Market Diffusion Theory and the Penetration of Combined Heat and Power

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ABSTRACT

The use of market diffusion theory can contribute significantly to the understanding of how technologies are deployed. This approach may more accurately characterize market penetration than do technology choice models that rely only on net-present-value analysis. Yet, the application of this analytical technique relies heavily upon a robust understanding of the market characteristics of new technologies like buildings CHP. For industrial CHP, we already have a strong literature and market data to draw upon. But our understanding of CHP in buildings is much more limited. For the market diffusion model to be successfully applied, it is important that we develop the data that can provide an improved characterization of the market potential for CHP in commercial buildings.

Introduction

The diffusion rate for combined heat and power (CHP) systems is a fundamental question that analysts must address if they are to reasonably project the long-term penetration of this technology in the marketplace. Such projections must reflect, of course, the impact of existing market or technology barriers as well as the influence of those barriers once they are removed[1]. Technology diffusion is a well-established area of research in academia (Griliches 1957, Mansfield 1961; Blackman 1971, 1974; and Packey 1993). DeCanio and Laitner (1997) have suggested that diffusion models may be more appropriate for projecting the market share than technology choice models that rely on net-present-value analysis. As will be discussed later in the paper, this perspective is supported by many documented examples of how different technologies have diffused into the marketplace. The evidence on how CHP systems penetrated the market in response to the Public Utility Regulatory Policy Act of 1978 (PURPA) is but one example.

We have experience with the diffusion of CHP in the industrial and institutional district energy sector (Elliott and Spurr 1999). Our experience with CHP in the buildings sector is much more limited, however. CHP systems in this sector are in general much smaller than most industrial and district energy systems. While industrial CHP systems are often 40 megawatts or larger, building systems are typically less than one megawatt in size.

To build on the combined evidence on market diffusion, this paper will discuss how the diffusion theory can be applied to CHP markets. We seek to identify specific insights that we might gain into the diffusion of CHP in the buildings sector based on our experience with industrial CHP. We start by discussing existing diffusion market theory, and then look at the

[1] See Elliott and Spurr (1999) for a more complete discussion of the barriers that slow CHP market penetration.

industrial CHP experience. We then identify similarities and differences between CHP in buildings and industry. From there we propose a framework on how to model the diffusion of CHP in the buildings sector based on experiences and insights drawn from other established technologies. Finally, we identify additional work that will be needed to apply the diffusion model within the buildings sector.

Basic Notions of Market Diffusion

Mansfield hypothesized that the rate of adoption of a new technology is the direct result of the profitability of employing the innovation and the decreasing size of the investment required to use it (Mansfield 1961). More specifically, Blackman noted four things that heavily influence the adoption rate of a given technology or innovation:

(1) As market share increases, more information and experience are accumulated on the innovation. Its adoption then becomes less risky, and a "bandwagon" effect occurs;
(2) The more profitable an investment, the greater the probability of adoption;
(3) Market share will tend to increase as the size of the investment decreases with respect to the level of service provided; and
(4) For equally profitable products that require an equal investment, the rate of adoption will vary among industries because of the different characteristics of risk, the expected rate-of-return in different industries, and the different investment criteria among the different industries (Blackman 1971).

Drawing from Blackman and Mansfield, we can estimate the adoptive influence of the technology as follows:

$$a(t_2 \,\&\, t_1) \;'\; Ln\left[\frac{\left(\frac{1\&MS_1}{MS_1}\right)}{\left(\frac{1\&MS_2}{MS_2}\right)}\right]$$

"MS" refers to market share, *"t"* refers to time, and *"a"* is the adoptive influence resulting from a given set of policies for a technology with a given set of characteristics. "*Ln*" refers to the natural logarithm. For example, if MS_1 is 10 percent (or 0.10) in the year 2000, and MS_2 is 90 percent (or 0.90) in 2010, then using the expression above, *a* is shown to be 0.44. In fact, DeCanio and Laitner (1997) have suggested that the variable *a* hovers closely to 0.40 for a large number of technologies.

As an example of this point, we can use the market share data from four case studies (EPA 1996) to estimate their adoptive influences on market share. These are calculated as:

Electronic Ballasts	0.49
Catalytic Converters	0.37
Commercial Jet Engines	0.38
VCRs	0.44

In a similar manner, we can determine the level of adoptive influence shown by CHP technologies.

