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Assessment of Incentives and Employment Impacts of Solar Industry Deployment

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ASSESSMENT OF INCENTIVES AND EMPLOYMENT IMPACTS OF SOLAR INDUSTRY DEPLOYMENT

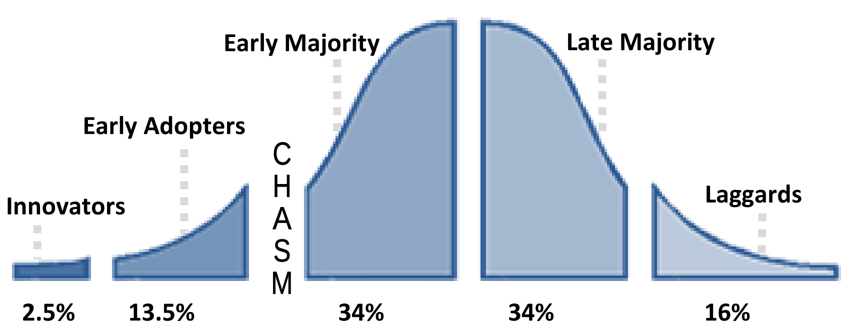
SUMMARY

A mixed portfolio of energy options has allowed Americans to enjoy long-term economic growth and prosperity. The federal government has engaged directly in developing each energy resource in the mix, although the dollar value estimates of this federal support vary considerably. In this report, we focus on a relatively new addition to the energy portfolio—solar power. This assessment considers the diffusion of solar energy technology in the United States in the context of the technology adoption process and federal engagement in developing energy options. We examine historical and current federal incentives in energy markets, focusing on incentives along the energy value chain and by stage of technology adoption. Considering the growth expectations for the domestic and international solar markets, we analyze the solar industry's U.S. job creation and solar power's potential contribution to addressing peak-demand period power needs and other benefits to the energy portfolio. *We find that solar energy is following the same incentive-driven path as other traditional energy sources before it, consistent with the government's decision to incentivize energy production for a variety of policy purposes. We also conclude that the federal investment in solar energy could bring about a number of tangible benefits, including increased employment, global business opportunities, and energy supply diversity.*

TECHNOLOGY ADOPTION AND LEAPING THE CHASM

Diffusion of solar energy technology in the energy markets is consistent with the less-than-smooth paths that many American industries have traveled as they entered the mainstream of commerce. The traditional technology adoption model labels early entrants into the solar market as innovators and early adopters. These individuals and firms enter for reasons that are not purely economic or based on a long-term strategy. One need only look to the early history of the automobile industry in the United States to realize that not

Figure 1. Technology Adoption Stages



all companies that enter the market early flourish, yet the industry itself can succeed. There is a "chasm" over which the industry must leap to expand to majority adoption. Depending on the type of industry, the propulsion for this leap can be demand-side factors, such as when General Motors made loans to automobile buyers in the 1920s, or supply-side factors, such as Henry Ford's assembly lines. When benefits accrue broadly, rather than to investors alone, a federal role exists, such as the defense and energy industries' benefits from NASA's funding the man-on-the-moon mission. Solar energy technologies are currently in the rapid growth stage between early adoption and the chasm that comes before majority adoption where government incentives can be most critical in helping new energy technologies become significant sources of energy production.

FEDERAL INCENTIVES FOR ENERGY PRODUCTION DESIGNED FOR PUBLIC POLICY PURPOSES

Historically, each energy resource had approximately a thirty year period of innovation and early adoption before beginning rapid growth that brought it across the chasm and into the phase for early majority adoption. The Chief Strategist for Shell echoed this finding recently saying, "It takes about 30 years for any new energy source to attain 1% market share."[1] Each traditional energy source has been developed with significant government engagement, which has included market control measures for oil, making pipelines available for natural gas, the construction of flood control dams that provide the fuel for hydropower and states surveying their coal resources.

Looking back to traditional fuels, we see multiple intentions for the federal government's engagement. During the pre-embargo period, federal energy policy was in effect industrial and economic development policy applied to energy industries to:

- *Maintain competition* by breaking up monopolies and holding companies, regulating interstate commerce and prices.
- *Provide for national security* by addressing potential domestic resource depletion with incentives for domestic production, leasing or directly investing in federally-owned natural resources, and a beneficial import/export policy.
- *Promote economic development* by stimulating growth and providing tax incentives to build a productive and competitive America through low cost energy.

Following the oil embargo, the Federal government engaged more explicitly in energy policy formation to:

- *Maintain competition* by deregulation.
- *Assure worker safety, public health, and environmental quality.*

[1] Harry Brekelmans (2011). "Harry Brekelmans on the future of Shell." Interview by Geoff Colvin of *Fortune* Magazine. Web. CNN Money. Accessed 23 Dec 2011.

- *Provide for energy security* by adding renewable energy options to the portfolio of energy resources, encouraging demand in specific markets, and discouraging demand in others.

FEDERAL INCENTIVES IN EXISTENCE FOR DECADES FOR ALL ENERGY SOURCES

Various estimates show that the federal government currently incentivizes every major energy production market. Energy agencies, the Government Accountability Office (GAO), industry groups, national laboratories, investment funds, and policy-watchdog groups have all issued estimates of federal incentives in energy markets. Information is now widely available, but the estimates vary significantly and conclusions conflict. A detailed analysis of the variables that contribute to the divergent estimates of federal incentives is outside the scope of this work, but the following important variables contribute to the variance.

- Methods, such as price gap analysis vs. budget analysis
- Time frames, including "snapshots" of a particular period; all-encompassing from the inception of each incentive; or during an initial period of incentivization
- Definitions and interpretations of incentives through including or excluding tax treatments that are not specific to a particular fuel type, regulatory costs, risk management costs or other incentive elements.

INCENTIVES: A THREE-DIMENSIONAL VIEW

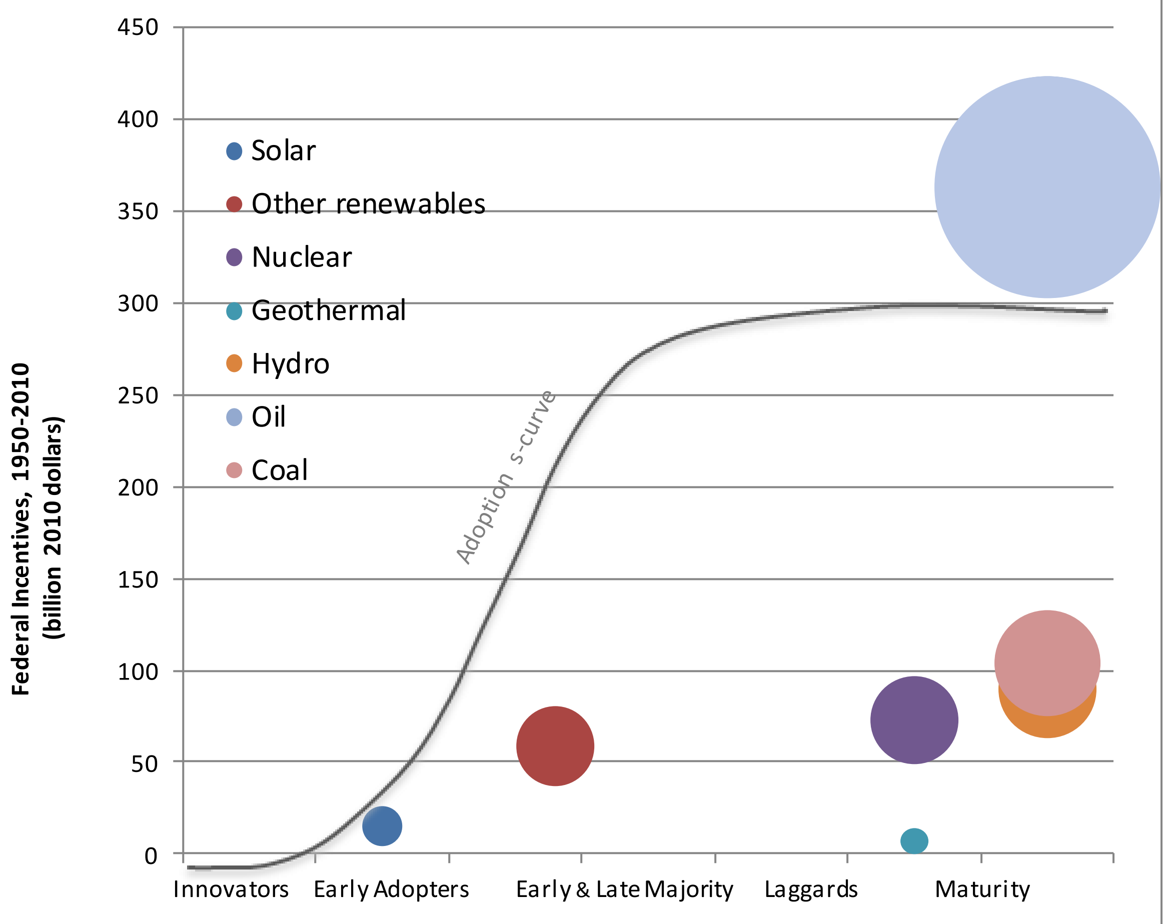
Federal incentives to energy markets exist along three key dimensions:

- Incentives can be applied at every stage in a given fuel's adoption process (technology adoption stages are shown in Figure 1).
- Incentives can be applied along each step of the energy value chain.
- Incentives can be applied for different purposes.

Technology issues can be found in each of the links in the energy value chain: resource production and refining, fuel transmission and distribution, electricity generation, electricity transmission, and consumption. Fossil fuels, biofuels, and nuclear power have had significant federal engagement in the resource production, refining, and transportation steps. Solar energy resources, which are widely distributed and are not transported, will not require government engagement in this part of the industry—a potentially significant savings.

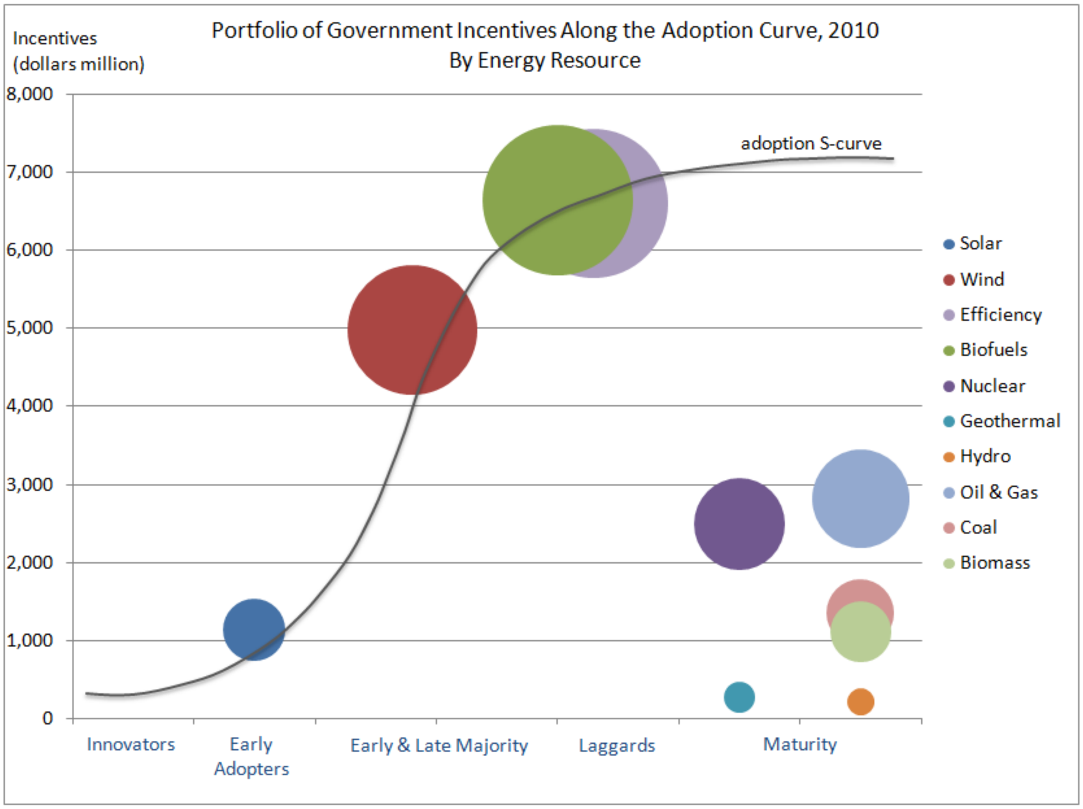
Figures 2 and 3 show the energy fuels according to their position in the adoption process, from innovation through maturity. Figure 2 shows the portfolio of government incentives for energy sources for the past 60 years and their position on the adoption curve. As can be seen, federal investment in solar technologies has been modest in a long-term historical context relative to other energy technologies. As expected, the largest cumulative incentives during this period have been associated with mature energy technologies that have been receiving incentives for the longest periods of time and are still supported through federal incentives. Figure 3 shows the value of federal incentives for each fuel in 2010 according to 2011 estimates from the Energy Information Administration (EIA). These tallies include investments made through the American Recovery and Reinvestment Act, which in terms of energy investment focused primarily on renewables. The graphic shows the results of policies that are consistent with the current era in which economic development depends on efficiency and sustainability, along with incentives related to industrial and economic development policies from the past based on mature fuel technologies.

Figure 2. Portfolio of Government Incentives along the Adoption Curve, 1950-2010, by Energy Resource



*Other renewables include wind, biofuels, biomass, and other minor fuels
Source: MISI (2011) and University of Tennessee Howard H. Baker, Jr. Center estimates based on MISI (2011) and EIA (2011)

Figure 3. Portfolio of Government Incentives along the Adoption Curve, 2010, by Energy Resource



Data source: US Energy Information Administration, *Direct Federal Financial Interventions and Subsidies in Energy in Fiscal Year 2010*, July 2011.

In 2010, biofuels have the largest incentive cost. The pattern of incentive costs is consistent with expectations along the adoption curve. If the goal of incentives is to bring a resource to the point of full market penetration, one would expect larger incentives for fuels that have not reached maturity. Incentives in the mature industries effectively raise the overall cost of government incentives needed to bring new resources up the adoption curve. Solar, which is early in the adoption process, has a lower total incentive cost than the wind, ethanol, or energy efficiency industries that are further along the adoption path.

EFFECTIVE INCENTIVES

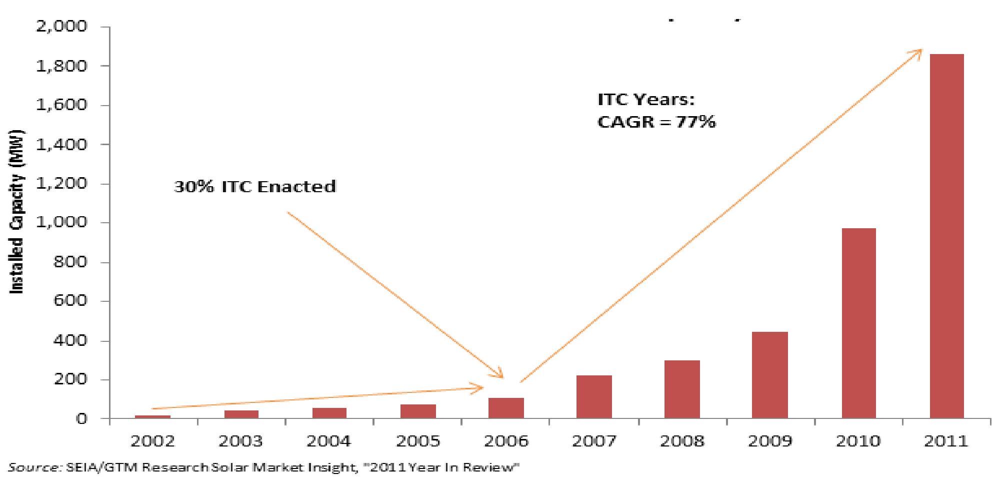
Effective incentives are *long-term* instruments that remove specific barriers, level costs to encourage long-term private investment, and/or offer stability during the adoption cycle that allows the new technology to "cross the chasm." Incentives provide opportunity for technology development that introduces economies of scale or production or conversion efficiencies that allow price-points attractive to adopters for whom price is the primary consideration. Ideally, incentives have a schedule built in to allow gradual reductions in the incentive as the industry matures. The antithesis of long-term, stable instruments are the production tax credits for wind power that have existed on one- to five-year cycles and twice expired, creating uncertainty and a choppy adoption path, or the Section 1603 Treasury program that operated on only a short-term basis.

Ideally, incentives for a market, such as electric power or transportation fuels, are developed in a coordinated fashion without introducing conflicting or cross-purpose policy inefficiencies. In the U.S., the umbrella for all energy incentives has been security and economic development, so that all energy sources are incentivized. The increasing complexity of the portfolio of federal incentives across energy sources has created situations in which incentives for one energy source are unintentionally countered by incentives in competing markets.

From an economic development perspective, a portfolio of incentives weighted towards mature industries will tend to insulate and maintain those profitable industries and suppress new industries, while a portfolio weighted towards industries in the adoption stage will tend to advance adoption of new industries. Since history shows that new industries are the source of growth in an economy and mature industries tend to either maintain or lose jobs over the long term, effective incentives from an economic standpoint are those that address industries in the early adoption stage.

