that a CHP unit would be allowed is essentially a function of the power-to-heat ratio. The more heat a unit generates per unit of electricity, the smaller the power-to-heat ratio and the more boiler emissions displaced. In other words, units with lower power-to-heat ratios displace more boiler emissions and thus are allowed more total emissions. Figure 3 shows the relationship between the maximum allowed emissions and the power-to-heat ratio.

Referring back to the example provided above, a unit with a power-to-heat ratio of 0.7 installed before 2005 would have a total emission rate equal to or below 0.72 lbs NO_x/MWh. A unit with the same power-to-heat ratio installed between 2005 and 2008 would have to emit below 0.36 lbs/MWh; after 2008, a similar unit would have emit below 0.27 lbs/MWh. While these emissions rates would still force technology improvement for most engines and microturbines, they would be much less of a stretch than the electric-only generators. This suggests that this approach would indeed drive generator manufacturers to develop CHP units as a strategy to comply with CARB's standards.

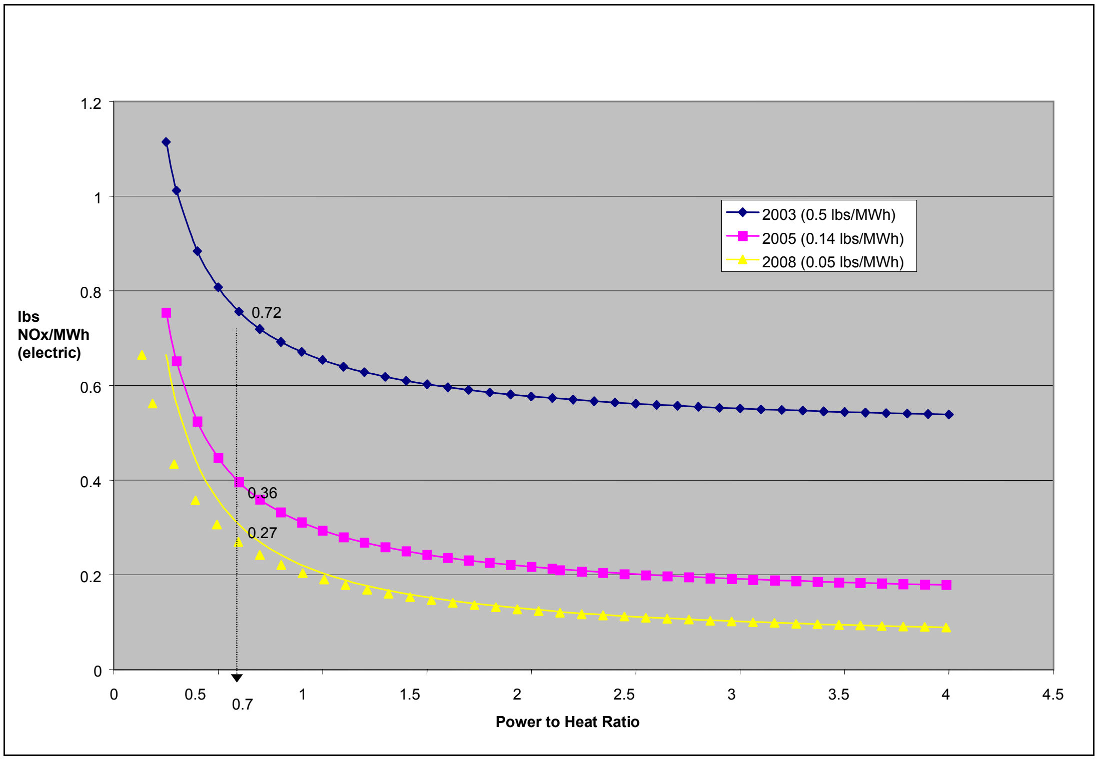
Establish Efficiency Requirements and Timetable for Improvements

As tighter air emissions standards begin to take effect over the next few years, distributed generation technologies will have to become more efficient and/or pollute less per unit of power output. This idea recognizes that DG technology performance efficiency is expected to improve over the next decade and will provide signals to developers and manufacturers regarding appropriate targets and also the benefits of achieving higher efficiency.