For purposes of illustration, and based upon the discussion that follows, it turns out that industrial CHP systems exhibit an adoptive influence similar to that of commercial jet engine technologies, or a value of 0.38. If we build on this value, and further assume a total cost-effective market potential of ~120 GW_e (gigawatts electric) by 2020, we can determine what the new market share might be in 2010. In effect, we need to solve for MS_2. When "*a* " (the adoptive influence) is known, the market share for any given year can be determined by the following calculation:

$$MS_2 = \frac{1}{\left[1 + \exp\left(Ln\left(\frac{1-MS_1}{MS_1}\right) - a \times dt\right)\right]}$$

If MS_1 is now 1/120 or 0.83 percent, a is 0.38, and t is 10 years, then by 2010 the growth of CHP would increase to a market share of 27.3 percent of the total 120 GW_e market potential, or 32.8 GW_e by 2010.

We can illustrate the changes that occur in market penetration as a function of both time and the adoptive influence of CHP technology. Figure 1 shows the different results over a broad range of *"a"* coefficients on an annual basis over a 20-year time horizon.

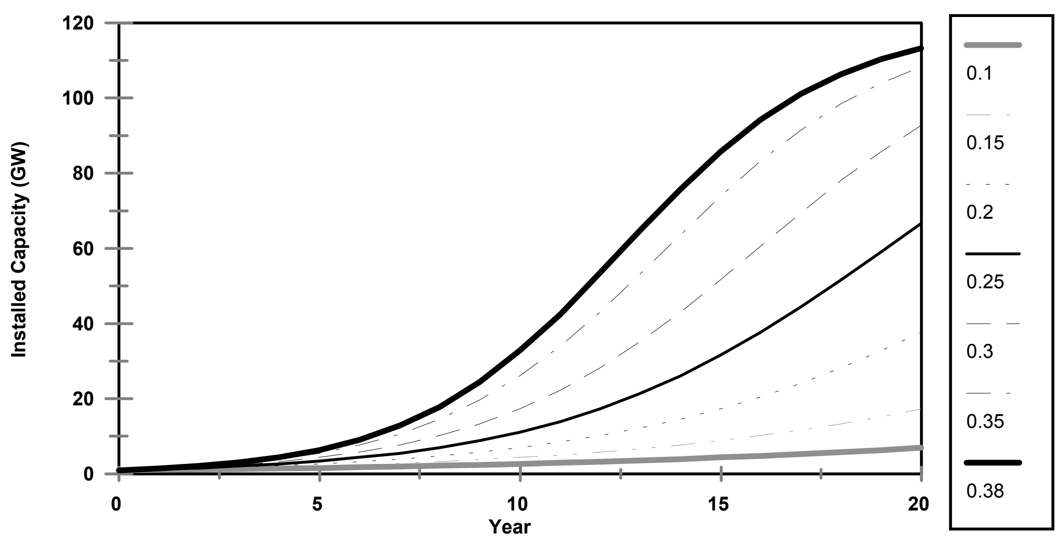

Figure 1. The Effect of a Diffusion Variable on CHP Market Penetration in GW_e over Time.

If the market diffusion variable is as low as 0.15, then by the 10th year (let's call it the year 2010), the CHP capacity would grow to only 4.4 GW_e. However, if the diffusion variable has a value of 0.38, then by the 10th year the capacity would grow to 32.8 GW_e as previously noted. This value implies a net gain of 28.4 GW_e.

What We Have Learned from Industrial CHP

There is strong evidence that the Public Utilities Regulatory Policy Act of 1978 (PURPA) played a critical role in expanding cogeneration in the United States. PURPA sought to increase the use of CHP in marketplace by addressing many barriers that were present at the time of its enactment. The act provided the only way for non-utility generators to sell excess electricity, requiring independent power producers to find a use for some of their waste thermal energy. Most generators found a "thermal host" to use the heat, usually an energy intensive manufacturing facility. This allowed these power producers to register as *qualifying facilities* (QF) under PURPA. These QF systems are optimized for the production of electricity, and are called "non-traditional" cogenerators. In contrast, the traditional CHP systems are thermally optimized to meet the needs of the host facility, with power production as a secondary output.

The 1980s saw a rapid growth of CHP capacity in the United States, and the majority of this capacity occurred in the industrial sector (EEA 1999). Installed industrial capacity increased from less than 10 GW_e in 1980 to almost 44 GW_e by 1993 (see Figure 2). Most of this capacity was from non-traditional facilities installed at large industrial complexes, such as pulp and paper, petroleum, and petrochemical plants.

