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Reduce, Reuse, and Renew:
One Possible Approach to Cut Carbon Emissions

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Abstract*

Global climate change has become an increasingly important issue over the last several years. This issue reached a climax at the Kyoto Conference in December, 1997 where the U.S. agreed to reduce its greenhouse gas emissions to 7 percent under its 1990 levels by 2010. This paper describes how distributed resources could be part of an overall solution to achieving these reductions. It illustrates how a system composed of energy efficiency, distributed cogeneration, and distributed photovoltaics could reduce fuel consumption by 70 percent in the residential and commercial sectors. This could be a solution that makes economic sense independent of the climate change debate if implemented over the next 30 to 50 years, a timeframe which is not much worse for the climate system than achieving them in 10 years according to most analyses.

The Kyoto Challenge

Global climate change has become an increasingly important issue over the last several years. This issue reached a climax at the conference that was held in Kyoto, Japan in December, 1997. At this conference, industrial nations around the world agreed to reduce their greenhouse gas emissions. The U.S. agreed to reduce its greenhouse gas emissions to 7 percent under its 1990 levels by 2010. This reduction equals the expected level of carbon emissions associated with generating electricity for the residential and commercial sectors in the U.S. in 2010 (EIA 1998a).

The Protocol encourages governments to pursue emissions reductions by improving energy efficiency, reforming the energy and transportation sectors, promoting renewable forms of energy, protecting forests and other carbon "sinks", phasing out inappropriate fiscal measures and market imperfections, and limiting methane emissions from waste management and energy systems. It creates new incentives for technological creativity and the adoption of "no-regrets" solutions that make economic sense and environmental sense irrespective of climate change.

A Distributed Resource Solution

How will the U.S. reduce its emissions? A part of the overall solution could come from the use of distributed resources to supply electricity to the residential and commercial sectors. Such a solution is attractive because: it will improve energy efficiency, reform the energy sector, promote renewable forms of energy, and be a solution that makes economic sense independent of the climate change debate. This last benefit assumes that the use of distributed resources is implemented over the next 30 to 50 years rather than the over the next 10 years. A massive implementation of distributed resources over the next 10 years would probably be very costly and may not make economic sense on its own merits.

Consider the effect distributed resources could have in the residential sector. Figure 1 presents the fuel consumed to produce electricity and the natural gas used for heating in the U.S. residential section in 1995. The figure is drawn to scale. It represents 16.5 Quads of energy consumption, 30 percent of which is natural gas and 70 percent of which is for electricity generation (EIA 1998a). The figure shows that two-thirds of the fuel consumed is lost in waste heat (48 percent is lost in the electricity generation and distribution process, 9

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percent is lost in the use of inefficient gas appliances,[1] and 9 percent is lost in the use of inefficient electric appliances[2]).

Figure 1 highlights the existence of two energy-savings opportunities. First, large energy savings can be realized by using electricity more efficiently at the point of consumption. This is because a unit of electricity saved at the point of consumption results in two additional units of energy that do not need to be produced in the first place. Second, energy savings can be realized by having more efficient gas appliances; the savings, however, are not as great as from an electrical perspective because there are minimal losses associated with delivering natural gas to consumers. Energy efficiency experts have recognized and exploited both of these opportunities for more than two decades.

Another way to view the potential for energy savings is to assume that the U.S. transitions from a centralized electric system to a distributed system. A distributed system is one in which the electricity is generated at the location where it is consumed. Some of the major benefits of a distributed system that have been identified in the past are a reduction in transmission and distribution system capacity requirements and a reduction in energy losses associated with the transportation of the energy. A third benefit is that it enables the consumer to capture waste heat, something that is impractical with central power plants because of the difficulty in transporting heat.

More specifically assume that each of the 100 million households in the U.S. takes a three-pronged approach to satisfying its electricity needs. Each household: (1) reduces its electricity consumption by one-third using electrical end-use efficiency measures; (2) replaces its gas furnace and water heater with a 2-kW cogeneration unit (and operates the unit so as to consume the same amount of natural gas as it currently consumes)[3]; and (3) installs a 2-kW photovoltaic (PV) system on its roof. The total fuel consumption for electricity and heating needs is as presented in Figure 2. The result is that all of the fuel used to generate electricity in the top portion of Figure 1 is eliminated. That is, 11.5 Quads or 70 percent of the total fuel currently used by residential consumers is no longer consumed.