Figure 4 shows the dramatic growth rate in installed solar capacity over the last five years. This 77% annual growth occurred during a period when State Renewable Energy Standards, less-expensive PV, and the federal investment tax credit (ITC) were in place. The ITC, passed in 2006 and scheduled to remain in place through 2016, is an example of a long-term stable instrument that could help solar energy cross the “chasm” to early majority adoption.

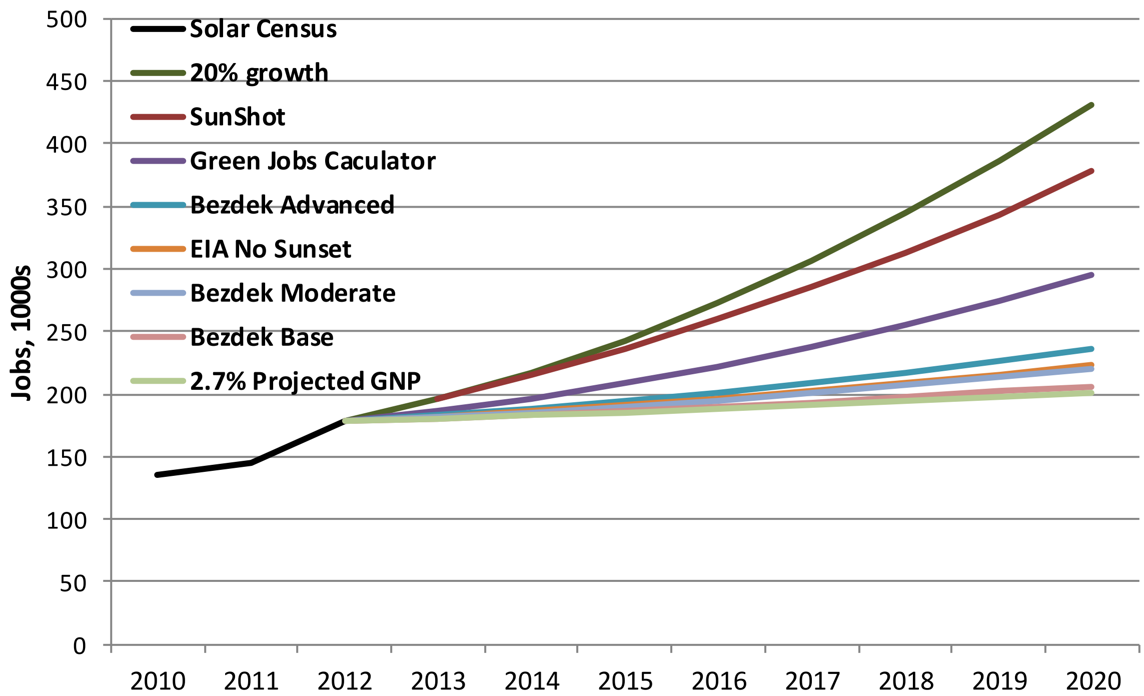
Figure 4. Annual Installed Solar Electric Capacity



SOLAR INDUSTRY BENEFITS EMPLOYMENT

With the significant recent increases in annual installed solar capacity—a near doubling between 2009 and 2010 and a further doubling in 2011—and long term annual cumulative growth projections for solar that range from 4.8% to 25%, the growing solar industry will be a boost to employment in the U.S. It should also be noted that the solar industry has historically produced more jobs per megawatt-hour than any other energy industry. Depending on the assumed growth rate in solar deployment, we estimate between 200,000 and 430,000 total jobs related to domestic growth in the solar industry (direct, indirect and induced)[2] in 2020 (Figure 5).

Figure 5. Total Employment Growth (Direct, Indirect & Induced) Related to Domestic Growth in the Solar Industry under Various Scenarios



Source: University of Tennessee Howard H. Baker Jr. Center for Public Policy

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[2] Direct Jobs are those related to the solar industry activity, indirect jobs are those generated by the purchases made by the solar energy industry, and induced jobs are those generated by the incremental spending of households earning wages from the direct and indirect impacts.

The export potential for U.S solar manufacturing and materials is also growing with the rapid increase in installed capacity that has occurred in Europe. A Pew Center brief on job opportunities recently concluded that, "Fostering domestic markets will create jobs and give lead industries the initial foothold they need to ultimately better compete in rapidly expanding international clean energy markets – and the sooner these industries can be established, the larger the share of these global markets they stand to gain in the decades ahead."

To understand the potential future economic benefits of maintaining and growing the positive trade balance, we used the estimates of expected worldwide installed solar capacity and the Solar Census employment estimate to project potential employment in the U.S. from future exports. Maintaining our current share of the export markets, the U.S. could add by 2030 another 67,700 direct, indirect and induced jobs to the existing solar industry employment.

SOLAR POWER BENEFITS THE U.S. ENERGY PORTFOLIO

As economic growth becomes ever more dependent on abundant, affordable, and sustainable energy supplies, solar energy offers secure hedging value to a diversified energy portfolio. Rooftop solar power alone could provide 20% of our electricity needs. Recent estimates of the solar resource show that capturing the solar resource using photovoltaic and concentrating solar power could provide even more. Expanding the use of solar energy would decrease the energy sector's overall sensitivity to supply disruptions and price volatility of other fuel sources.

Solar power also has the benefit of greatest availability during peak demand times. Adding low marginal cost renewable energy to the front of the dispatch curve shifts the curve out and provides cheaper peak rates, benefitting all consumers.

CONCLUSIONS

Experience from other fuel sources and non-fuels industries in the United States shows that stable, long-term programs that smooth the development and adoption process have contributed to the development of the portfolio of fuels in the United States. Incentives provided to the solar industry are consistent with those provided in the developmental stages of all other energy sources that the federal government has chosen to incentivize for public policy purposes. Evidence from recent years' deployment of solar power suggests that solar incentives are working. Under these circumstances, the solar power industry can provide employment benefits, global market opportunities, and a resource to meet peak power demand at minimal marginal cost.

CHAPTER 1 TECHNOLOGY INNOVATION AND ADOPTION

1.1 Technology adoption curves: the process from early adopters to laggards

Only in retrospect is technology change smooth. Within its own historical context, it is rough and uncertain with many false starts and byways. The social history of technology change is replete with stories of early technology adoption in unexpected niches. Often the early innovators are not the ones who profit from the process. The process of electrification demonstrated that technology adoption is "shaped by complex social, political, technical, and ideological interactions" and is never either "natural" or "neutral."[3] There were necessary losers—among them direct current and small generation stations—spotty adoption, reversals, and despite the social transformation that electrification allowed, electrification remained a mostly urban phenomenon for more than fifty years. This chapter introduces the normal adoption curve for new technologies and looks to the history of technology adoption in other industries for a context in which to consider the solar technology adoption.

The Adoption Curve

Everett Rogers' now-classic technology adoption curve, as a representation of technology diffusion, segments the diffusion process into market sectors based on characteristics of the potential adopters.[4] One could rank the potential users from most likely to use the technology to the least likely to use or adopt. The individuals are then grouped by the general willingness to adopt (Figure 1-1). The first stage is when the technically oriented individuals (or firms) and experimentalists (the innovators) start developing the technology. When a technology first comes to market, typically at a higher cost, the initial interest is expressed by those individuals (or firms) that appreciate the non-price attributes of the technology and are comfortable using novel approaches. These individuals are referred to as the "early adopters." The market becomes mature when the "early majority" and the "late majority" come on board. Finally, the last persons on board are the "laggards."

In this view, the adoption of a new and potentially disruptive innovation tends to proceed from a small subset of consumers (innovators and early adopters) to the more conservative majority. The ranking may also express a willingness to pay for the new innovation. The innovators and early adopters, since they value non-price attributes, are willing to pay a higher price. The rest may view price and the price of substitute technologies as important decision criteria.

[3] Nye (1992).

[4] See Rogers (2003). The stages of adoption were first posited by Ryan and Gross (1943). The ideas of Joe Bohlen and George Beal of Iowa State College were captured by the Agricultural Extension Service, (1955). Rogers' expansion of the technology adoption process was first published in 1962.

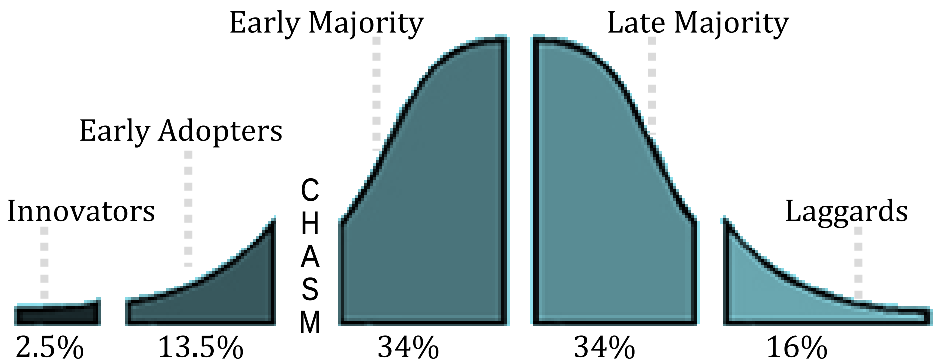

Figure 1-1. Technology Adoption Curve (Rogers 2003 and Moore 1991)

Economic factors alone do not explain which individuals or firms will adopt the technology first. Adopters are heterogeneous in ways that affect their assessment of the value of the innovation, and adoption always entails tradeoff between up-front costs (equipment, learning, adapting, etc.) and expected benefits. Barriers (and facilitators) have several dimensions, including environmental or contextual factors, characteristics of the individuals and organizations that adopt the innovation, and characteristics and attributes of the innovation itself. Known attributes that do relate to adoption include awareness and knowledge of the technology, its applicability to the firm, the firm's expectation of economic return, the size of the firms, the perceived riskiness of technology, and the absolute magnitude of required investment.[5] It is well accepted currently that technology, economics, and social/psychological factors all contribute to adoption decisions.

The economic barriers to adoption relating to the high initial cost of the new technology abate when the industry moves to market scale and reduces production costs. In the early adoption period, there may be many alternative techniques or products that are representative of the technology. Increasing production and expanding demand simultaneously for each alternative may be difficult. As individual preferences are expressed in the market, the number of techniques or products will narrow. At this point, production will be more focused and economies of scale can be captured by building large production facilities and consolidating smaller early production facilities, i.e. supply side factors. Also, demand side factors—a shortage of information, financing, or institutional mechanisms—may also repress the potential adopter.

The gap between the early adopters and the early majority can be a significant barrier to widespread adoption. Geoffrey Moore posited that there are breaks between each stage and a "chasm" occurs before the majority adoption of almost every new technology (Figure

[5] See Jaffe and Stavins (1994) and Shove (1998). Rogers (2003) also reviews relevant literature.

1-1). The chasm is a wider gap that represents a stage at which the nature of the adopters and the perceived strength of the barriers make advancing to the next phase of adoption a bigger leap than transitions between other stages. Moore popularized the concept of managing the movement to scale as a firm or industry expands the market from the early adopters to the early majority.[6] This issue was further expanded by Murphy and Edwards to situations when an industry moves from public support in the early adoption state to full private sector financing as part of the movement along the adoption curve.[7]

Crossing the Chasm

Two U.S. industries are representative of the technology diffusion model and the particular challenges of moving from early adopter phase to early majority. These industries—automobiles and personal computers—while representative are also considered technologies that ushered in rapid social transformation. The development of these industries took over twenty years. During this period the variety of technology options available in the early adopter phase filtered down to a few. A growth in demand generated the impetus to produce at a level that could gain benefits of decreasing cost due to scale. The decrease in cost facilitated the increase in demand. The path through this process was slightly different in each.

Horseless carriages—powered by electricity, steam, or internal combustion engines—were introduced in the mid to late 1800s, but not for another 40 years, in 1918, did 7.7% of American families have an automobile. Only a decade later, in 1929, 60% of American families had autos.[8] [9] The annual production of passenger vehicles increased from 4,000 in 1900 to 4.6 million in 1929 before falling drastically during the Great Depression (see Figure 1-2).

It was a combination of new manufacturing technology, business consolidation, and new purchasing options based on consumer credit that pushed the industry across the chasm. Between 1896 and 1930 there were over 1,800 different car manufacturers in the United States.[10] Data on 1,695 of these industries companies was available to show the time profile of passenger vehicle manufacturers operating in each year. The consolidation of the industry as a part of expansion of the industry is clearly shown in Figure 1-2. Ford Motor Company became the dominant producer by using manufacturing economies of scale and a single style manufactured on assembly lines to lower cost. Henry Ford also paid higher than average wages to help stimulate demand. While Ford continued to seek lower costs,

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[6] Moore (1991).
[7] Murphy and Edwards (2003).
[8] Kenney (2009).
[9] Smiley (2010).
[10] Car History 4 U (n.d.).

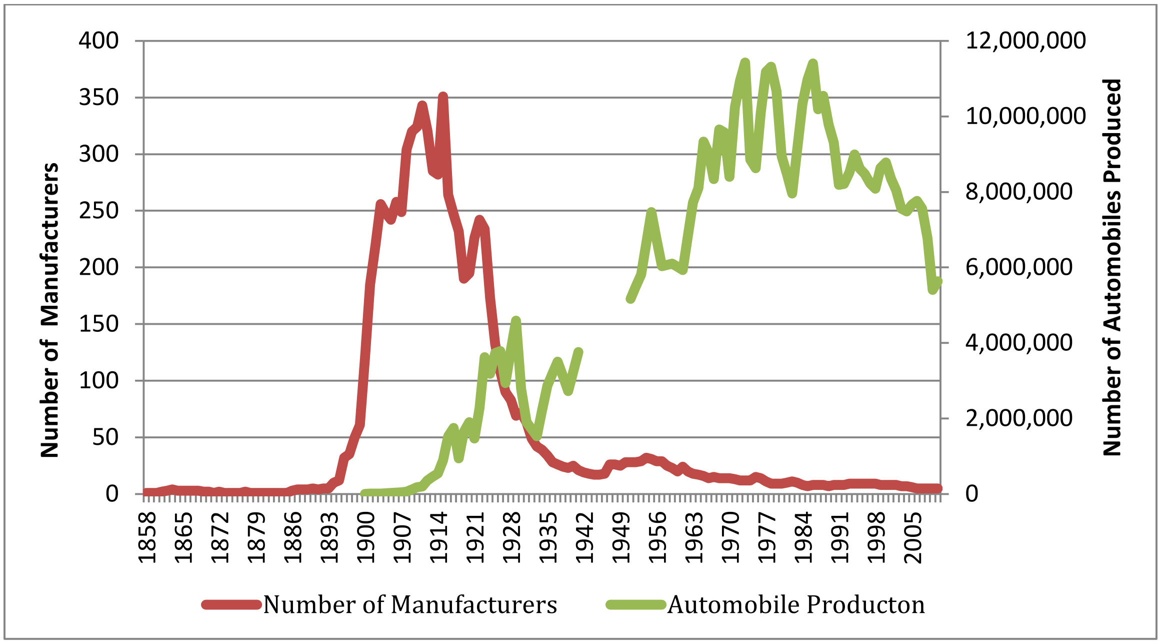


Figure 1-2. Development of the U.S. Automobile Industry

General Motors was working on a different strategy and eventually overtook Ford in the 1920s through the leadership of Alfred P. Sloan. In 1903, Oldsmobile and Buick merged into General Motors, then absorbed, Cadillac, Oakland (Pontiac) in 1909, model changes to aid in planning production and increasing demand. To facilitate purchase, General Motors Acceptance Corporation was formed to provide financing for new vehicles.[11] In the solar industry such financing through third-party ownership of PV systems is widely viewed as a game-changing innovation for residential and commercial solar installations. Like GM's approach with GMAC, some solar manufacturers are now setting up their own financing structures.

Personal computers, another ubiquitous technology, also went through a lengthy adoption process that eventually was spurred by reducing the diversity in operating systems so that the utility of the product could be expanded with add-on software. The first appearance of a "personal" machine was the Altair kit for hobbyists in 1967.[12] A decade later, the early commercial computers were introduced, with the marketing of the Apple II, the Pet 2001 and Radio Shack's TRS-80. While other machines came forth, it was not until 1981 that the IBM PC was marketed. The IBM was based on standard hardware and the Microsoft DOS operating systems was available separately. Clones soon developed and provided greater variety in capabilities and pricing. The personal computer remained an early adopters-only technology until business productivity software became available. VisiCalc, introduced by

[11] Finklestein (2003).
[12] History of personal computers (n.d.).

Dan Bricklin[13] in 1979 and WordStar released for DOS in 1982 were the first "Killer Apps" that made the computer useful to the early majority. With the advent of Microsoft Windows 3.0 in 1990, the personal computer became a viable business tool and the expansion of the personal computer into daily use began. The full adoption of the computer thus required complementary products to make the tool accessible and useful to the general market.

Analogous to the PC and PC software industry is the solar industry's development of technologies and refined products to serve specific needs: micro-inverters and power optimizers for residential and small commercial installations, and non-penetrating racking for large commercial rooftops. As good software is a necessary component of a good computer, good components are necessary for a good solar energy system. Likenesses between the development of the solar and automotive industries are drawn in the box on the following page.