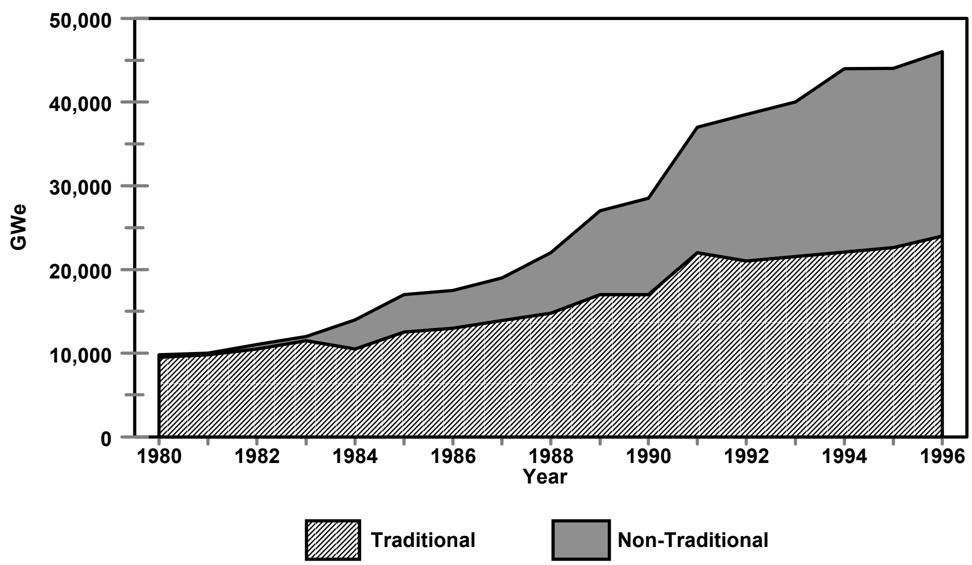

Figure 2. Installed Industrial CHP Capacity (EEA 1999).

It is useful to further explore the decomposition of the CHP market by category of ownership. Prior to PURPA, CHP facilities were overwhelmingly owned and operated by the thermal host. With PURPA and the emergence of non-traditional CHP systems, third-party ownership and operation began to dominate for new systems. In addition, some traditional systems were either constructed or acquired by third parties. The significance of ownership lies in the evaluation of economic viability for projects. This, in turn will affect the rate of market penetration of CHP units.

Due to competition for capital, many industrial and institutional entities require a high implicit rate of return (i.e., greater than 30%). This level of return can be achieved for some CHP projects, but is limited to the most attractive applications. A third party however will find an investment with a 15% rate of return highly attractive, and may consider investments of 10% or less (Sutcliff 1999). This lower threshold for economic viability expands the number of attractive CHP opportunities.

Additions to capacity slowed as the impacts of the Energy Policy Act of 1992 (EPAct) began to be felt in the mid-1990s (Figure 3). The EPAct initiated the current wave of utility restructuring, and created a new category of non-utility power plants, the exempt wholesale generator (EWG), that had no cogeneration requirements as was imposed under PURPA.

EPAct also expanded the number of potential ownership strategies for CHP systems. Consequently, third party developers, such as Trigen Energy and Onsite Sycom Energy moved aggressively into the marketplace. Many experts feel that most new capacity will be third party owned (Elliott and Spurr 1999).

It can be argued that the changes, which occurred under PURPA, are analogous to those that are anticipated should the current barriers to CHP be removed. It is therefore reasonable to use this experience to project future CHP market behavior. Resource Dynamics Corporation (RDC) has developed such an estimate of CHP diffusion, based on an analysis of the historical new capacity installation trends that occurred after PURPA was enacted (Figure 3). They used their proprietary DISPERSE model to estimate the industrial market potential for traditional applications (52,000 MW) based on the assumption that no output is sold back to the local utility. They also estimate the traditional and non-traditional application (96,000 MW) based on sales that are sold back to the grid (using prevailing sellback rates) (RDC 1999).