[1] In 1995, space heating used 69 percent of the natural gas and had average losses of 27 percent and water heating used 25 percent of the natural gas and had average losses of 47 percent (EIA 1998a, 1998b). Assuming that all other uses of the natural gas are totally efficient, the lost energy due to inefficiency is about 30 percent of the natural gas consumed. 30 percent of 30 percent equals 9 percent.
[2] This number is based on the assumption that there are 40 percent losses associated with the use of the electric appliances.
[3] A cogeneration unit is one that produces both electricity and heat.

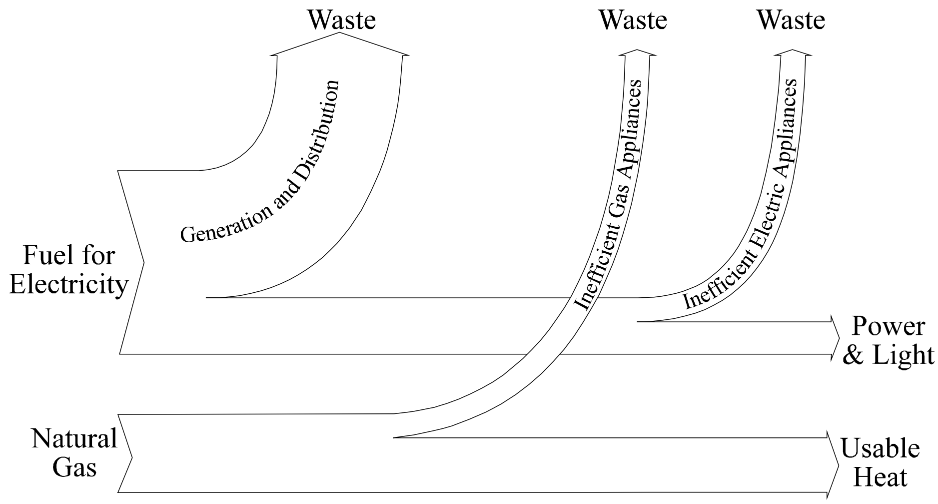

Figure 1. Actual energy consumption (U.S. residential sector in 1995).

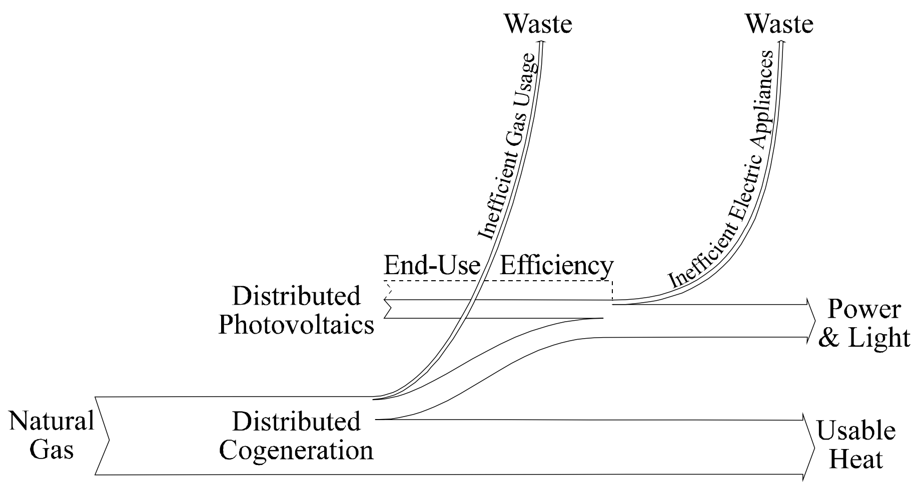

Figure 2. Potential energy consumption with distributed resources (U.S. residential sector in 1995).

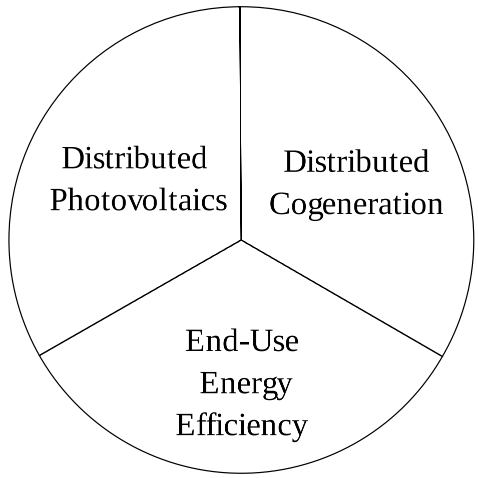

Figure 3. Fraction of electricity supplied using distributed resources.