Not Every Entrant Succeeds

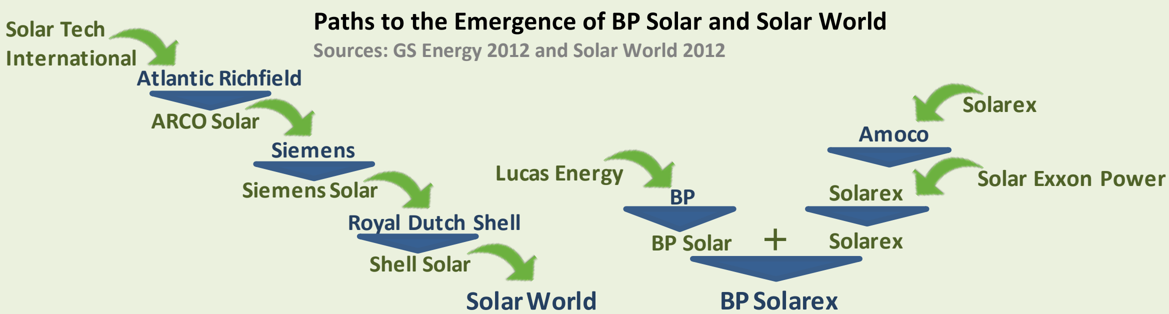
Businesses fail. Technologies fail. Sometimes the technology succeeds while the business does not, while at other times the technology fails although the business survives. New businesses are more likely to fail than established businesses. So it goes with firms engaged in the early stages of technology diffusion. The identification of technologies that were not able to leap the chasm and become ubiquitous technologies has become an interesting game on the technological blogs. The Polaroid Polavision instant movie system was a product introduced after its technology had already been leapfrogged by other technological advances. Apple's HyperCard was a widely successful and imitated product, but the company lacked the insight to see that it had the makings of what Tim Berners-Lee would later develop as Hyper Text Transfer Protocol (http) and the makings of the World Wide Web.[14]

The automotive and personal computer industries demonstrate how the number of players gets rapidly winnowed down in emerging industries. In general, business startups in both new and established industries have a difficult time. A Bureau of Labor Statistics' analysis of 212,182 firms across several sectors from March 1998 to March 2002 showed that 34% failed in the first two years, and another 22% failed after four years.[15] In a study of high technology startups that began operations in Silicon Valley in 2000, it was found that only 17% of them remained in 2009.[16] However, those firms that did survive had an increase in their employment. Larger firms—those t hat require Dun & Bradstreet (D&B) identifiers and

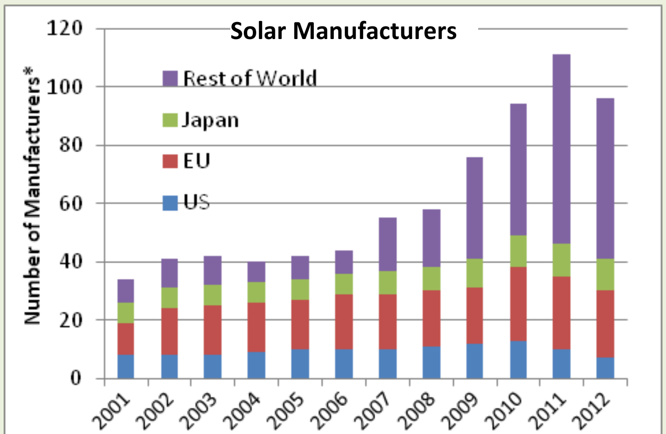
[13] Bricklin (2009).
[14] McCracken (2009).
[15] Knaup (2005).
[16] Luo and Mann (2011).

The Solar Industry: Precedent in the Automobile Industry

As the automobile industry in the U.S. matured, the number of manufacturers declined as non-competitive or less-preferred technologies and less-efficient operations lost out and mergers among smaller, competing companies produced larger, more efficient industries. Changes in the solar industry in the U.S. show similarities to the maturation path of the auto industry, with considerable buy-outs and mergers over time that ultimately align technologies and access to capital to produce a competitive, healthy industry. Two cases are shown in the figure, below. One case produced the largest U.S. manufacturer, while the other produced a once dominant industry player that announced in late 2011 that is was exiting the solar market.



The number of solar manufacturers has very recently decreased (see figure, right). Although available data track only commercial manufacturers (not pilot-scale manufacturers) and exclude module assemblers, they show some recent contraction in the industry across all regions, including those such as China where the most significant manufacturing increases have occurred. Expected attrition in the industry may have been accelerated by the short-term oversupply of photovoltaic panels and the losses the industry incurred because of oversupply. Yet to be seen is whether the depressed cost and improved financing options will foster continued rapid growth in the technology's adoption, as occurred in the automobile markets in the 1930s.



Source: Paula Mints, Navigant Energy Division
* Excludes pilot-scale manufactures and all module assemblers

are accordingly tracked—also face challenges. Figure 1-3 shows D&B estimates of business failures among the firms in its databases, from 2007 through 2010, along with a failure index for manufacturing firms (relative to all firms). Similarly, small business start-ups typically have difficulty: in 2004, the U.S. Small Business Administration loan failure rate was 2.4%, but it increased yearly to nearly 12% for 2008.[17]

[17] Maltby (2009).

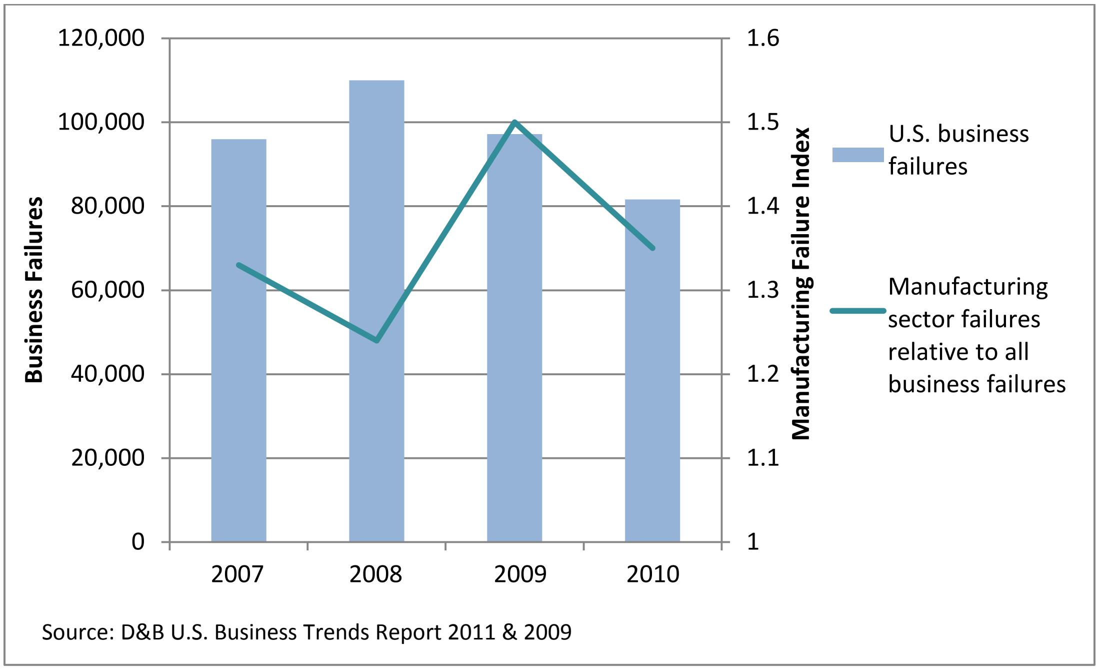


Figure 1-3. U.S. Business and Manufacturing Sector Failures

Federal Support for Technology Diffusion

The federal government has historically played a significant role in both R&D and support for transfer of new technology into the economy (Figure 1-4). This support has been important not only for the primary use of the technology in government service, but also to capture the indirect benefits. A National Academy of Sciences Panel identified some of these benefits, as follows.

> The importance of technology adoption means, among other things, that the economic benefits from the innovative activities of high-technology industries are not confined to those industries, but potentially can be reaped by firms in so-called low-technology, less R&D-intensive industries.[18]

The Federal Government has also been involved in moving technologies from the R&D phase into the market. The most successful and perhaps oldest program is the Farm Extension program of the Department of Agriculture. Agriculture support for experiment stations, land grant colleges and direct interactions with farmers have been part of the agricultural economy since the Hatch Act in 1887. Other areas that

[18] Panel on the Government Role in Civilian Technology (1992).

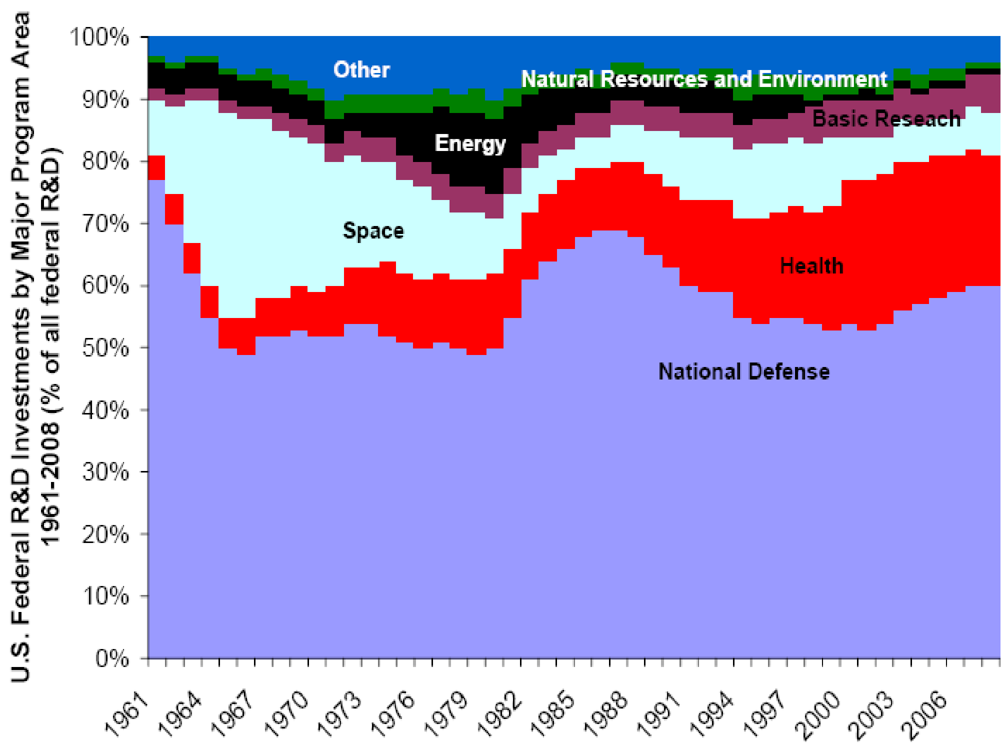


Figure 1-4. U.S. Federal Government Involvement in R&D by Major Area of Focus[19]

have seen federal support of "technology commercialization and the adoption of new technology in private firms"[20] are the National Institutes of Health, the Department of Defense (DOD), and the National Advisory Committee for Aeronautics (NACA).[21]

Federal spending has also had indirect impacts on technology growth in providing demand for new technologies. For example, the foundation for the computer industry started with the development of the Punched Card Sorter by Herman Hollerith and was used in the 1890 Census. This was followed by the use of the early electronic computers for defense department activities in World War II. [22]

Government intervention to prod some direction in the whirlpool of activity in the technology adoption process takes several forms—laws, tax codes, regulations, research, direct government involvement, and incentives. Laws and regulation are crude brute force tools and may have a wide influence and unanticipated consequences. Incentives are targeted to specific technologies and have less of an impact on the economy as a whole.

[19] Dooley (2008).
[20] *Ibid.*
[21] *Ibid.*
[22] Kempf (1961).

While limited funds must go to a limited number of incentive applicants as a matter of necessity, the intent of government incentives is not necessarily to pick specific winners and losers but to maintain a particular line of development as an option in the wider playing field of technology selection, also known as the creative destruction process.

1.2 Technology adoption along the energy value chain

Analysis of the adoption of a new technology must be done within the context of the relevant market and associated demand and supply elements. In regard to energy systems, the technology issues can be found in each of the links in the supply chain: resource production and refining, transformation, and consumption.

The adoption process can be affected by technological change in each of the various steps in the energy value chain which begins with resource production and goes through energy applications. Incentives can be applied at any stage of the energy value chain.

A. Technology adoption opportunities in the energy value chain (resource production, resource refining, fuel transmission and distribution, centralized or distributed electricity generation, energy applications) (See Figure 1-5).
B. Energy value chain for traditional fuels and solar

The structure of an industry, government policies and the state of the economy provide the environment for technology innovation within the industry. Traditional fossil fuel production has a multi-step supply chain. As shown in Figure 1-5, the provision of fuel from traditional sources involves resource production (exploration and extraction), resource refining to a fuel and then transportation and distribution of the fuel to users. The fuel can be used directly by the consuming sectors or indirectly through electricity generation that is used by end consumers. The value chain indicates that there are many sub-markets for examining technology use and innovation. The first three markets in the energy value chain do not apply to solar since solar is a widely distributed, refined resource that does not require production, refining, or fuel transportation.

Before a fuel can cross the chasm to majority adoption, technologies must be in place at each step in the supply chain (for example, diesel fuel and diesel engines need to develop in parallel for either to be of immediate use and reach majority adoption). As an industry matures, and responds to changing environmental and economic forces, new techniques may need to be developed and deployed to maintain economic competitiveness. In the review of technology adoption and interventions, the particular step in the fuel chain and the stage of development of the industry as a whole, needs to be taken into account. It is also useful to think of a general adoption of a particular fuel cycle determined by the adoption of all the necessary techniques in each step of the supply chain to provide fuel to

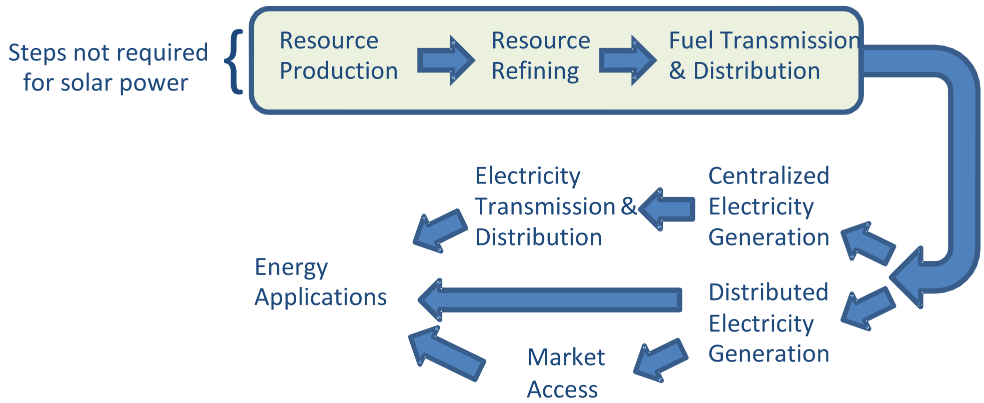


Figure 1-5. Energy Value Chain

end consumers. If successful after this initial adoption process, a mature industry is formed. However, even in the mature industry, a continuous process of recreation of competitive technology in each stage of the fuel cycle may take place. It is important to note that in a complicated mature industry with a long value chain the adoption of new techniques can take place at any part of the value chain. Today the fuel cycles of coal, petroleum, natural gas, and electricity generation represent mature industries. The solar industry on the other hand is in the initial stages of wide-spread adoption and deployment. Much of the new entrant activity in this area is still in the research and development or demonstration stages while other products (such as traditional PV panels) are making the leap from early adoption to early majority as they ramp up to large scale production.

CHAPTER 2.

THE DEVELOPMENT AND DEPLOYMENT OF ENERGY RESOURCES

Fossil energy resources provided the fuel for rapid industrialization of the United States. Thus, the development of these resources occurred during a period in which industrialization and geographic expansion, along with world wars, led to significantly increased energy demand in the United States. Hydropower and nuclear energy were adopted in the 20th century, adding resources to the electrification of America in the era of economic development. Then the oil embargo, energy crisis, and environmental concerns of the 1970s led to energy and environmental policies aimed at building a more efficient and sustainable economy. Throughout this time to meet its goals of expansion, security, prosperity, and efficiency, the government engaged in these fuels' development and markets through regulation and other market interventions to protect the public from the natural monopoly characteristics of the industries and to address externalized costs.

In this chapter we review the adoption of fossil, hydro, and nuclear resources, with specific focus on government engagement along the adoption curve for each resource. Although these resources are quite different in characteristics, and developed in different eras of American economic development, each resource has approximately a thirty year period of innovation and early adoption before beginning rapid growth. Another common characteristic for the fossil fuels was that coal displaced wood over a fifty year period, then oil and gas displaced coal—except for electricity generation—over a fifty year period.[23] Hydropower and nuclear energy largely supplemented coal for electricity generation in a period of significantly increasing demand.

In the last section of this chapter, we review the development of the solar industry, which is occurring during the era in the U.S. economy characterized by energy efficiency and sustainability. History suggests that solar is now at the critical point in time for adoption. Solar power's recent rapid growth may be sustained if the conditions in which it has occurred are stable and persistent.