We recommend requiring higher efficiencies in future years to qualify for the efficiency/CHP credits. The time scale would match the timeframes adopted for the emission factors and would—as the emission values—adopt a technology-forcing standard. Many designers of CHP systems consider 55% total efficiency to be the minimum efficiency for a well-designed system. This could be a starting point from which incentives would be offered. The minimum efficiencies for incentives would then increase on a 3- to 5-year schedule. We recommend the following efficiency schedule for the offering of incentives:

2003: minimum 55% system efficiency
2008: minimum 60% system efficiency
2012: minimum 65% system efficiency

Figure 3. Emissions and the Power to Heat Ratio: Maximum NO_x Emissions from Units



Source: Greene's calculations based on NRDC's Proposed Emission Certification Standards and displacing 80% efficient boiler

Establish Operational Requirements: Minimum 20% Thermal Output or 20% Electrical Outlet

In 1978, Congress passed the Public Utilities Regulatory Policy Act (PURPA), which created the category of independent power producer for those facilities that used cogeneration. PURPA provided the only way for non-utility generators to sell excess electricity. The act required that only 5% of the usable output of a system must be heat. Such a small amount of recovered heat, however, results in a system with a relatively low efficiency. In order to reach efficiencies in excess of 55% based on a higher heating value (a figure that has been accepted by advocates of CHP as a minimum efficiency for a well-designed system) and to be economically viable, CHP systems must have a power-to-heat ratio somewhere between 0.2 and 5. The European Union has supported similar operational requirements for giving credit to CHP. This treatment was included in an earlier draft of the CARB draft rule. Such treatment provides assurance that the technology is delivering high-efficiency performance and should remain in the standard.

Labeling Strategy or Certification

Labeling serves to differentiate products within the same product group. One of the goals of labeling is to educate the buyer in the hopes that s/he will purchase an energy-efficient technology, thus decreasing the market for less-efficient technologies and eventually pushing them out of the market. For example, the European auto labeling initiative hopes to raise the fuel economy of cars by using the label to impact buyers' decisions, potentially increasing the demand for more fuel-efficient autos (Austrian Energy Agency 2001). Because lower efficiency products are removed, the efficiency of the entire product line increases.

Labeling also allows for standardization of testing within a market. With standardization, a buyer can know that all the products in the line are tested in the same way. Standardization also allows for product differentiation and creates tools for marketers of efficient products. For example, highly efficient home appliances qualify for the ENERGY STAR® rating from the U.S. Environmental Protection Agency (EPA). Marketers can use this as leverage over other products in the same product class.

Obviously, for the label to influence consumers, the emissions information must be included and the label must be prominently displayed either on the unit itself or in promotional material.

ADDITIONAL RECOMMENDATIONS FOR PROMOTING CHP

The measures that have been described thus far are of utmost importance in creating a regulatory environment that allows CHP its fair place in the market. In this section, we outline several recommendations that can be used in conjunction with the ones described earlier, but would in and of themselves not provide adequate impact in the market. They should be thought of more as complimentary measures to the ones already outlined.

Recognizing CHP under DG/Renewable Incentive Programs in California and Elsewhere

California has established a few incentive programs in recognition of the benefits of renewable energy and DG resources. For example, the Solar Energy and Distributed Generation Grant Program, developed by California Energy Commission under California Senate Bill 1345, provides grants to help Californian developers offset the cost of purchasing and installing new solar energy and distributed generation systems (Carter 2001). The current annual funding for the DG program amounts to $750,000 (Carter 2001). Eligible DG technologies include microcogeneration, gas turbines, fuel cells, reciprocating internal combustion engines, and electricity storage systems.

The state could consider adoption of benchmark requirements (e.g., emission standards or efficiency of the CHP system) and provide credit to clean, efficient CHP under the program. Since CARB's emission standard could well be adopted as the trigger for these incentive programs or interconnection rules, it is critical that the standard set appropriate technology-forcing mechanisms. The emissions levels recommended by NRDC (as described above) would achieve this goal.