A Three Pronged Approach: Reduce, Reuse, and Renew

Consider how such a result is possible in more detail. The three prongs of this approach are: 1) reduce electricity consumption through the use of end-use efficiency; 2) reuse energy lost in the space and water heating process through the use of distributed cogeneration; and 3) supply the remainder of the electricity demanded using renewable energy. As shown in Figure 3, each of these prongs satisfies one-third of the electrical demand.

Reduce

The first prong is to reduce electricity consumption by using the energy more efficiently. The Department of Energy's Energy Information Administration (EIA) estimates that the potential for energy savings associated with lighting is 35 percent of the electricity used on lighting (EIA 1996). Assuming that the potential for energy savings is the same for all other uses of electricity, employing electrical end-use efficiency measures will reduce electricity consumption by one-third.

Reuse

The second prong is to reuse energy lost in the space and water heating processes through the use of distributed cogeneration. While the approach of using cogeneration in industrial applications has been widely implemented, the use of cogeneration at the residential scale is virtually non-existent.

According to the EIA, 70 percent of the natural gas used for heating purposes was converted to useful heat while 30 percent was lost. Residential cogeneration units that have a 70 percent thermal efficiency and a 25 percent electrical efficiency would continue to produce the same amount of useful heat as the existing heating units without consuming any additional fuel.[4] In addition, they would generate one-third of the electricity consumed in the residential sector.[5] And this would occur with no additional gas usage. Small distributed resources that use natural gas could make residential cogeneration feasible.

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[4] Note that 25 percent electrical and 70 percent thermal efficiency may not be optimal. In fact, improved heat and electricity source/sink match may improve things even at a lower overall efficiency. In addition, it may be desirable to have the capability to dynamically adjust performance characteristics.

[5] In 1995, residential customers used 5.01 Quads of natural gas and 3.56 Quads of electricity. Twenty-five percent of 5.01 is approximately equal to one-third of the electricity consumed.

Renew

The third prong is to satisfy the remainder of the demand using renewable energy. Suppose that every household in the U.S. installs a 2-kW photovoltaic (PV) system on their roof. A 2-kW PV system in an average location in the U.S. will produce 3,500 kWh of electricity in a year. This equals one-third of the electricity consumed by the average residential consumer.

The Match Between Consumption and Production

Residential Sector

An important issue that arises after examining Figure 2 is whether or not there is a balance between production from the distributed resources and consumption over time. The first step in addressing this issue is to examine the match on a monthly basis. Figure 4 presents the measured electricity consumption and estimated production using distributed resources by month for the residential sector in 1995. The solid line is the measured consumption as reported by the Energy Information Administration (EIA 1995a). The bottom portion of the area plot is the estimated savings from energy efficiency (it equals one-third of the solid line), the middle portion is the amount of electricity produced by cogeneration (it equals 25 percent of the natural gas used for space and water heating – EIA 1995b), and the top portion is the amount of energy produced by the PV systems (the output distribution is based on measured data from Sacramento Municipal Utility District's PV Pioneers systems - Wenger, Hoff, and Pepper, 1996).

The figure suggests that there is a good match between consumption and production.[6] This is due to the fact that electricity produced by distributed cogeneration occurs primarily during the winter when space heating requirements are the greatest while electricity produced by distributed PV occurs during the summer when there is the most sunlight and cooling need. That is, the cogeneration and PV complement each other.

[6] The figure assumes that the cogeneration unit is operated to satisfy space and water heating demands at a constant efficiency. One may obtain an even better match between production and consumption by operating the unit differently.