2.1. Oil, gas, and coal development

During the development periods for these energy sources, industry argued that the public interest was best served by private initiative and free markets rather than through a national energy policy that intervened in energy markets in the public interest. This attitude only partially prevailed, with government intervening in areas that affected competition, such as interstate commerce and breaking up of monopolies and holding companies. In the mature phase of these industries, government continued to intervene with industrial

[23] Schurr and Netschert (1960).

policies that deregulated well-head prices in the natural gas industry and encouraged a more distributed power generation industry. This industrial policy, along with state deregulation of the electric power industry in the 1990s, has once again created an industry dominated by large, vertically-integrated utility holding companies or utilities that recently have separated their generation and distribution businesses.

One dominant story during the adoption of coal, oil, and gas is the amount of federal engagement required over many years to regulate these industries. The fossil industries are characterized by centralized resources, interstate commerce, environmental issues, and a natural economic tendency for vertical integration that leads to oligopoly or monopoly. As a result, the federal government burden imposed by these industries is substantial unlike distributed energy resources that can be more easily regulated at the state and local levels (e.g., manufactured gas during the same era).

In addition to regulatory policy, national security quickly became a driving policy issue, especially for petroleum. But despite repeated attempts for national planning across energy sources between WWI and WWII, the U.S. failed to intervene directly to reduce waste or promote substitution of other energy resources for oil. While the government acted on industrial and economic policy, energy policy was a different matter. It was not until the oil embargo and energy crisis of the 1970s that energy policies were added to industrial policy to encourage or discourage supply or demand in specific energy markets based on the public interest.[24]

As hydro and nuclear energy resources were being developed as fuel sources for electricity generation, significant productivity gains were achieved by fossil fuels in this market, keeping these fuels viable as the industries matured. Figure 2-1 shows the productivity gains from 1920 to 1970. These gains, along with new policies to encourage unconventional production of oil and gas and development of clean coal technology, have continued to keep coal and natural gas viable in the new era of efficiency and sustainability.

Coal industry development[25]

Technology. Starting from simple hand production of coal, the industry became capital intensive during its growth to reach deeper seams and increase production. Electric cutting machines and new systems for pumping and ventilating mines increased productivity in the 1880s and 1890s. Surface mining technology developed, increasing productivity over the years. In the 1970s, reclamation and emissions controls developed as a priority.

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[24] Fuel oil and gasoline rationing during WWII was both short lived and not related to either energy policy or industrial policy.

[25] Primary sources for this section are Adams (2003) and Adams (2006).

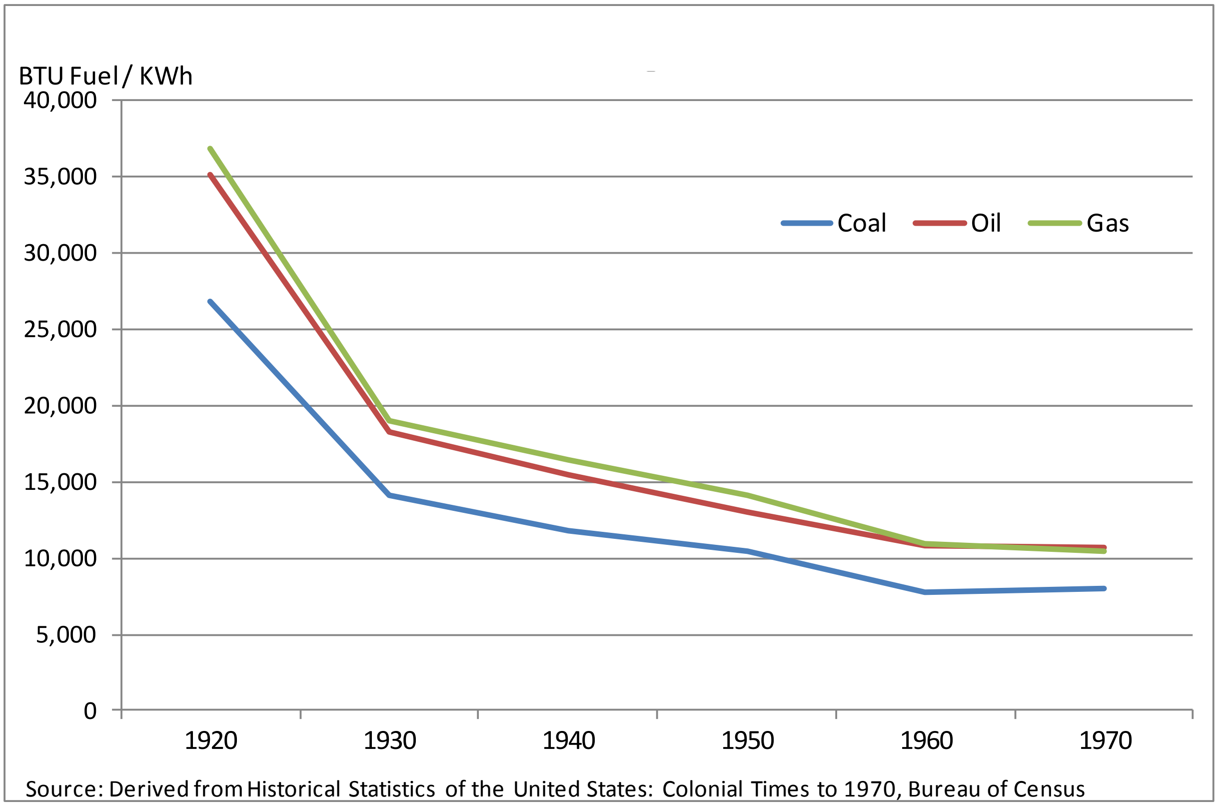


Figure 2-1. Fuel Efficiency Gains in Electric Utility Generation

Safety remained a concern as the industry matured. Technology markets for the coal industry include

1. Underground mining,
2. Surface mining,
3. Safety,
4. Reclamation, and
5. Emissions controls.

Applications. Coal displaced wood in many applications. Coal and its derivative coke were used in industry for furnaces and to raise steam, as fuel for steam locomotives and ships, and to heat homes and buildings, especially with anthracite coal along the east coast. With the later development of electricity and the displacement of coal in transportation by oil, coal has become primarily a fuel for steam boilers in the electric power industry.

Adoption and the Government Role. Due to the abundance of wood in the U.S., coal was not adopted as an energy source to a significant degree until the mid-1800s. To encourage and protect the domestic coal industry, the government imposed a tariff on imported (British) coal that averaged about 10% of the price between 1798 and 1842. Historian Sean Adams, speaking of the 19th century adoption of coal in the U.S. has said, "Nature made coal abundant; public policy made it cheap." As with oil and gas, most early government actions in the market were at the state level where the resource was first developed. States sponsored geologic surveys, and to encourage the use of anthracite, Pennsylvania exempted it from taxation (reversed in 1913). Early coal production depended on hand labor and allowed for easy entry into the market, but that changed once demand started to grow and the easy seams were mined. By 1880, with coal becoming the dominant energy source in the U.S., the character of the industry had changed, becoming capital intensive and involved in interstate commerce with reliance on the railroads for transportation to markets. Railroads, in turn, became increasingly reliant on coal for their locomotives, creating conditions ripe for vertical integration and formation of monopolies. Anthracite coal resources, in particular, became increasingly owned by the railroads. Given that the railroads were already becoming monopolies that controlled prices in markets along their lines, the coal industry found itself involved in the regulation of interstate commerce with the Interstate Commerce Act of 1887. This act provided for rate setting in the railroad industry, much like the Hepburn Act of 1906 intervened in the oil pipeline industry to break up monopoly power and set rates. From the perspective of developing the country's coal resources, ineffective regulation of interstate commerce in the years following the enactment of the law allowed for the railroads to indirectly control production and prices in the coal industry. The mechanization of the coal industry also resulted in labor issues regarding safety and pay, which led to the formation of the United Mine Workers and strikes, in which the federal government intervened in the public interest. Mine safety issues resulted in federal legislation in 1910 and continuing to the present. In its mature stage in the twentieth and twenty-first centuries, coal mining has benefitted from tax incentives, low royalties, and more recently under energy and environmental policies, through government investment in clean coal technologies. Selected government actions include

1. Federal tariff imposed on imported coal in late 18th century,
2. Pennsylvania exempts anthracite from taxation in the early 1800s,
3. States sponsored geologic surveys,
4. Interstate Commerce Act of 1887,
5. Mine health and safety regulations (1910 – 2006),
6. Black Lung Disability Fund and Abandoned Mine Reclamation Fund established,
7. R&D funding and industry support for syngas from coal in the 1970s and 80s, and
8. Clean coal (carbon capture) becomes the focus of federal R&D for coal.

The sharp rate of growth in coal production in the U.S. between 1880 and WWI is mirrored in the period between 1960 and 1985 with the electrification of America (Figure 2-2). Coal was the dominant fuel source for the electricity industry during its early adoption stage.

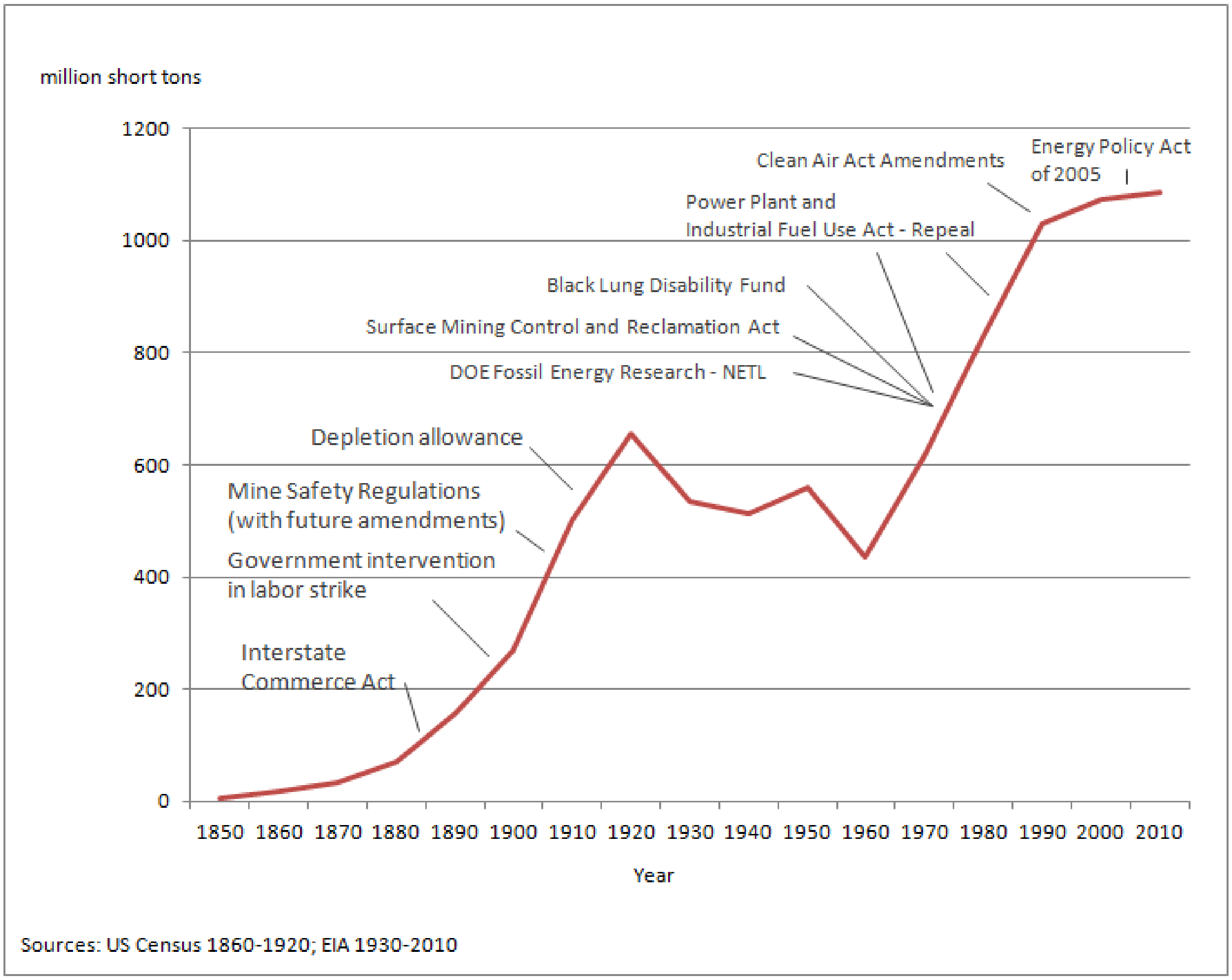
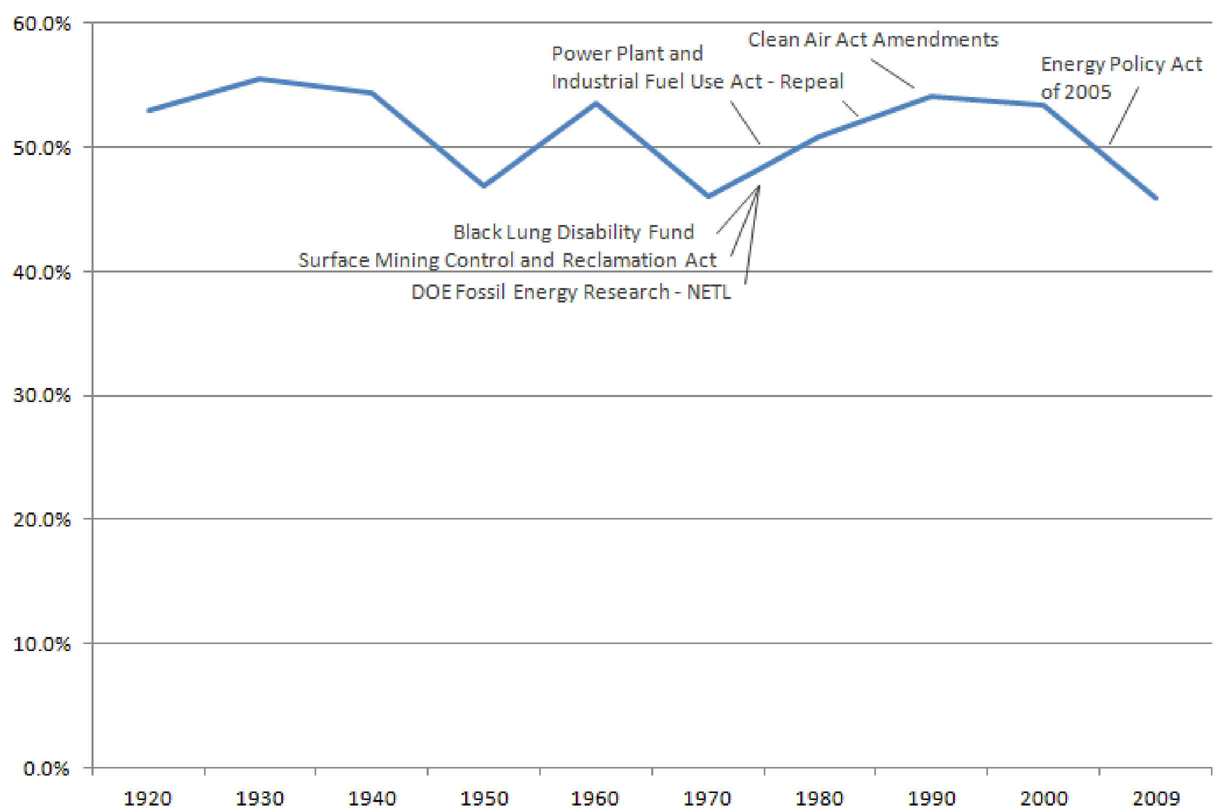


Figure 2-2. Coal Production

Figure 2-3 shows the market share of coal in the electricity generation market since 1920. Although specific data are unavailable for the period prior to 1920, it is known that coal and hydro dominated the electricity generation market. Coal has remained competitive in this market throughout its mature phase.



Sources: 1920 - 1970 Historical Statistics of the United States, Colonial Times to 1970, Bureau of the Census; Electricity Net Generation: Electric Power Sector 1949 - 2009, EIA

Figure 2-3. Coal Market Share, Electric Utility Market

Unlike in the electricity generation market, in the other energy applications markets (transportation, space heating, process heat, etc.) coal has been displaced in its mature industry phase by other energy resources. Note that in Figure 2-4, data are not available for all sectors prior to 1950.