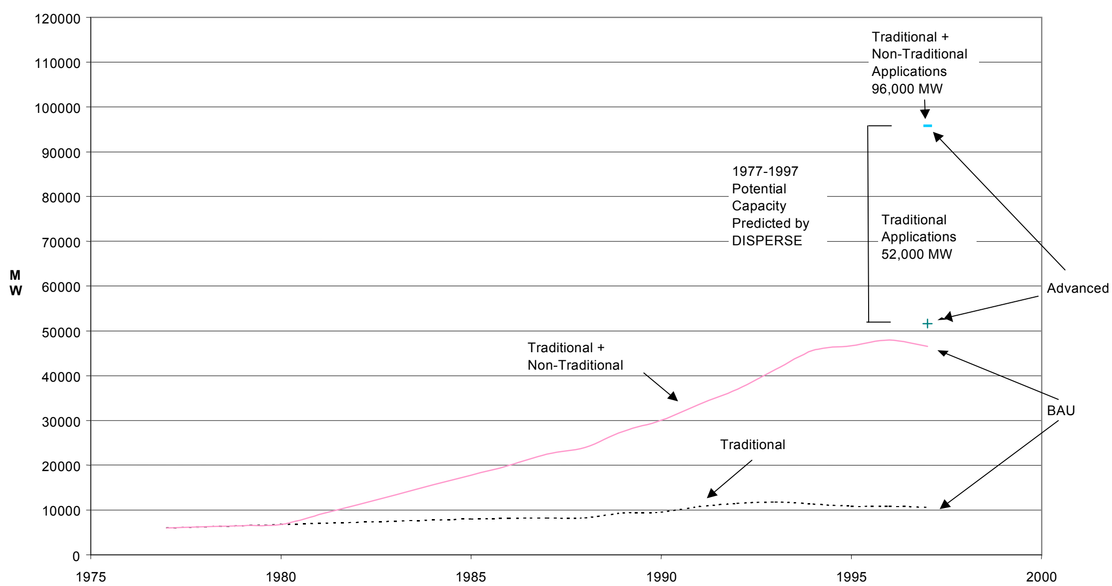

Figure 3. Predicted Economic Industrial CHP Potential (RDC 1999).

Using this methodology, RDC has developed parameters for future industrial CHP diffusion. In deriving the expected rate of penetration, however, the DISPERSE model uses the period from 1983-1993 as indicative of future growth. This assumption is made to avoid the early period (1977-1983) when the utility industry had overestimated demand growth, and was constructing excess capacity, which caused industrial firms to re-evaluate their cogeneration projects. Similarly, the 1993-1997 time frame was affected by electric utility restructuring, which again caused industrial establishments to reconsider plans to develop new CHP capacities. Projecting the 1983-1993 growth over the 2000-2020 time frame, an 18 percent market penetration rate was projected.

In this instance, it appears that CHP technologies will show a net gain of 4.4 GW_e by 2010. If the economic potential is 46 GW_e, the implication is that CHP will achieve 9.6 percent of potential market share by 2010 (RDC 1999).

For purposes of this analysis, let us assume a 1.0 GW_e capacity in the year 2000, or an assumed market share of 2.2%. Adapting the formula above, plugging in the relative market shares over the 10-year span and solving for *"a*," we would find that the adoptive influence of CHP is a very low 0.155. This level of market penetration is inconsistent with the DOE and EPA challenge to industry to double CHP capacity by 2010 which would yield about 30 GW_e of new capacity (Elliott and Spurr 1999).

Need for a New Modeling Framework

While RDC analysis represents an excellent historical exercise, the authors of this paper have several concerns in applying that specific analysis to the future market diffusion of CHP systems. First, the slowdown in new CHP capacity additions during the 1990s is likely the result of external market pressures. We believe that the market would still have been in an expansion phase. Hence, we can view the 1990s as an interruption in the classical "S-shaped" logistic curve. With a greater level of certainty established within the market, it can be argued that diffusion would resume at a rate similar to that experienced before the interruption.

In addition, we saw the introduction of several new technologies during the 1990s, most notably the low-cost, high-efficiency gas turbines that offered significant improvements in air emissions over earlier technologies. These technologies also improved the economics of CHP and expanded the range of feasible applications. Similar to the development in commercial jet engines (as we discuss below), these improvements should have accelerated the diffusion of CHP technologies, but we saw only limited market response.

The PURPA years also saw a change in the marketplace from owner-operated projects, to third party owned and operated projects (Elliott and Spurr 1999). This shift resulted in a gradual change in the economic criteria used to evaluate new projects. EPAct accelerated the shift in ownership while at the same time interrupting the expansion of new CHP markets. Again, the changing ownership patterns will affect the diffusion rate beyond that predicted by a conventional net-present-value analysis.

A PURPA-driven diffusion scenario may be an insufficient model for an aggressive scenario in which market barriers are removed, as described in Elliott and Spurr (1999). If we compare the policy drivers that are currently discussed for CHP with the drivers behind the historical diffusion related to the PURPA influences, we would conclude that the two scenarios are significantly different. A dramatically different economic and environmental context exists for each.