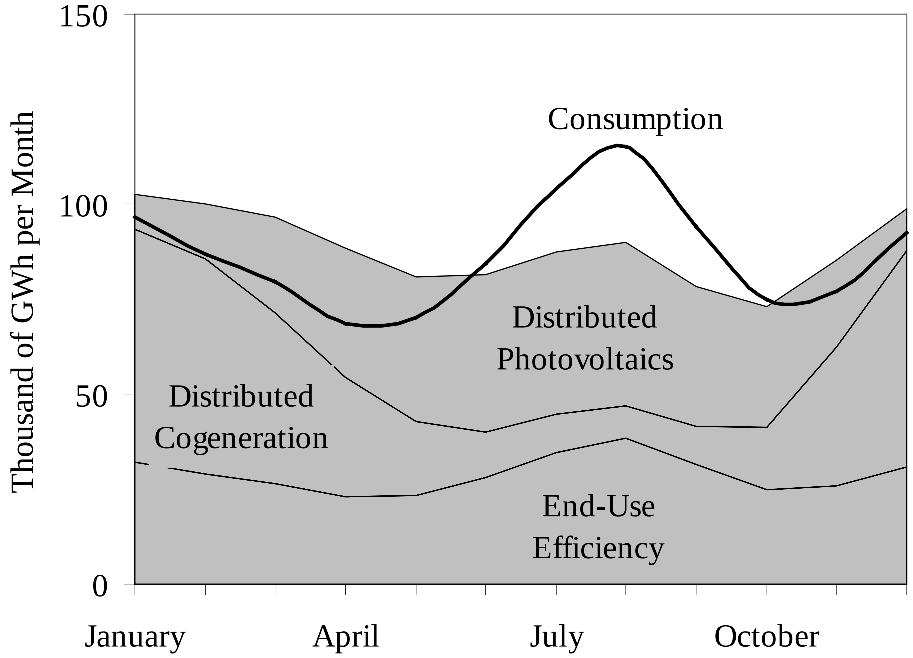

Figure 4. Measured electricity consumption and estimated production using distributed resources (U.S. residential sector in 1995).

Commercial Sector

The residential sector consumed 35 percent of the electricity and the commercial sector consumed 31 percent of the electricity in 1995. Suppose that the preceding analysis is repeated for the commercial sector. In this case, the commercial sector has a higher percentage of its end-use energy from electricity (3.23 Quads) than from natural gas (3.16 Quads). The electricity needs are met as follows: one-quarter from cogeneration, one-third from end-use efficiency, and the remainder from 200 GW of PV (this is same amount of PV as is installed on residences). The energy production is presented by month in Figure 5. Once again, production and consumption are well-matched.

Residential and Commercial Sectors

Figure 6 presents the match between production and consumption when the two sectors are added together.

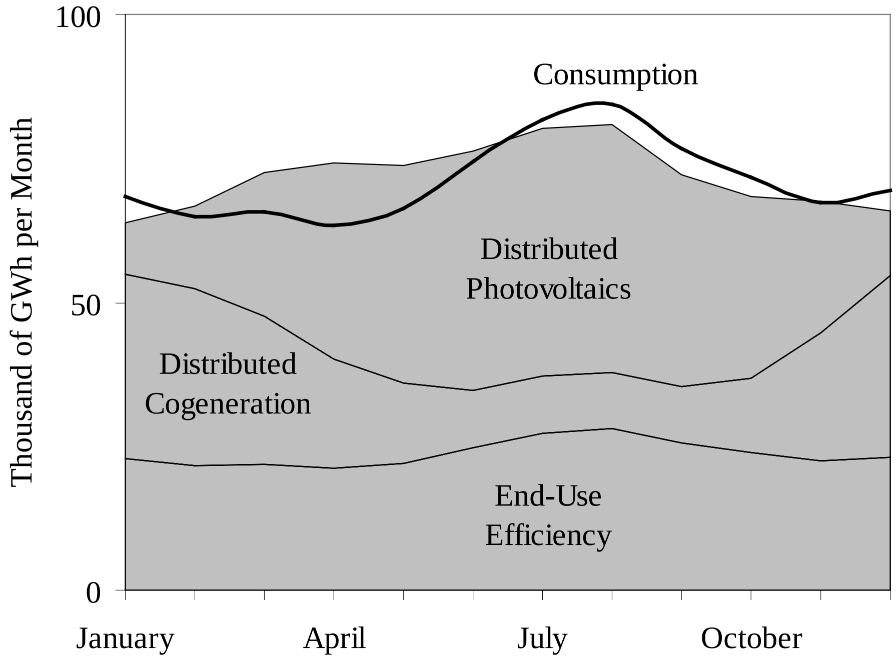

Figure 5. Measured electricity consumption and estimated production using distributed resources (U.S. commercial sector in 1995).