Creating Incentives for CHP under Cap-and-Trade Programs

Currently several emission cap-and-trade programs affect power generation units, including the federal Acid Rain Program's NO_x State Implementation Plan in the eastern United States, and the RECLAIM emissions market in southern California (Li 2001; U.S. Environmental Protection Agency 2001a). Under an emissions cap-and-trade program, an emission source must hold, and subsequently retire, emissions allowances equal to its past annual emissions. The rule of allowance allocation can both affect the costs of new generation and help create a more favorable environment for the adoption of clean, efficient technologies.

Compared to allowances allocation based on historic fuel input such as in the Acid Rain SO_2 trading program, an output-based allocation encourages clean, efficient plants and helps leveling the playing field for CHP generation (U.S. Environmental Protection Agency 2001b). Under an output-based system, plants receive the same allocation of allowances for the same level of production. However, the more efficient CHP plants will surrender fewer allowances with relatively lower emissions, resulting in an end-of-the-year revenue bonus. EPA's guidance document on NO_x cap and trade program has explicitly addressed output-based allocation to CHP systems (U.S. Environmental Protection Agency 2001a). The cap-and-trade model has been extended to the discussion of reducing carbon dioxide (CO_2) emissions, which would most directly reflect the efficiency benefits of CHP.

In a trading system where emission allowances are allocated to CHP, particular provisions are needed to avoid allowance double-counting. CHP displaces emissions from the electricity-generating units from the grid, as well as emissions from boilers. Therefore, when allowances are awarded to the CHP system, the allowances should be subtracted from the allowances pool for the power plants and boilers. The administrative and political challenge of reduced allowance allocation to existing power plants and boilers is not trivial.

Offset Credits

New generators must purchase emissions offsets to cover their potential emissions if they locate in non-attainment areas. Offsets are created when plants shut down and cease to emit or when existing sources undertake voluntary emission reductions (in excess of current regulations) and agree to new, federally enforceable emissions caps. Areas with more severe non-attainment status (i.e., southern California) typically have fewer and more expensive offsets available. States could adopt policy provisions to certify emissions offsets of CHP systems in displacing boiler emissions (e.g., NO_x and CO_2) and qualify the offset credits in regional emission reduction banks.

Emissions "Feebate" on an Output Basis

Offering an emission credit is sometimes insufficient in and of itself to encourage the adoption of efficient technologies. A combination of incentives for efficient technologies as well as disincentives for technologies that do not meet requirements can offer higher degrees of adoption. One such strategy could be a feebate program, similar to programs that have been proposed to promote efficient automotive technologies (DeCicco, Geller, and Morrill 1993).

A “feebate” program could be established for fossil heat and power sources within an air basin. Equipment with efficiencies worse than an established benchmark would pay a fee per British thermal unit, which would fund a system of rebates for operators of equipment with efficiencies better than the benchmark. The benchmark could improve over time on a prescribed schedule to push the envelope (and ease political opposition to the program at its inception). Investment planning could take rebate availability into account in determining what efficiency design targets should be set.

Cogeneration Portfolio Standard

Similar to the renewable portfolio standard adopted by states (American Wind Energy Association 1997; Massachusetts Division of Energy Resources 2000), a standard could be set to prescribe the percent of power that must be generated by either CHP technologies or generating plants with high efficiencies. A high-efficiency standard could be set by determining a heat rate benchmark and qualifying all plants below this heat rate. If set at a level above the average of the current generation mix, a portfolio standard will encourage the development of new, efficient generating technologies and CHP applications.

Summary and Conclusions

The inherent energy efficiency and fuel utilization benefits of combined heat and power systems make them an attractive option to conventional power and thermal energy systems. In this report, we have outlined several measures that can be implemented to overcome the current regulatory barriers to the implementation of CHP.