Thus, if the barriers are removed, the diffusion of CHP into the industrial market should be equal to or greater than that experienced after the implementation of PURPA. Still, we do need some kind of benchmark to identify an appropriate alternative framework of analysis. We suggest a more meaningful model may be the diffusion of commercial jet engines. As with CHP, we see third party ownership of engines and airframes, with leasing to airlines, as an important element in the market development. As we will show, there are other parallels as well.

Diffusion of Commercial Jet Engines

The jet engine was first developed in the United States during World War II, but did not saturate the commercial airline industry until the late 1960's and early 1970's. The relatively rapid diffusion of the jet engine into the commercial airline industry can be attributed to three major factors (Mowery and Rosenberg 1981).

First, technological spillover allowed commercial producers to adapt the expensive jet technologies that were developed primarily for military purposes. Without having to heavily invest in the initial engine development, private producers could more easily produce a profitable jet airbus for the commercial sector. Producers also received spillover technologies from the chemical, electronic, and materials industries. In many cases, these are the same industries that benefit from CHP applications.

Second, the government also affected the diffusion of the jet engine from the demand side. Not only did the military support the research and development (R&D) of the jet program, their contracts with plane producers allowed for companies to develop the capital equipment and production hardware needed for the production of military aircraft lines. These tools were then used again in the production of commercial aircraft.

Finally, the economics of the commercial airline industry dictated the rapid diffusion process. Economically, commercial jet planes flew at higher load factors than propeller models. In the regulated, fixed price environment of the time, it was far more profitable to fly jets. There were considerable demand-side advantages that drove the incorporation of jet engines. From a competitive standpoint, jet planes were more appealing to passengers. Jets proved to be not only much faster than props, but they produced a far more comfortable flying environment. These advantages were demanded by consumers. The airlines responded by ordering new jet fleets.

In many ways, this experience maps reasonably well into the experience associated with CHP systems. If we assume that industrial CHP will have similar advantages and policy support commercial jet engines, then we can assume a diffusion variable of 0.38 to continue our analysis. In that case, then, CHP capacity would be expected to grow to 32.8 GW_e by the 10^{th} year, as we showed in the earlier example. This value implies a net gain in industrial capacity of 28.4 GW_e, a level of market penetration which is consistent with the DOE and EPA challenge to industry to double CHP capacity by 2010 (Elliott and Spurr 1999). We can conclude from this analysis that commercial jet engines may provide a reasonable, albeit a more aggressive, reference for future diffusion of CHP in the industrial market compared to the PURPA model.

Developing a Model for Buildings CHP

What insights can we draw about how CHP technologies might diffuse in the buildings sector? In the past, the penetration of CHP systems in the United States has been dominated by larger industrial facilities. Many experts project that future growth will expand to smaller applications (Kaarsberg, et al. 1998). Current CHP system configurations — with electric capacities down to about 1 MW — are applicable to larger commercial buildings and district energy systems (Elliott and Spurr 1999). These systems are being developed by the same third parties that currently develop industrial facilities. We can assume that these facilities are part of an expansion of current CHP market diffusion that we have projected for the industrial sector.

New technologies, such as advanced gas engines, microturbines and fuel cells, hold promise to expand CHP in smaller commercial and residential building systems below 1 MW (Spurr and Elliott 1999). Perhaps more to the point, the technologies in this market segment are still emerging. Consequently, there are significant uncertainties as to the pattern of diffusion for buildings CHP. System configurations are likely to be different from current larger systems. New technologies and design practices will be needed to efficiently make use of heat in these applications (DOE 2000).

New institutional arrangements will likely emerge to meet the needs of these markets. Moreover, the CHP systems will benefit from economies of scale and scope, and from learning by doing and learning by using. However, while there will clearly be some acceleration of the diffusion rate beyond that suggested by a PURPA-like model, this mini and micro CHP may need to be considered as having a separate technology diffusion pattern. Looking to the history of these larger systems may shed light upon what can be anticipated for the market diffusion of the smaller systems.