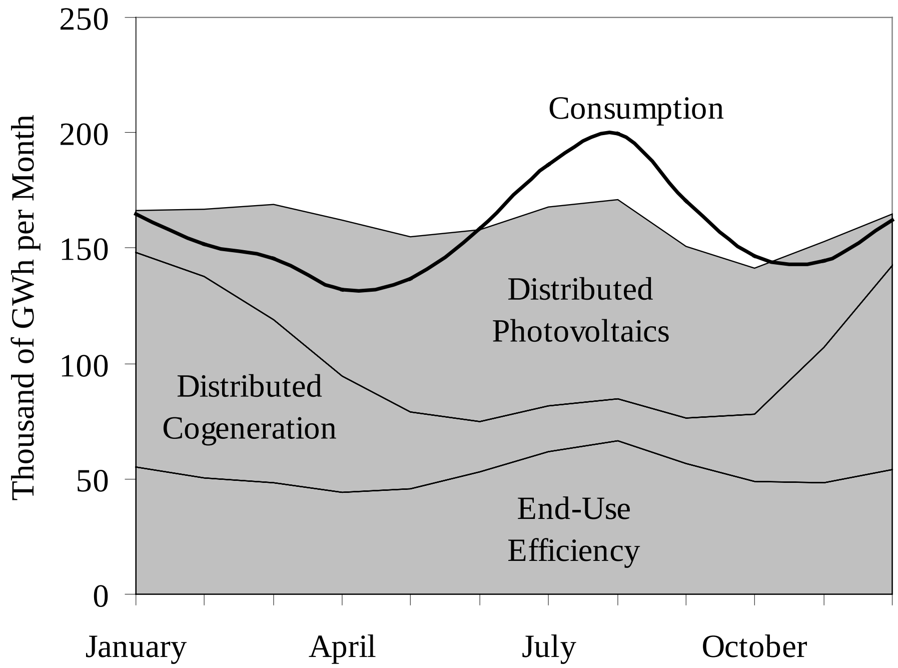

Figure 6. Measured electricity consumption and estimated production using distributed resources (U.S. residential and commercial sectors in 1995).

Investment Feasibility

The preceding discussion indicates that a distributed resource solution may be technically feasible but nothing has been said about the economic feasibility. Consider, first, the economic feasibility from a consumer perspective.

A Consumer's Perspective

The average U.S. residential household spent $300 on natural gas and $900 on electricity in 1995.[7] Suppose that the three pronged approach described above is implemented and that the existing utility manages the system imbalances associated with the distributed resources and charges each customer $100 per year for this service.[8] The average consumer would then have up to $800 per year for capital investments in the distributed resources.

[7] Each household consumed 10,500 kWh of electricity and 500 therms of natural gas (EIA 1998a).

[8] The $100 is calculated as follows: average consumption with the distributed resources will be 2/3 of the current level of 10,500 kWh per customer due to end-use efficiency or 7,000 kWh. Assume that 75 percent of the electricity produced by the distributed resources (5,250 kWh) will match demand and 25 percent (1,750 kWh) will not. At a cost of $0.06/kWh to manage the imbalance, the annual cost will be about $100. While this number may seem low compared to utilities' existing costs, one needs to keep in mind that the delivery requirements of the system are likely to be greatly decreased because much of the power will be consumed at the location where it is generated.

Table 1. Annual gas and electric utility bill.

	Current Bill	New Bill
Electric Bill	$900	$100
Natural Gas Bill	$300	$330[9]
Finance Charge for Capital Costs of: Efficiency: $1,700 Cogeneration: $1,000 PV System: $5,000 Total Capital: $7,700	$0	$755
Total Bill	$1,200	$1,185

As stated earlier, the distributed utility is composed of end-use efficiency improvements, a 2-kW cogeneration unit,[10] and a 2-kW PV plant. Suppose that the end-use efficiency improvements cost $1,700[11] and have a 10-year life, the 2-kW cogeneration unit has an effective cost of $1,000[12] and a 15-year life, and a 2-kW PV system costs $5,000[13] and has a 30-year life. Thus, the added capital cost for the distributed resources is around $7,700. If one took out 7 percent loan for each of these investments corresponding to their lives,[14] the payments would total $755. As shown in Table 1, the consumer's new annual utility bill is comparable to the current bill. In addition, there may be tax savings for the consumer if the interest on the investments can be written off the consumer's taxes.

A National Perspective

Consider, next, the feasibility of such large-scale electricity capacity additions from a national perspective. The *Annual Energy Outlook 1997* estimates that there will be about 15 GW of new capacity added each year between now and 2015. There are currently 100 million households in the U.S. Suppose that 3.3 percent (or 3.3 million households) make the capital investments in distributed resources per year so that the system is fully implemented in 30 years.[15] This translates to capacity investments of 13.2 GW per year for residential customers. It is likely that investments of about 10 GW would be needed to transform the commercial sector. Thus, the required investment is within the same order of magnitude of the distributed resource investments.