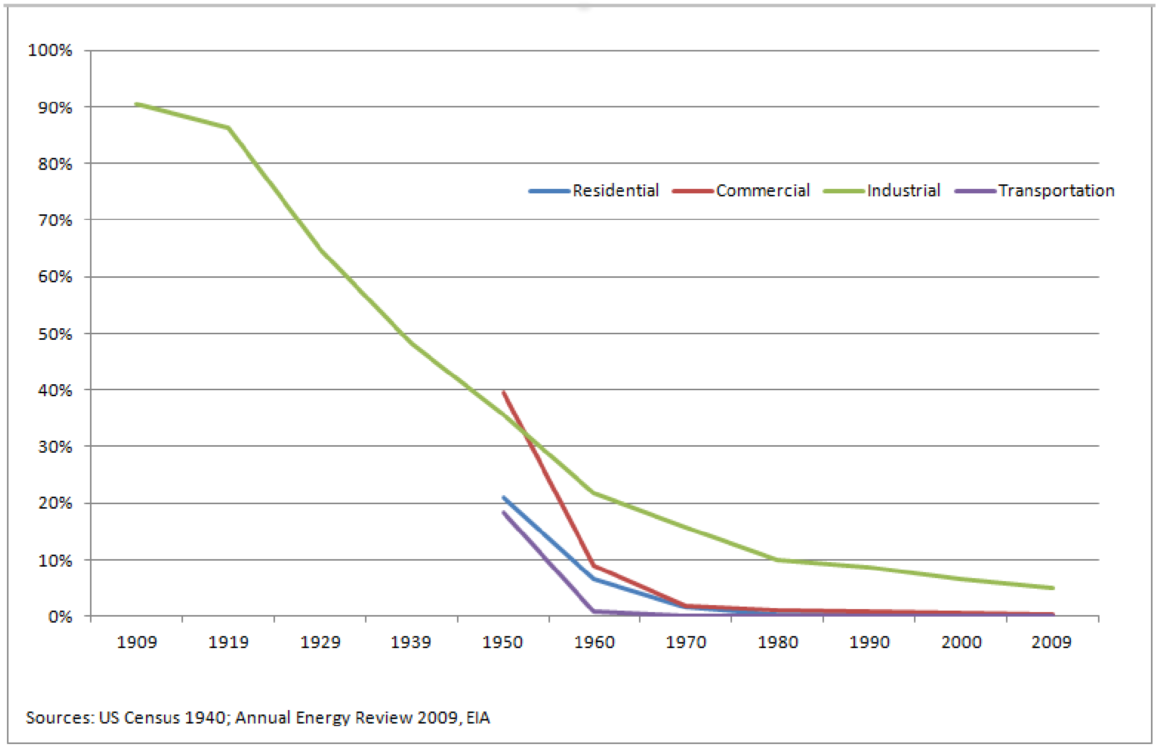


Figure 2-4. Coal End Use Market Share, by Sector Excluding Electricity Generation

Oil industry development[26]

Technology. Salt mining technology initially was used for drilling oil wells. Refining efficiency increased due to technology improvements, with yields per barrel of oil increasing from 25% to 40% during the 1920s, and improvements in pipeline technology facilitated development of an interstate pipeline network. The Bureau of Mines was involved in exploration and production research during World War I. Technology markets included

1. Exploration and production,
2. Refining,
3. Pipelines, and
4. Applications.

Applications. Oil from initial wells in Pennsylvania was used for industrial lubricants and kerosene for lighting. The introduction of the auto further drove demand, as did the use of fuel oil to heat buildings, especially in locations where natural gas was not available. During WWI, petrochemicals and fuel oil were critical uses in industry. Energy applications markets for oil include industry, buildings, electricity generation, and transportation.

[26] Primary source for this section is Clark (1987).

Adoption and the Government Role. Petroleum became an industry in the late 1800s, following a path of development that included vertical integration and monopolization of the industry through the control of pipelines. Congress acted by creating common carrier status for oil pipelines regulated through the Interstate Commerce Commission and the breaking up of Standard Oil. To stimulate domestic exploration and risk taking, the oil depletion allowance was included in the Federal Income Tax in 1913 and later amended many times.

During the Great War, the federal government supported exploration and production through U.S. Geological Survey (USGS) surveying and research conducted by the Bureau of Mines. Oil quickly became a continuing national security issue, with domestic demand exceeding supply. In 1920, public lands were opened to oil and gas leasing and a Federal Oil Conservation Board was created to develop policies to conserve oil. Using oil only for efficient applications (transportation, petrochemicals) was promoted but never accepted. Another issue taken up by government was waste in the production of oil that resulted from lack of unitization of oil fields. Each driller would pump as fast as they could to get the most oil for themselves from a field, resulting in a quick drop in pressure and a significant amount of oil that could never be recovered. The National Resources Committee considered "whether the nation shall permit this exploitation to continue…." The Committee wanted to use taxes to intervene in markets, with a coordinated policy across energy sources, but the several commissions and boards created in the 1920s and 30s were never successful except in agreeing to more anti-trust legislation to break up oil monopolies. The government did encourage development of foreign resources. During WWII, the federal government built pipelines from the East Texas oil fields to the Northeast in response to the sinking of tankers off the East Coast by German U-boats. After the war, in a bit of political maneuvering, these pipelines were auctioned to the natural gas industry. Selected key government regulatory actions for the oil industry include

1. Hepburn Act (1906) – common carrier status for oil pipelines,
2. Breakup of Standard Oil (1911) – breakup monopoly and create competition,
3. Oil depletion allowance (1913) – stimulate exploration,
4. USGS oil surveys (WWI) – support exploration and production,
5. Bureau of Mines research station (WWI) – support exploration and production,
6. Mineral Leasing Act (1920) - open public lands for production,
7. Federal Oil Conservation Board (1924) – safeguard national security by conserving oil,
8. National Resources Committee (1930s) – coordinated planning and management,
9. Federal pipelines (WWII) – brought oil and refined products to Northeast markets,

10. Dual Capacity Taxpayer Foreign Tax Credit (amendments and interpretations of the Revenue Act of 1918, and related case law) – royalties considered as income taxes paid to foreign countries and available as income tax credits (beginning in 1983 credits limited to the amount of tax that would be imposed by the U.S. tax code), and
11. Power Plant and Industrial Fuel Use Act (1978), repeal (1987) – restricted construction of new power plants fueled by oil and natural gas.

Crude oil production in the U.S. followed a typical technology adoption curve, initially aided by federal tax incentives and exploration and production research during WWI (see Figure 2-5).

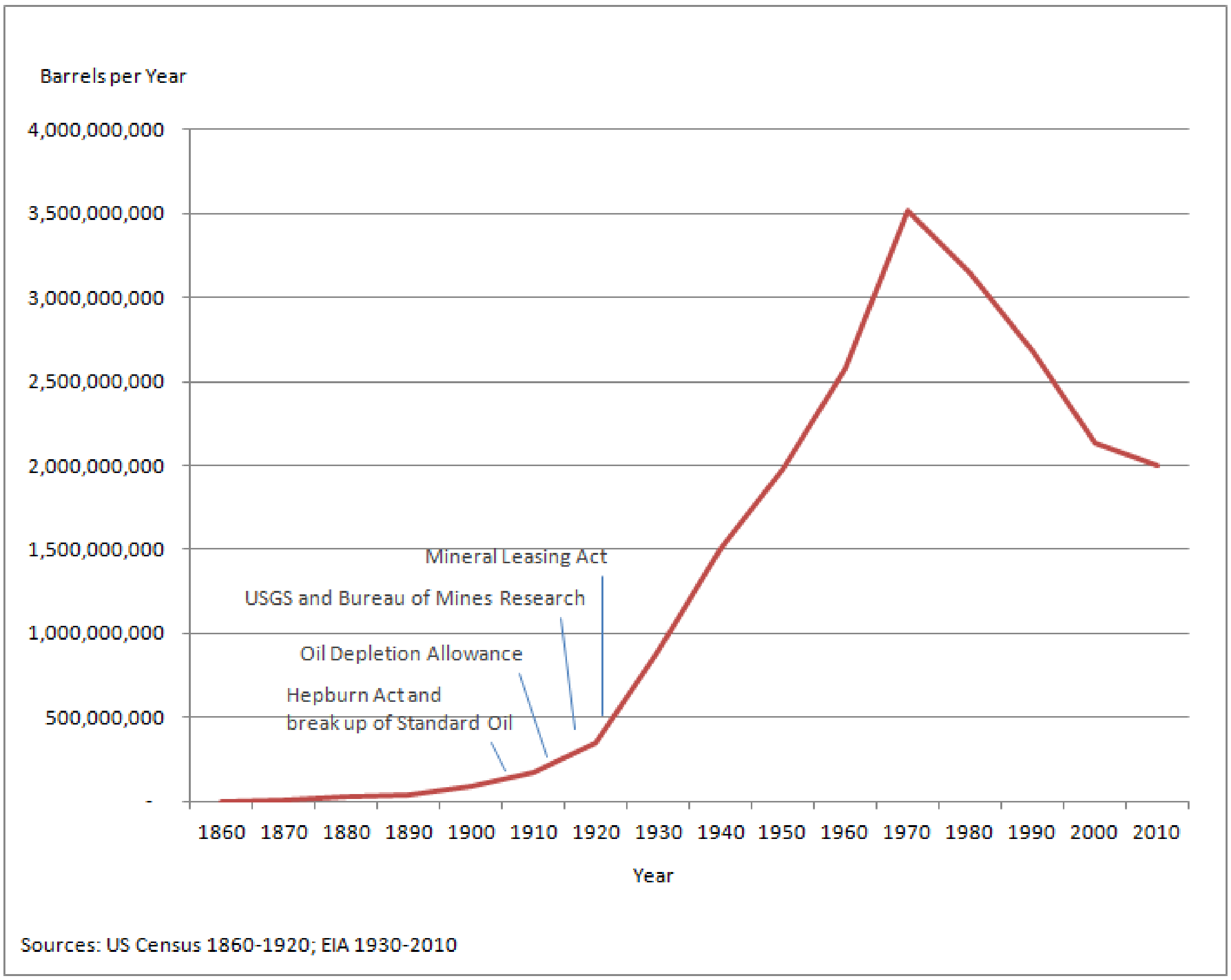


Figure 2-5. Crude Oil Production

Fuel oil technology adoption in the electric utility market has been discouraged several times by federal government policies primarily for national security purposes to conserve domestic oil reserves. As shown in Figure 2-6, adoption in the electric generation market has been choppy rather than following the typical curve.

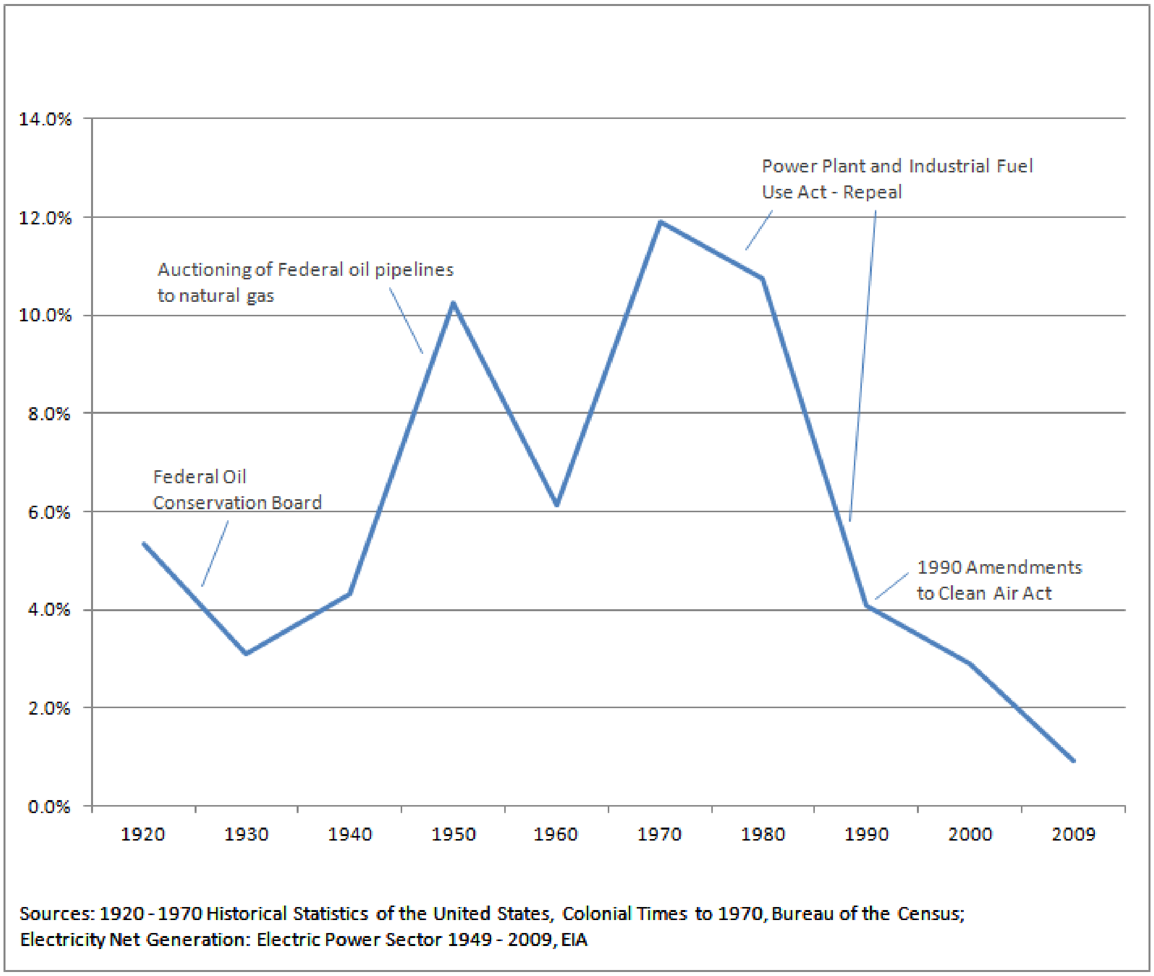


Figure 2-6. Fuel Oil Market Share, Electric Utility Market

Petroleum technology adoption in the other applications markets is driven by the transportation sector. As shown in the Figure 2-7, petroleum technology market share has remained almost constant for the past fifty years in the industrial and transportation sectors, indicating its use in applications in which there have been few new technology substitutes to displace petroleum fuels in these sectors. Note that data are not available for some sectors prior to 1950.

Figure 2-8 shows technology adoption in the transportation market of diesel locomotives. During a twenty year period, diesel locomotives displaced coal-fired steam locomotives in the railroad market.

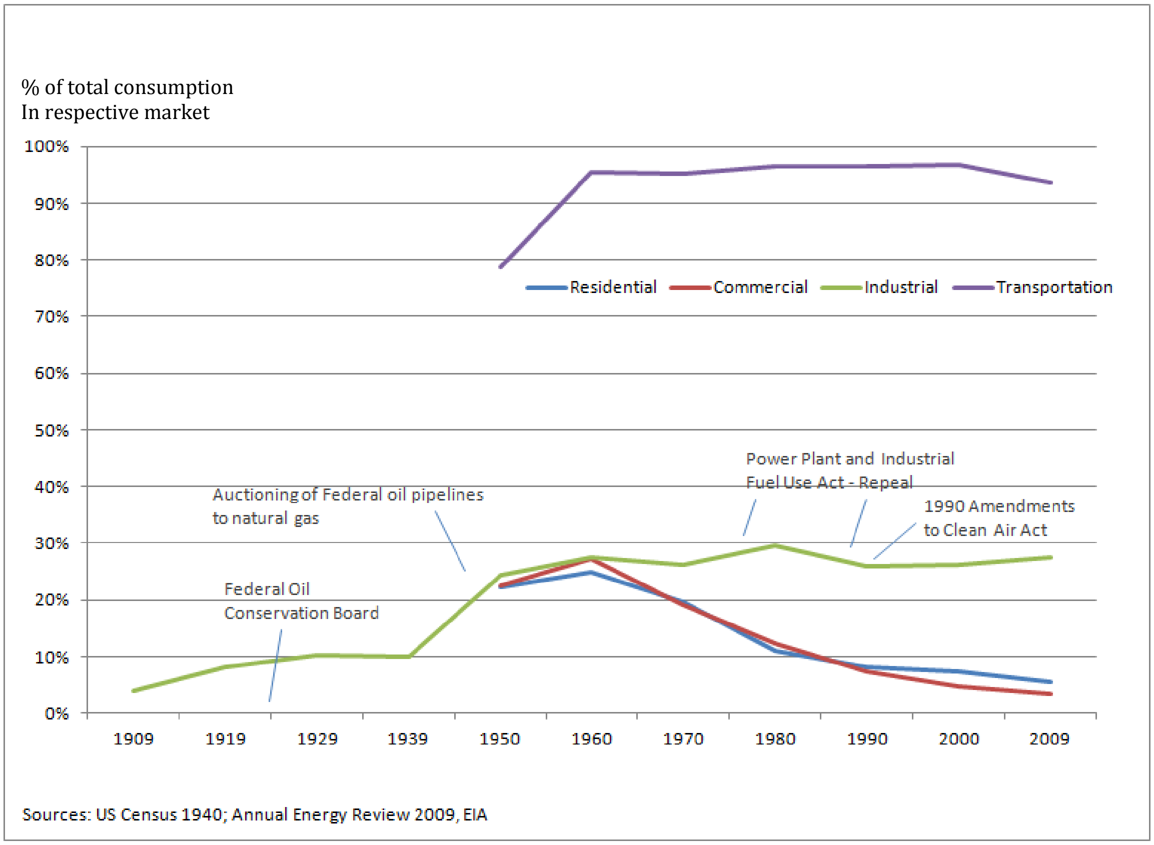


Figure 2-7. Petroleum Market Share in Four Market Sectors

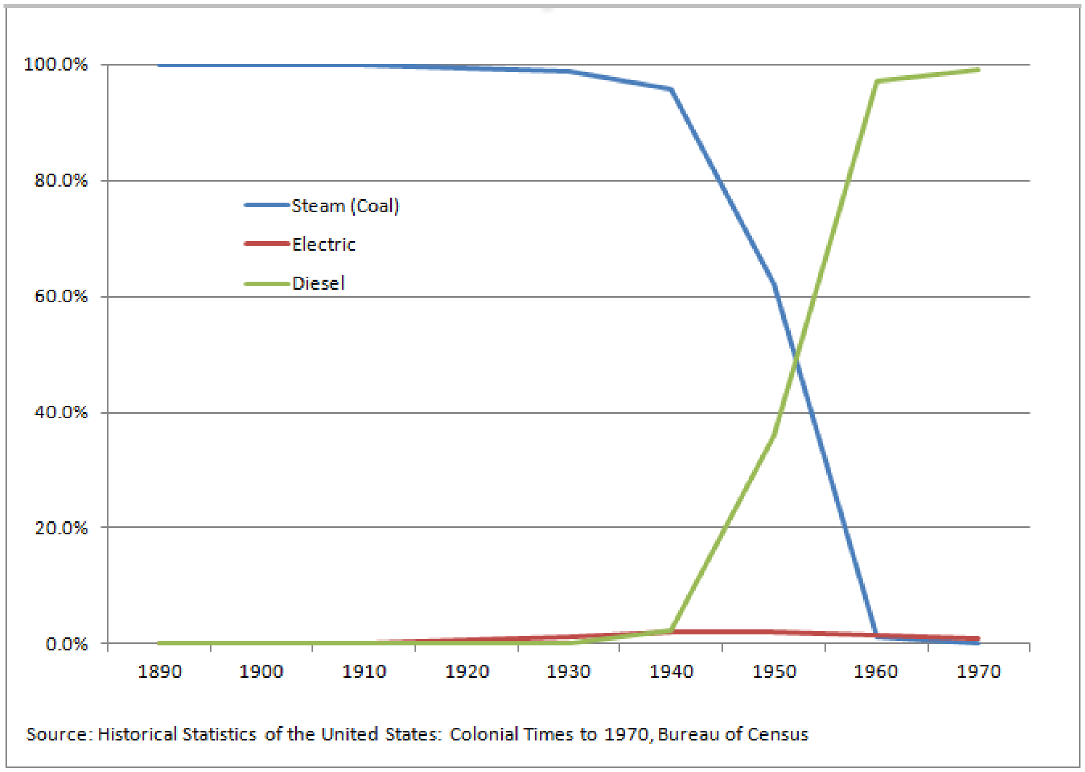


Figure 2-8. Locomotive Technology Market Share

Natural gas industry development[27]