Many similarities do exist between the buildings CHP market and the commercial jet engine and industrial CHP markets. The changes in all three markets are in part driven by the introduction of new enabling technologies. In all cases, much of the enabling technology is derived from Department of Defense (DOD)-funded products. The U.S. Airforce spurred the development of turbine technology that first drove the jet engine, then the industrial combustion turbine, and now the microturbine. DOD and NASA research spurred the development of fuel cell technology that promises to play a major role in the buildings CHP (Kaarsberg, et al 1998). Department of Energy R&D will spur further advances. We are also likely to see the same third party trends emerge in these smaller CHP systems.

In the commercial jet engine example, the deployment of the technology resulted in profound changes in the transport market, in which air travel became faster and more affordable. In the industrial market, CHP is showing the promise of greater energy reliability and less costly environmental compliance. The benefits for the buildings market are less clear, but may parallel those for industrial CHP.

One notable difference in the buildings market is that the buildings market tends to be less involved with technology than does the industrial or air transport sectors. This may indicate that an important factor affecting the ultimate deployment of CHP is the need for systems that offer high reliability with limited customer involvement. Unfortunately, this does not characterize current technologies.

Implementing a Diffusion Model for Buildings CHP

If we make the reasonable assumption that the diffusion of CHP in buildings is likely to be similar to the experience with the previously discussed commercial jet engine, then we already have an estimated value for the adoptive influence of the buildings CHP. As we also noted earlier, a value of 0.38 is very close to the locus of values for many technologies, 0.40 (DeCanio and Laitner 1997).

Despite the currently limited data on small-scale CHP market penetration, we still need to determine two key parameters to be able to estimate future market diffusion. While hard numbers are unavailable, a consensus has emerged that the current installed base is about 50MW (Energetics 1999). The most important parameter, however, is an estimate of the market potential for CHP in the buildings marketplace.

Although analysts have begun to estimate CHP market potential in the buildings sector, a great deal of uncertainty exists in these projections. The best current source is Kaarsberg, et al. (1998) who have investigated the potential for three small-scale CHP technologies in the buildings sector: gas reciprocating engines, microturbines, and fuel cells. They projected economic potential of 15-25GW in 2010 for buildings CHP.[2] If we accept the higher number as a reasonable estimate of the near-term market potential for CHP, then we can use the diffusion equation to project future additions to CHP capacity in the sector. Assuming market drives and policies similar to those supporting the diffusion of commercial jet engines, results of that analysis are presented in Table 1.

Table 1. Projected Diffusion of CHP into the Buildings Market with Market Barriers Removed

Year	Market Share	Cumulative Additions to Capacity (GW_e)
2005	1%	0.3
2010	8%	2
2015	37%	9
2020	80%	20
2025	96%	24

Assumes that the adoptive influence *a* = 0.38, that installed based is 50 MWe in 2000, and that the market potential is 25 GW_e.

We can see under this scenario that while the capacity installed in 2005 is modest, the potential additions to capacity could become significant by 2015. This analysis suggests that CHP in buildings could be a significant contributor to a national energy and climate change strategy. This estimate relies heavily upon the estimate of market potential. Unfortunately, many of the optimistic assumptions about the rapid development of the technology made two years ago by Kaarsberg, et al. are not being realized in the market. Hence, the results project above may not be entirely realistic without other policy drivers to support market penetration.

[2] This range is consistent with a recent estimate from Onsite Sycom Energy (2000) that concluded the technical potential for systems below 1 MWe is 48 GWe.

Conclusions

The use of market diffusion theory can contribute significantly to the understanding of how technologies are deployed. This approach may more accurately characterize market penetration than do technology-choice models that rely only on net-present-value analysis.

The insights drawn from the market success of established technologies, together with an understanding of market diffusion principles, can perhaps serve as better models for estimating the adoptive characteristics and diffusion patterns for new technologies. Yet, the application of this analytical technique relies heavily upon a robust understanding of the new technology and its market potential. For industrial CHP, we already have strong literature and market data to draw upon. However, our understanding of CHP in buildings is much more limited. For the market diffusion model to be successfully applied, it is important that we develop a more robust understanding of the market potential for CHP in commercial buildings.

We can draw from the experience with industrial CHP and commercial jet engines to understand the important impacts, both positive and negative, that public policy can have on the diffusion of a technology. PURPA provided a powerful impetus to the market adoption of industrial CHP. In addition, the benefits of federally funded R&D have helped reduce the cost and improve the performance of both technologies. The cost has been further reduced by the purchase of early units by government. On the other hand, EPAct effectively halted the diffusion of industrial CHP. Notwithstanding the potential for unintended consequences, these observations and analytical tools should embolden public policy makers in their use of these concepts to promote the commercialization of new technologies.

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