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[9] The natural gas bill increases by 10 percent due to the switch from an electric dryer to a gas dryer.

[10] It is assumed that the cogeneration unit has a 25 percent electrical and 70 percent thermal efficiency. At a 25 percent electrical efficiency, the energy input requirements of a cogeneration unit that had a peak electrical output of 2 kW would be 0.27 therms per hour (this is equivalent to the energy input requirements of a 30-gallon water heater) and the unit would run an average of 5 hours a day with a maximum of 10 hours per day in the winter (because of the space heating needs) and a minimum of 2 hours per day in the summer (because there are only water heating needs).

[11] Hoff, et. al. (1998) suggest that an investment of $1,700 could result in an electricity savings of 3,750 kWh/year. The investments (and annual kWh savings) are: compact fluorescent lights - $200 (750 kWh), air conditioning tune-up - $250 (600 kWh); new refrigerator - $750 (1,200 kWh); switch to gas dryer - $500 (save 1,200 kWh and increase gas usage by 50 therms).

[12] The effective cost of $1,000 is calculated as follows. Assume that the cogeneration unit is installed in a new house or in an older house when the old space heater wears out. Assume that the cogeneration unit costs $3,000 and that a new space heater and water heater cost $2,000. The consumer will spend $3,000 on the cogeneration unit and save $2,000 on not having to buy a new space heater and water heater. Thus, the effective cost of the cogeneration unit is $1,000.

[13] While the current market price for a 2-kW PV system is about $12,000, it is estimated that the price will be around $5,000 when systems are manufactured and sold on a large scale.

[14] The annual payments for efficiency, cogeneration, and PV would be $242, $110, and $403 respectively.

[15] It is worth noting that the US Census Bureau reports that about 3 Million heaters were sold in 1996; the report is not explicit about the size of the heaters to avoid disclosing data for individual companies.

From a total capacity perspective, there are currently 700 GW of generating capacity in the US, more than 70 percent of which use fossil fuels (EIA 1997a). If every household and commercial business had distributed resources, the total capacity investments would be about 700 GW.

Conclusions

Distributed resources represent a part of the solution to reducing carbon emissions when implemented over a 30-year time period. A three-pronged approach of using electrical end-use efficiency, distributed cogeneration, and distributed photovoltaics can be used to provide electricity at the point of consumption with a substantial reduction in fuel use and thus, a reduction in carbon emissions. All of the electricity requirements for the residential sector would be satisfied locally if every household in the U.S reduced its electricity consumption by one-third using end-use efficiency, replaced its space heater and water heater with a 2-kW cogeneration unit, and installed a 2-kW PV system. If the commercial sector made proportionately similar investments, the combined reduction in central station generated electricity would correspond to a reduction in emissions that met the reduction targets set at the Kyoto conference. The reduction, however, is likely to come over a 30-year time period rather than a 10-year time period. According to most analyses, however, a 30-year solution is not much worse for the climate system than a 10-year solution.

There are a number of barriers to the widespread implementation of distributed resources, including. Two of the most important barriers are the lack of residential cogeneration products and the cost of the investments (the authors are unaware of any 2-kW residential cogeneration products so that it is unknown what the cost of cogeneration will be; the cost of PV is currently about 2 to 3 times the cost assumed in this paper). Other barriers include: insufficient PV manufacturing capability (1996 U.S. production was 0.05 GW); structural changes required to move from a centralized utility with thousands of generators to a distributed utility with millions of generators; the period of time it will take to turn over the existing capital stock of space and water heating equipment; and potential imbalances between supply and demand on a shorter time scale (days, hours, seconds, and milliseconds).

Much can be done immediately without resorting to a massive and costly market intervention. One should commit to policies and measures that promote energy efficiency, residential and commercial cogeneration, and distributed photovoltaics on their natural timing (i.e., a steady implementation over the next 30 years rather than a rapid implementation over the next 10 years) rather than to meeting specific emissions targets. Taking the right actions today will result in some reductions initially; the bulk of the benefits of distributed resources will come over time.

Taking such an approach will encourage other countries to consider such an approach as well. This is valuable because the use of distributed resources may be applicable to developed as well as developing countries. The implementation of distributed resources on a global scale could make a significant impact on the reduction in global carbon emissions.

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