The implementation of these recommendations on both a state and federal level would help to create a fair market for combined heat and power technologies. As has been stated earlier, current regulations do not allow CHP to reflect the increased fuel utilization and reduced emissions inherent to the technology. Correction of the regulatory structure currently in place will help CHP compete with other DG technologies.

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APPENDIX A—BENEFITS OF CHP

Environmental Benefits

The significant increase in efficiency with CHP results in lower fuel consumption and reduced emissions compared with the separate generation of heat and power. Emission reductions include GHGs and regulated air pollutants such as nitrogen oxides, sulfur dioxide (SO_2), and particulates. Compared with NO_x emission rates of between approximately 0.5 and 2.2 lbs/MWh_e for non-diesel, small, DG technologies, CHP can emit less than 0.1 lbs/MWh_e. CO emissions can easily be reduced by 70%, and if the efficiency requirement presented in the body of this report are adopted by 2008, the CO_2 emissions of CHP units would be half that of most engines.

CHP is an economically productive approach to reducing air pollutants through pollution prevention, whereas traditional pollution control achieved solely through flue gas treatment provides no profitable output and actually reduces efficiency and useful energy output. In addition, since CHP generally displaces older thermal and electric generating equipment with newer, cleaner, and more efficient equipment, air pollution and GHG emissions are further reduced.

Economic Benefits

CHP can boost U.S. competitiveness by increasing the efficiency and productivity of our use of fuels, capital, and human resources. Dollars saved on energy would available to spend on other goods and services, promoting economic growth. Past research by ACEEE (Laitner et al. 1995) has shown that savings are retained in the local economy and generate greater economic benefit than dollars spent on energy. Recovery and productive use of waste heat from power generation is a critical first step in a productivity-oriented environmental strategy.

On a more local basis, CHP can be an engine for economic development, offering clean, low-cost energy solutions to many sectors of the economy. Some regions of the country are facing constraints in their electricity supply infrastructure, as evidenced by power shortages during the summers of 1999, 2000, and 2001. While efficiency and renewables have a crucial role to play in meeting our energy needs, new, efficient, and clean generation capacity can help meet the growing demand for electricity and replace aging power plants as they are retired. The market is already beginning to respond by building new merchant power plants in regions with limited reserves.

Benefits from Avoided Transmission and Distribution (T&D)

Our current electricity supply infrastructure relies upon power plants located remotely from the centers of electricity load growth. Transmission losses range from around 5% to near 20% in the United States, with the national average hovering near 10%. CHP facilities are located near the source of demand and can eliminate this additional loss.

It is becoming more difficult and costly to site new supply infrastructure due to congestion and opposition from neighbors to T&D lines and substations. Many people consider these facilities unsightly and potentially dangerous. The process to gain approval for the construction of these facilities can take years. In some areas, the T&D system is becoming overtaxed, leading to increased concerns about the reliability of electricity service, particularly during periods of peak demand. CHP alleviates this problem by locating the generation near the demand. In addition, district cooling systems have the ability to shift power demand from on-peak to off-peak periods using thermal energy storage.

By generating power at or near the site ("distributed generation") and using thermal energy storage, CHP helps avoid the construction of new central station power plants, and capacity in existing facilities can be freed for use by other customers for whom CHP is not an option. CHP capacity can be constructed more quickly than large central facilities, and the thermal energy can be recovered to meet local demand. In addition, DG reduces the load on the T&D infrastructure, helping to address capacity constraints and reliability concerns. DG reduces the need to build new T&D facilities, while allowing for demand growth. The load on the existing infrastructure is reduced by adding capacity within a transmission-constrained area, freeing capacity to meet other users' demand. In addition, some electric loads can be converted to thermal or direct-drive systems, further decreasing the electricity load.

CHP can play an important role in reducing peak demands. In states such as California, where peak demand coincides with periods of high temperatures and air conditioning loads, CHP can offer an alternative means of generating space conditioning while reducing summer demand peaks. The thermal energy captured in CHP systems can be converted to chilled water or ice during non-peak times (at night, for example) and used to provide cooling during times of high electricity demand.