Technology. Major innovations included i) mantle lighting and appliance conversions to compete with manufactured gas, ii) pipeline technology including electric arc welding, gas compressor and ditching technologies to create a new interstate pipeline industry, iii) gas turbines for electricity generation, and iv) unconventional production such as coal seam gas production. Technology markets included

1. Gas production,
2. Gas pipelines,
3. Gas storage, and
4. Gas appliances.

Applications. Pittsburgh industrial companies adopted natural gas in the 1880s to replace coal, which was creating a dirty city. Natural gas displaced manufactured gas in buildings as it was a heating gas compared to a lighting gas, and gas could not compete well with electricity for the lighting market. In the 1950s, California began using natural gas for electricity generation due to clean air concerns. Natural gas is now a significant fuel for peak

[27] Primary source for this section is Castaneda *(*1999).

and base load electricity generation. Compressed natural gas is used for transportation. Energy application markets for natural gas include industrial, buildings, electricity generation, and transportation.

Adoption and the Government Role. Natural gas was first used for lighting in New York with localized distribution systems that utilized pine pipes. Natural gas became a new industry in the 1880s in Pennsylvania. The Pennsylvania legislature created a competitive industry, which spurred investment (e.g., Westinghouse applied for 28 gas industry patents). The primary market was industry, especially steelmaking (e.g., Carnegie switched from coal to gas). The industry grew and consolidated over the next two decades, creating monopolies based on control of pipelines. While the U.S. Congress passed a law in 1906 creating common carrier status for petroleum pipelines, natural gas was not included. Standard Oil was broken up into separate companies in 1911. The industry further consolidated with electric utilities, leading to the Public Utilities Holding Company Act of 1935 to promote competition. In 1938, the Natural Gas Act was passed, creating regulated rates for gas transmission and later with the Phillips decision, regulation of wellhead prices. One barrier to natural gas adoption that was never addressed by law was the railroads blocking right-of-way access for pipelines, especially in the Northeast region. These markets were not served until the Big Inch and Little Big Inch petroleum pipelines, built during WWII by the federal government, were auctioned to the natural gas industry following the end of the war. The Natural Gas Policy Act, which was passed in 1978, led to open access orders that deregulated wellhead prices and gave gas marketers control of the industry. With clean air regulations and unregulated wholesale electricity generation in the Energy Policy Act of 1992, natural gas demand has increased. Selected government actions include

1. Pennsylvania Natural Gas Act (1885) creating competitive industry,
2. Break up of Standard Oil (1911),
3. Federal Power Commission (1930s) expands use of gas for economic development,
4. Public Utilities Holding Company Act (1935),
5. Natural Gas Act (1938),
6. Auctioning of federal petroleum pipelines (post-WWII),
7. Phillips decision – regulates wellhead prices,
8. Natural Gas Policy Act (1978) and FERC Orders 436-636 deregulating wellhead prices,
9. Power Plant and Industrial Fuel Use Act (1978), repealed 1987, and
10. 1990 Amendments to Clean Air Act and 1992 Energy Policy Act.

Natural gas production peaked in the 1970s and, after declining for twenty years, is growing again through unconventional production such as tight sands, coal bed, and shale gas (Figure 2-9).

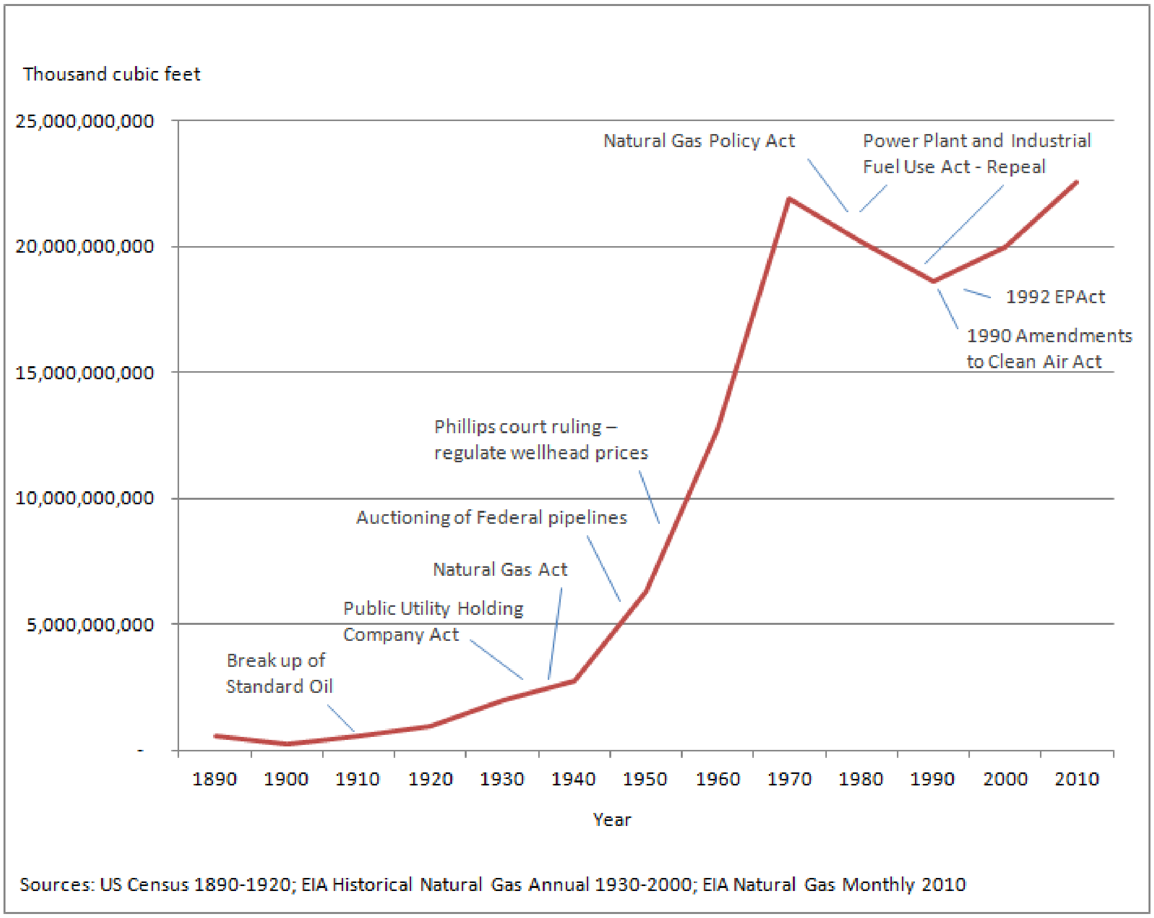


Figure 2-9. Natural Gas Production, 1890-2010

Natural gas technology's share in the electric utility market also peaked around 1970 and, after declining for twenty years, is growing again in response to disincentives for coal and fuel oil use due to pollution and climate change concerns, low gas prices and the higher efficiencies associated with new combined-cycle gas turbines (Figure 2-10).

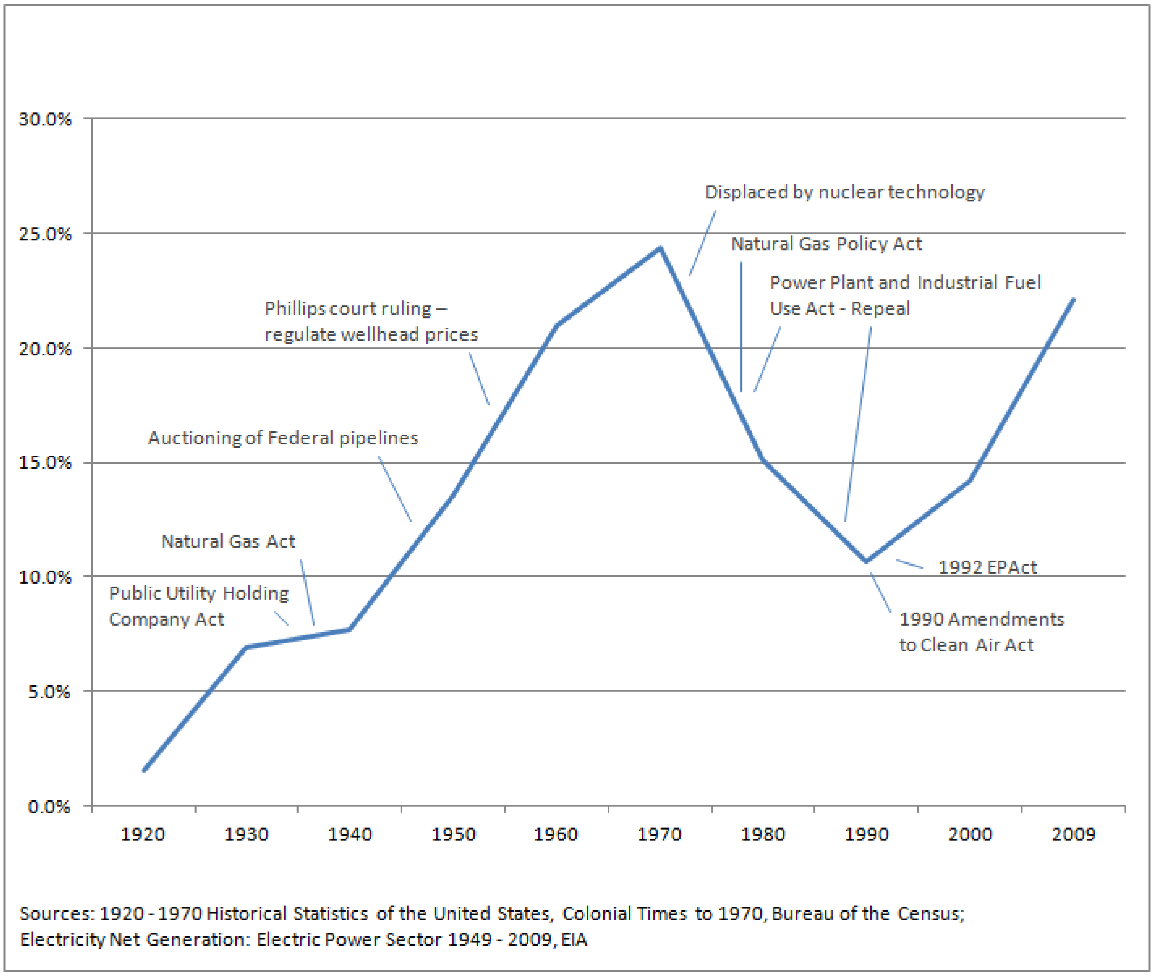


Figure 2-10. Natural Gas Market Share, Electric Utility Market

Natural gas technology adoption in the applications markets rose steadily since the development of the Mid-Continent and Texas fields and interstate pipelines from these fields to the Northeast region. Following the shortages of the 1970s, adoption continued to decline some in the residential sector until use increased again in the early 2000s. The residential market's use still has not returned to its early 1970s peak. However, the decline appears greater than it actually is because while absolute use of natural gas use in the residential market declined slightly, the total market has grown. In the commercial sector, the natural gas use has grown but not at a rate equal to the total market growth. Figure 2-11 shows adoption by applications market. Note that data are not available for some sectors prior to 1950.

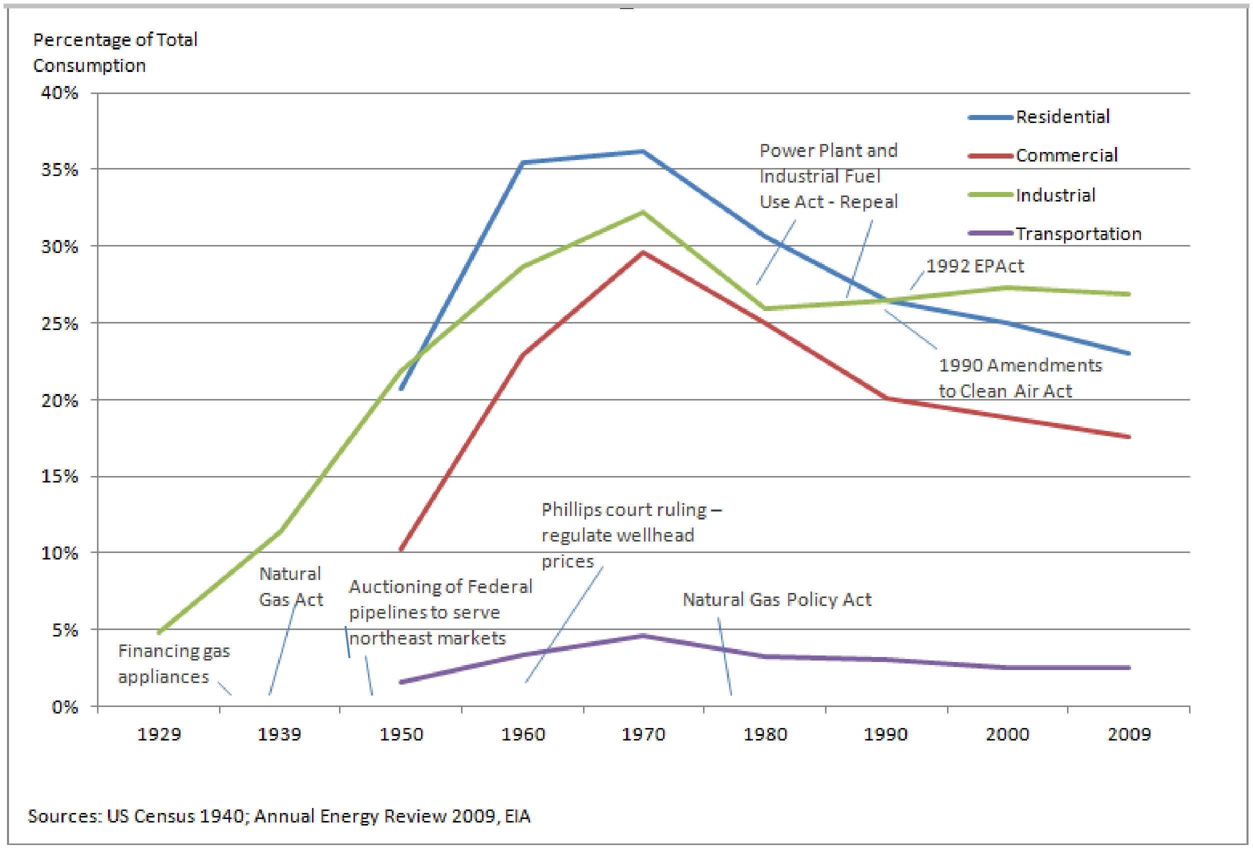


Figure 2-11. Natural Gas Market Share by Sector

Manufactured gas industry development[28]

Technologies. Coal gas technology and engineering services were initially imported from England. Significant technology innovations occurred in resource use (coal, pine rosin, oil), carbureted water processes to produce gas more efficiently, and use of meters. Technology markets included

1. Gas-producing apparatus,
2. Gas purifying,
3. Gas distribution system,
4. Gas metering, and
5. Gas appliances.

Applications. Initial applications were for better lighting compared to oil lanterns and candles. Early adopters were industrials (e.g., cotton mills) and government for street lighting. Gas lighting eventually was replaced by electric lighting, although manufactured gas

[28] Primary source for this section is Castaneda (1999).

was still used for heating and cooking until natural gas distribution arrived in the Northeast in the 1950s. Energy application markets included industry, buildings, and street lighting.