Conventional separate heat and power generation wastes enormous quantities of energy, with significant environmental and economic implications. CHP represents a low-risk strategy for reducing pollution and increasing economic efficiency. CHP technologies are proven, cost-effective, and readily available. What are needed are policy and market signals that encourage adoption of CHP.

APPENDIX B: ISSUES RELATED TO EVALUATING THE ENVIRONMENTAL IMPACTS OF CHP

When considering ways to encourage the adoption of this highly efficient and economically attractive technology, there are several issues to consider, including valuation of thermal output, sizing of systems, system output and parameters, efficiency requirements, and possible labeling strategies.

Systems Should Be Sized Based on the Thermal Load

In order to understand how CHP systems are sized, it is important to examine the concept of the power-to-heat ratio. The thermal output of a CHP system is captured as the ratio of the power manufactured to the usable thermal energy. This parameter, the power-to-heat ratio ("), is the ratio of electrical and mechanical energy to thermal energy, and it varies with equipment selection and system design. This ratio is expressed as:

$$\alpha = \frac{e_{electric} + e_{mechanical}}{e_{thermal}}$$

So, for the example in Figure 1:

$$\alpha = \frac{35}{50} = 0.7$$

Typical power-to-heat ratios for combined heat and power systems range from 0.2 to 2.

The high efficiencies achieved in CHP systems are dependent on a facility's ability to utilize waste heat. Because of this, CHP systems must be designed to meet the thermal load, not the electrical load, of the system. The electrical load of the system can generally be met by adjusting the power-to-heat ratio of the system. If a facility experiences an unusually high electrical demand on a given day or time period, additional electrical power can be purchased from the grid. In many cases, agreements with local utilities can also be established in which excess electricity from a CHP system can be sold back to the utility.

Valuation of the Thermal Energy from CHP Systems

Most people approach CHP systems form the perspective of the power the systems generate, intentionally or unintentionally devaluing the thermal energy they produce. This approach stems in part from the experience with PURPA cogeneration systems, in which the efficiency of power generation was compromised by the extraction steam at a pressure above condensing in order to satisfy the needs of the "thermal host." At the time of PURPA's enactment, cogeneration was the only option for non-utility generators to play in the electricity market. With EPAct, that situation has changed and those focusing on power generation can build conventional power-only systems. Today, if an entity builds a cogeneration facility, it is in its economic interest to maximize the value of the heat produced.

This thermally based CHP approach requires a paradigm shift—the thermal load becomes the driver, with power generation being the by-product. Otherwise, onsite thermal demand would be met with a boiler or other thermal device. CHP systems add power generation to the thermal load, with a resulting increase in the onsite fuel consumption. The marginal fuel required to generate power is converted at a very high efficiency, usually significantly less than 4,000 British thermal units per kilowatt-hour (Btu/kWh). The resulting optimization of a CHP system, while thermodynamically identical to cogeneration, will produce a different design, usually with greater system efficiency and lower emissions.

The ratio of the net power generation to the thermal energy is referred to as the *power-to-heat ratio*. A facility will also have this ratio. While recent technology advances in allow for higher power-to-heat ratios, in most cases the facility ratio will be greater than the ratio for the CHP systems. As a result, the facility will be a net power purchaser. This fact has complicated the design of those systems in which facilities "island" themselves from the utility grid.

Energy is said to have a *quality*—the ability to do work. Electricity has the highest quality, with various thermal energy sources having decreasing value. The goal of system optimization is to match the quality of available energy to the quality required by the load. While higher quality energy can be used to satisfy a lower quality load (e.g., using electricity to produce hot water), the resulting system efficiency will be lower. Unfortunately, all facilities have significant low-quality thermal demands, so they may be limited in the maximum efficiency achievable.

Some potential exists for shifting energy demands to a lower-quality energy source. For example, mechanical refrigeration can be shifted to thermally activated cooling (e.g., desiccant or absorption), allowing for an increase in the overall system efficiency.