Adoption and the Government Role. In 1816, Baltimore granted the first gas light franchise to open streets for pipes, using coal as the source for gas. New York City developed an oil gas works in the 1820s, and then switched to rosin which was more cost effective. In the 1830s, Philadelphia opened the first municipally owned gas works, while in Cincinnati an exclusive franchise was granted to a public/private partnership. In all cases, a significant share of demand was for public street lights. In the 1850s, Chicago began regulating gas prices. From this point forward, the manufactured gas industry continued to grow until it competed as a mature fuel with natural gas and then electricity in the latter part of the nineteenth century. With railroads preventing pipeline right-of-way, however, the industry continued to serve some markets in the Northeast region until the 1950s. The industry tried to reinvent itself during the energy crisis in the 1970s, using technology developed by Germany in WWII and further developed in Europe and South Africa after the war. But the industry faced a barrier to opening plants because of required Environmental Impact Statements. The industry lobbied for subsidies, and in 1979 the Federal Government created the Synthetic Fuels Corporation to provide financing for commercial manufactured gas plants. The $2.1 billion Great Plains Synfuels Plant was the only facility to emerge as viable, producing gas from lignite coal for distribution to eastern markets. Selected government actions include

1. Local franchises (1816 – 1950s),
2. Public investment in municipally owned plants and distribution systems (1830s – 1950s),
3. Demand for public street lighting (1816 – 1900s),
4. State law for formation of Gas Light Companies (NY 1848),
5. Regulated rates (1850), and
6. Federal subsidies (1979 – 1980s) - Energy Security Act.

Data on market penetration are not available for the gas light era. But technology adoption can be approximated by using number of establishments as reported by the U.S. Census during this time period. Since manufactured gas was a distributed energy technology deployed city by city, the number of establishments can serve as an approximation of the market penetration of this energy source. As shown in Figure 2-12, manufactured gas began rapid growth around thirty years after the industry's introduction in the market, facilitated by state formation laws and rate regulation. The industry began to decline around 1910, which was about thirty years after the introduction of natural gas in the market. Note that data on manufactured gas was not collected in 1880, creating a gap in the chart.

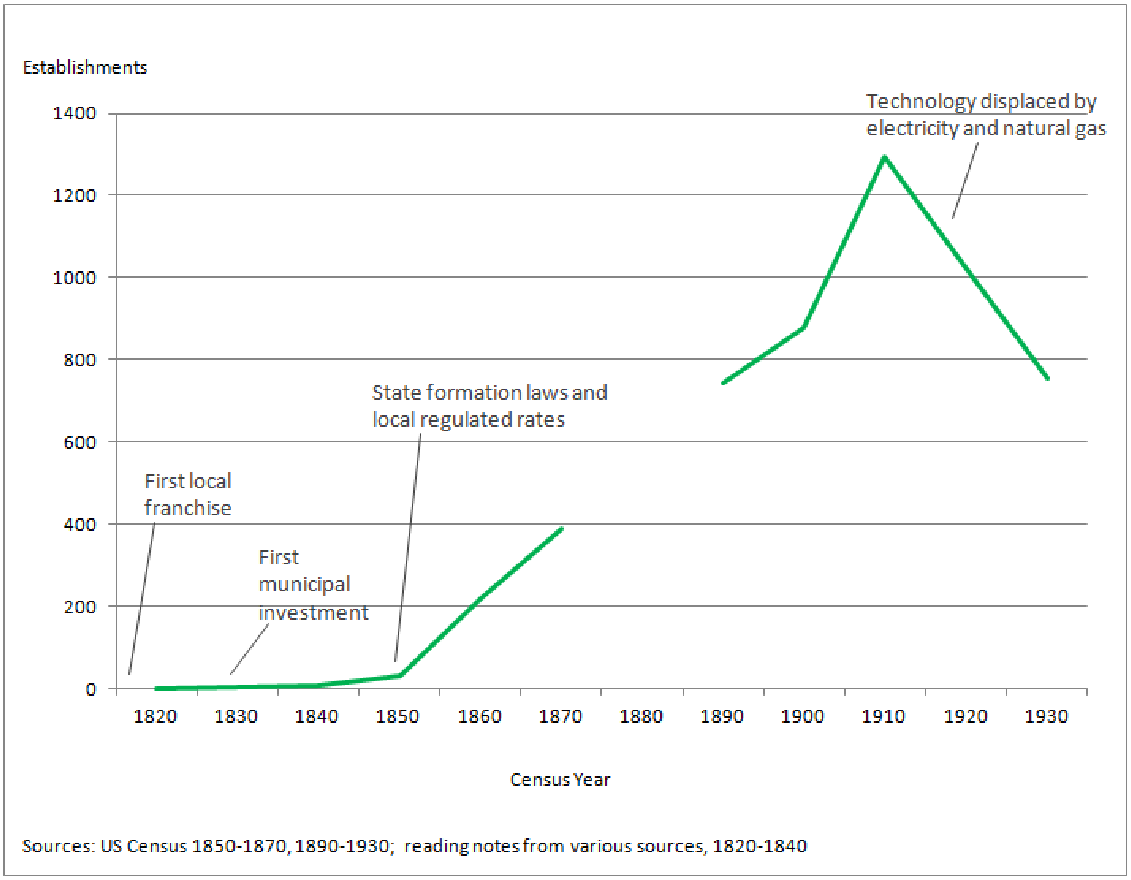


Figure 2-12. Manufactured Gas Establishments

2.2 Hydro and nuclear power development

Hydropower developed during the birth of the electricity industry alongside the development of oil and gas and at the height of coal's dominance as an energy source. During the initial years of development, hydropower benefitted from an ease in licensing plants at desired river locations. But this initial no charge, no-time-period approach by the government in granting the use of water resources to industry soon became an issue, especially related to navigation of the rivers and interstate commerce. As such, the initial government engagement in the industry was to regulate commerce and thus was similar in purpose to early actions in the fossil fuels markets. But once up the adoption curve, government began to enact economic development policies that provided for direct federal investment in hydropower resources. This role of direct federal involvement in the development of an energy resource carried over to the nuclear power industry, where publicly-funded research, public-private partnerships, and policies to remove specific market barriers characterized government engagement with hydro and nuclear.

Hydropower industry development[29]

Technology.[30] From the initial dynamo, the electrical technologies that developed in association with hydro resources became the electric power industry in the U.S. With Nikola Tesla's alternating current innovation and ultimate commercialization by Westinghouse, power could be generated at rivers and transmitted long distances, paving the way for expansion of the hydropower industry. Technology innovations included water turbines, generators, transformers, and alternating current and distribution systems. The water turbine technology had to compete with steam raising technologies in the central station electric generation market. Hydro power depended on stream flow, which was a disadvantage to coal and its ability to provide for continuous output. But, compared with coal, hydro had no fuel costs, although significant up-front capital costs. Other specific technology related to hydropower includes pumped storage facilities, where reservoirs are filled during off-peak times for release at peak periods. Technology markets for hydro include

1. Turbines,
2. Generators,
3. Transformers and distribution systems,
4. Storage, and
5. Small-scale generator systems.

Applications. Hydropower was initially used to generate electricity for transmitting to cities and large industries, and on a smaller scale to generate electricity for use onsite. During the period of adoption of hydropower, industry was adopting the electric motor and the modern office building was coming into existence. Cities used electricity for street lighting and street railways. Figure 2-13 shows the growth in demand for electric motors in industry that occurred in parallel with the adoption of hydropower.

[29] In this study, we consider hydroelectric development as an energy source for electricity. Hydro also was an important energy source for mechanical power in the development of the U.S.
[30] Cost economics of hydroelectric technology and demand are discussed in Player (1908).

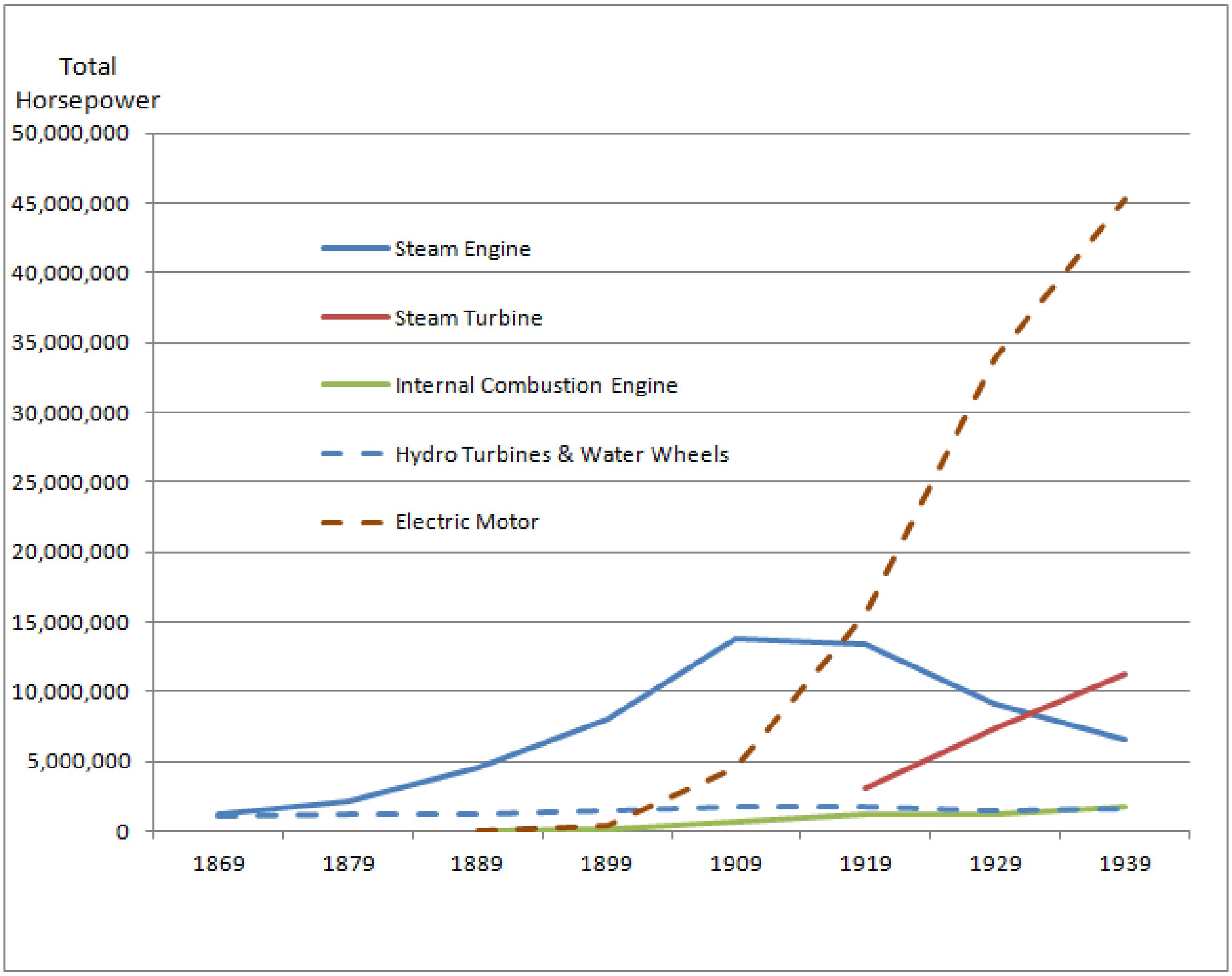


Figure 2-13. Electric Motor Technology Adoption in the Industrial Sector vs. Other Drive Options, 1869-1939

Adoption and the Government Role.[31] The first hydroelectric plants were developed in the early 1880s. By the end of the decade, two hundred electric companies generated some or all of their electricity using hydro resources. But hydro facilities were still limited by direct current. As the industry grew, tensions rose between river use for transportation and for power generation. The federal government began to intervene to regulate development of the industry with the Rivers and Harbors Acts of the 1890s, requiring no-charge, no-time-limit licenses for hydroelectric facilities and giving the Army Corps of Engineers responsibility for maintaining open navigation on rivers. More regulation followed, with the Reclamation Act of 1902, which established the Reclamation Service and gave it the authority to develop hydropower on its reclamation projects. The building of the Hoover Dam began in 1905. In 1906, the General Dam Act was enacted to require navigation at dam

[31] This section in part draws from information presented in McFarland (1966) and Hay (1991).

sites to be paid by the investor in the hydroelectric facility, which had the effect of discouraging new hydroelectric power. At this time there was also movement by the government to stop giving away the right to the resource, changing the no-charge, no-time-limit principle that had been followed since the beginning of the industry. This debate continued, leading to the Federal Power Act in 1920 that established the Federal Power Commission and gave it the authority to issue licenses to develop hydroelectric facilities on public land. By this time, hydropower had established itself as a primary energy source in the electric generation industry, with the private sector providing most of the investment in hydroelectric stations. The government then began investing significantly in hydropower to encourage development of resources, with the Tennessee Valley Authority Act in 1933 and the National Recovery Act, which provided authority and funds to construct dams. The Bonneville Project provided for the marketing of power from dams built by the federal government. By 1940, there were 1,500 hydroelectric facilities in the U.S. The Flood Control Act of 1944 gave authority to the Army Corps of Engineers to construct reservoirs, which led to continuing development of hydropower production. In 1968, the government prohibited development of some resources with enactment of the Wild and Scenic Rivers Act. This Act began a series of policies over the next twenty years that considered environmental factors and other uses of rivers, such as recreation, when issuing licenses. In the post-oil-embargo era, government policies have included incentives to encourage small-scale hydropower production. Selected government regulatory actions related to hydro include

1. River and Harbors Acts (1890s),
2. Reclamation Act (1902),
3. General Dam Act (1906),
4. Federal Power Act (1920),
5. Tennessee Valley Authority Act (1933),
6. Flood Control Acts (1936 and 1944),
7. Wild and Scenic Rivers Act (1968),
8. Energy Security Act (1980),
9. Windfall Profit Tax Act (1980),
10. Electric Consumers Protection Act (1986), and
11. Energy Policy Act (2005).

Figure 2-14 shows the adoption curve for hydropower in the central electric generation industry, using available data from that time period starting with the 1902 Census. Because the electric industry was entering a rapid growth stage during this time period, hydropower achieved and maintained more than a 30 percent market share. But the adoption rate did slow following the General Dam Act of 1906 and subsequent consequences of the debate to no longer follow a principle of no-charge, no-time-period granting of licenses. With the Federal Power Act of 1920 causing more deliberate additions to hydropower resources and the rapid increase in electricity production using other resources—primarily coal through

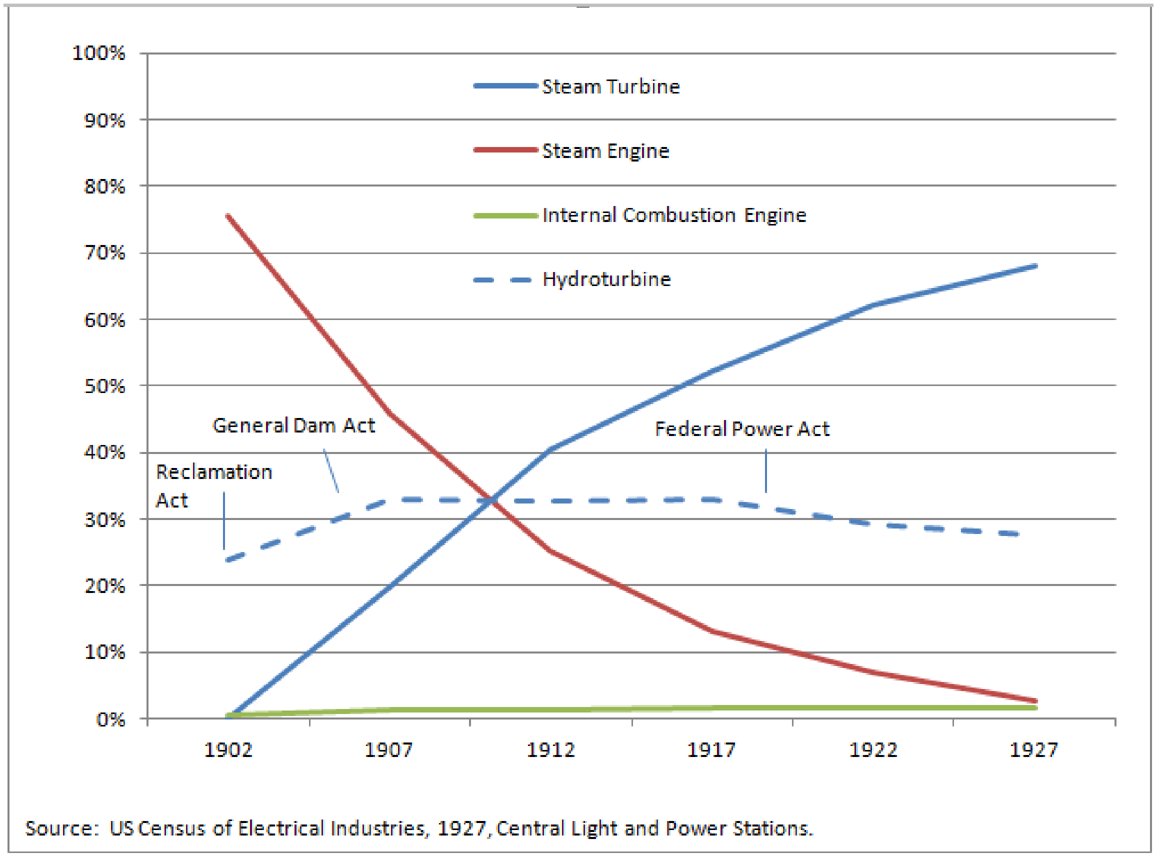


Figure 2-14. Market Share of Installed Capacity in the Central Power and Light Station Industry by Technology

the 1950s, nuclear in the 1960s and 70s, and more recently gas and renewables—hydropower started to lose market share at beginning of the 20th century as total electric generation has grown while hydro generation has remained relatively flat (Figure 2-15).

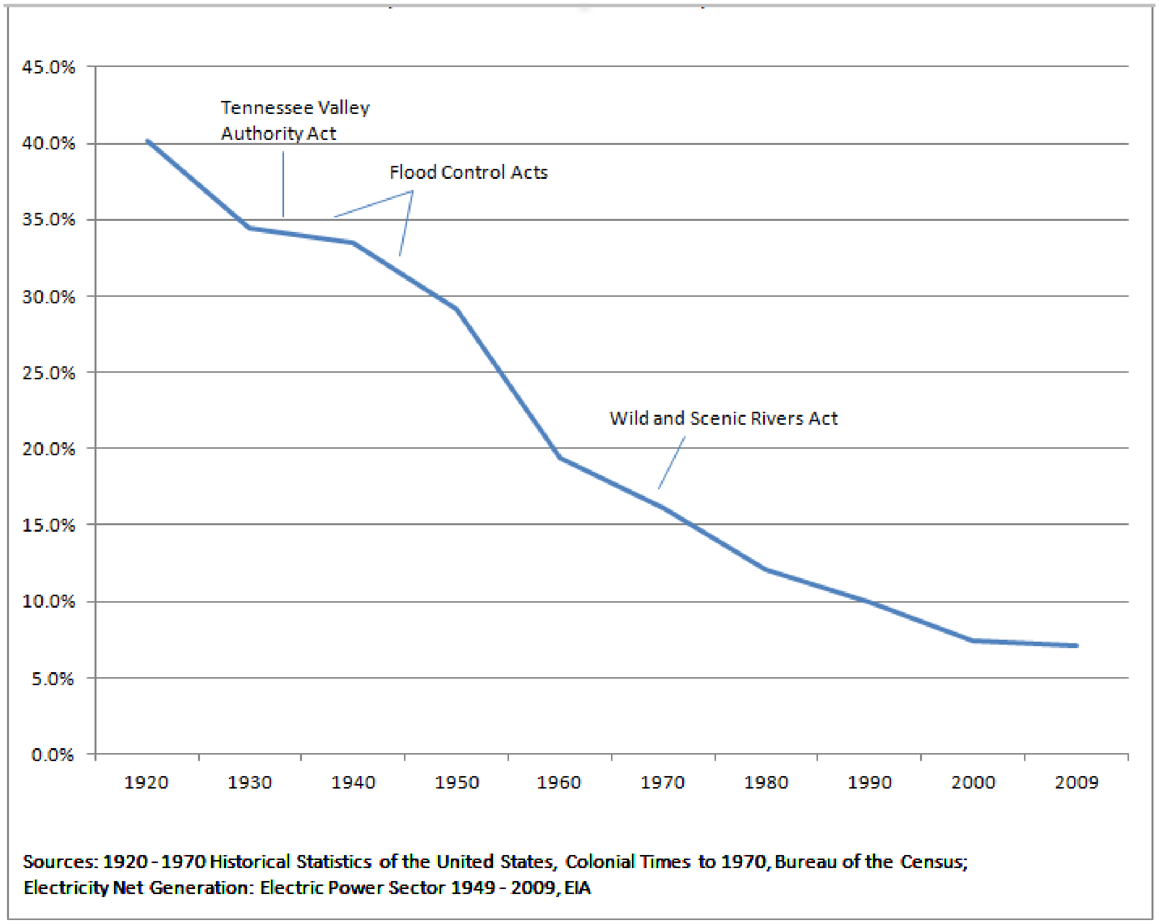


Figure 2-15. Hydro Market Share, Electric Utility Market

Nuclear power industry development

Technology. Major innovations included the light water reactor for commercial power production. Work continues on advanced reactor and safety technology for the next generation of nuclear power plants. Waste remediation technology continues to be a significant issue for the industry. Technology markets for the nuclear industry include

1. Reactor type and size,
2. Safety, and
3. Waste remediation.

Applications. Initial peacetime applications included centralized electric power generation and nuclear-powered ships. From the initial reactor for electricity generation in Idaho in 1955, to the first non-government funded nuclear power plant in 1959, nuclear power grew to become an important energy source for centralized electricity generation in the U.S., with a penetration rate exceeding 20% of production by 1990. Nuclear power plants also became important energy sources for military ships and submarines, starting with the initial sub in 1953. The first subsidized merchant ship was launched in 1959, but only a few nuclear merchant ships were ever built. A few Russian nuclear icebreaker ships remain active. Energy application markets include electricity generation and transportation.

Adoption and the Government Role. Following WWII, the federal government created the Atomic Energy Commission, which funded research and development of the first experimental nuclear power plants for electricity generation and ships. Shortly after Eisenhower's "Atoms for Peace" speech, the Atomic Energy Act of 1954 gave the private sector further access to nuclear technology. Industry and government cooperated in demonstrating nuclear power plants, leading to the first non-government funded power plant in 1959. The Price-Anderson Act in 1957 paved the way for this private sector investment by limiting private sector liability in event of an accident. The technology was further commercialized to the private sector through the Private Ownership of Special Nuclear Materials Act in 1964, which allowed the electric power industry to own nuclear fuel. By the 1970's, nuclear power plants were on the growth curve, leading to the creation of the Nuclear Regulatory Commission in 1974 to regulate the industry. The government continued to support development of the industry through research, creating a special R&D program in 1980 to dispose of spent fuel following the Three Mile Island reactor accident along with the Nuclear Waste Policy Act in 1983, which established fees to industry to fund disposal of radioactive waste. The government continues to be active in regulating and supporting the industry, with the Energy Policy Acts of 1992 and 2005. Selected government regulatory actions include

1. Creation of Atomic Energy Commission (1946),
2. Development of first experimental reactor (1949) and nuclear submarine (1952),
3. Atomic Energy Act (1954),
4. Power Demonstration Reactor Program (1955),
5. Price-Anderson Act (1957),
6. Private Ownership of Special Nuclear Materials Act (1964),
7. Energy Reorganization Act (1974),
8. Nuclear Waste Policy Act (1983),
9. Energy Policy Act (1992), and
10. Energy Policy Act (2005).

Nuclear technology adoption in the electric utility market has been supported by federal government policies as shown in Figure 2-16. The government was heavily involved in getting the technology commercialized successfully through research and development expenditures, cooperative agreements with industry, and the Price-Anderson Act that limited liability in the case of accidents. New nuclear production that helped nuclear to capture more market share after 1980 was the result of upgrades and new units at existing facilities.

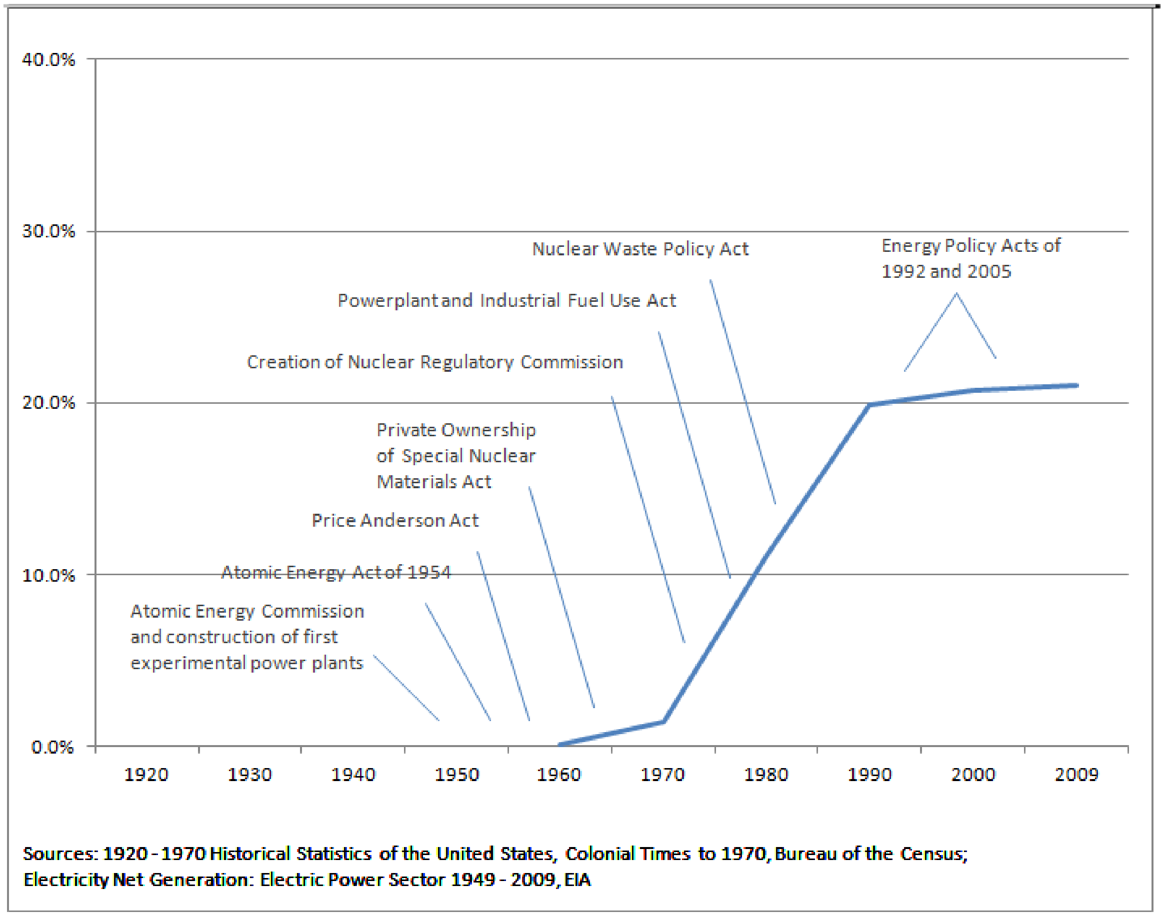


Figure 2-16. Nuclear Market Share, Electric Utility Market

2.3 Solar Development

The vast majority of the country's solar energy resources have yet to be developed. Following the oil embargo in 1973, the government enacted policies to invest in the development of solar resources. But unlike hydro and nuclear resources, the government commitment to develop the country's solar resources was short-lived. In 2005, the federal government restarted the process of developing the country's solar resources with the enactment of the Energy Policy Act of 2005, with the industry now at a key inflection point on the adoption curve.

Technology. Solar technologies fall into three primary groups, photovoltaic (PV), concentrating solar power (CSP) and solar heating and cooling (SHC). Photovoltaics convert light directly into electricity. Concentrating solar power uses mirrors to collect heat to produce steam used to generate electricity. Solar heating and cooling technologies collect heat for water heating, space heating, pool heating, industrial process heat and heat for absorption chillers for cooling applications. Associated technologies include inverters, trackers, power optimizers and racking. Technology markets for solar include

1. Solar heating and cooling (SHC)
    a. High, medium and low temperature collectors
2. Concentrating solar power (CSP)
    a. Specialized mirrors
    b. Trackers
    c. Molten salt thermal storage
3. Photovoltaic (PV)
    a. Modules
    b. Inverters
    c. Power optimizers
    d. Racking
    e. Trackers

Applications. Solar heating and cooling applications include using medium temperature collectors to produce hot water for residential and commercial markets; low temperature collectors are most commonly used to heat swimming pools. Solar electric applications include centralized electricity generation, distributed electricity generation especially in commercial and residential markets, and consumer products such as outdoor lights and electronic devices. Distributed generation applications can interconnect with the electrical transmission and distribution grids or provide stand-alone power with battery storage.

Adoption and the Government Role. One of the earliest organized solar research initiatives in the United States was initiated in the 1940s when the Massachusetts Institute of Technology built a series of houses over a decade to review methods to exploit solar energy. This resulted in several organized activities in the 1950s and 1960s sponsored by the National Science Foundation and later by the United Nations. In 1955, the Association for Applied Solar Energy was formed and by 1971 had become the International Solar Energy Society. By 1970, twenty research structures demonstrating various solar heating technologies were in operation. Although photovoltaic technology had been in development since the 1950s, it was not until the early 1970s that various off grid applications began to develop.

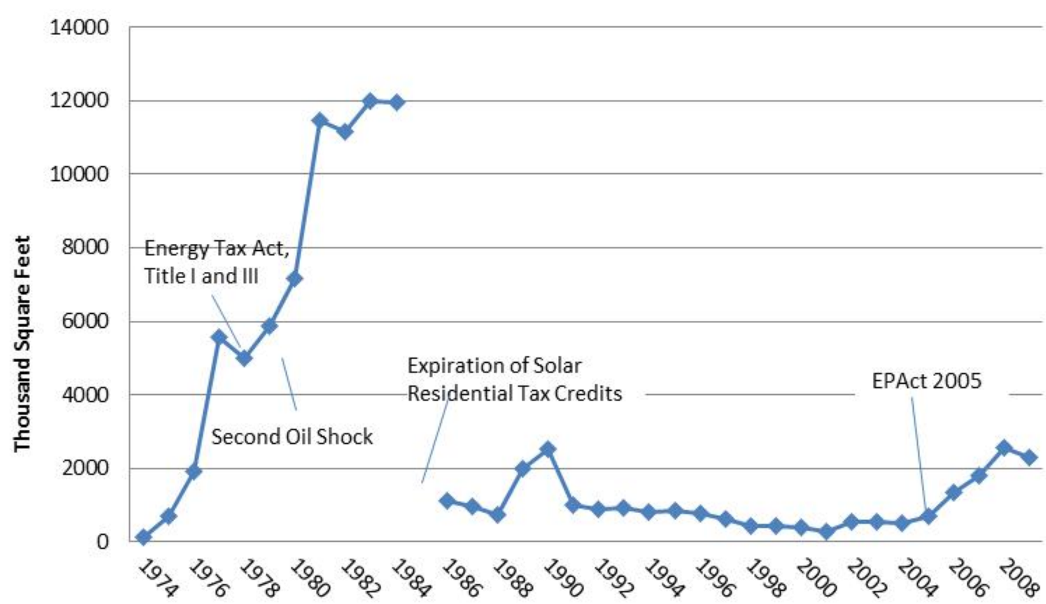
In response to the oil embargo, the government began to actively target solar energy research and development in 1974. Federal involvement in the research, development, and deployment of solar technologies grew significantly, and various incentives were developed both at the federal and state levels to accelerate the deployment of these technologies.

Facilities were quickly developed to address solar research requirements, and included the development of various federally funded research programs housed at existing laboratories and federal facilities, as well as new programs at universities. One major outgrowth of the program was the formation of the Solar Energy Research Institute (SERI) in 1977 which would later become the National Renewable Energy Laboratory (NREL). In the late 1970s, Congress passed several Acts containing significant provisions for solar technologies. These included the Department of Energy Organization Act in 1977 which created the position of the Assistant Secretary for Solar Energy Research, the Department of Energy Act of 1978 which authorized loans and guarantees for research, development and deployment of solar programs, the Energy Tax Act of 1978 which provided a series of tax credits for residential and commercial consumers of solar energy technologies, the National Energy Conservation Policy Act of 1978 which required some application and demonstration of solar heating and cooling in federal buildings, and the Crude Oil Windfall Profit Tax Act of 1980 which resulted in energy credits for residential installation of roof mounted solar panels. The Energy Securities Act of 1980 established a Solar Bank to assist residential and commercial consumers with financing, but the subsequent administration blocked funding the Bank. Also, by the mid 1980's oil prices had dropped significantly and solar funding was scaled back. The industry continued to grow worldwide in response to environmental concerns, but it was not until the Energy Policy Act of 2005 that the U.S. government showed renewed interest in development of the solar industry. Selected government actions include

1. NASA, NSF research (1950s),
2. Solar Heating and Cooling Demonstration Act (1974),
3. Solar Energy Research Institute (1977),
4. Solar Energy Research, Development, and Demonstration Act (1978),
5. Energy Tax Act (1978),
6. Crude Oil Windfall Profit Tax Act (1980),
7. Energy Policy Act (2005),
8. Emergency Economic Stabilization Act (2008), and
9. American Recovery and Reinvestment Act (2009).

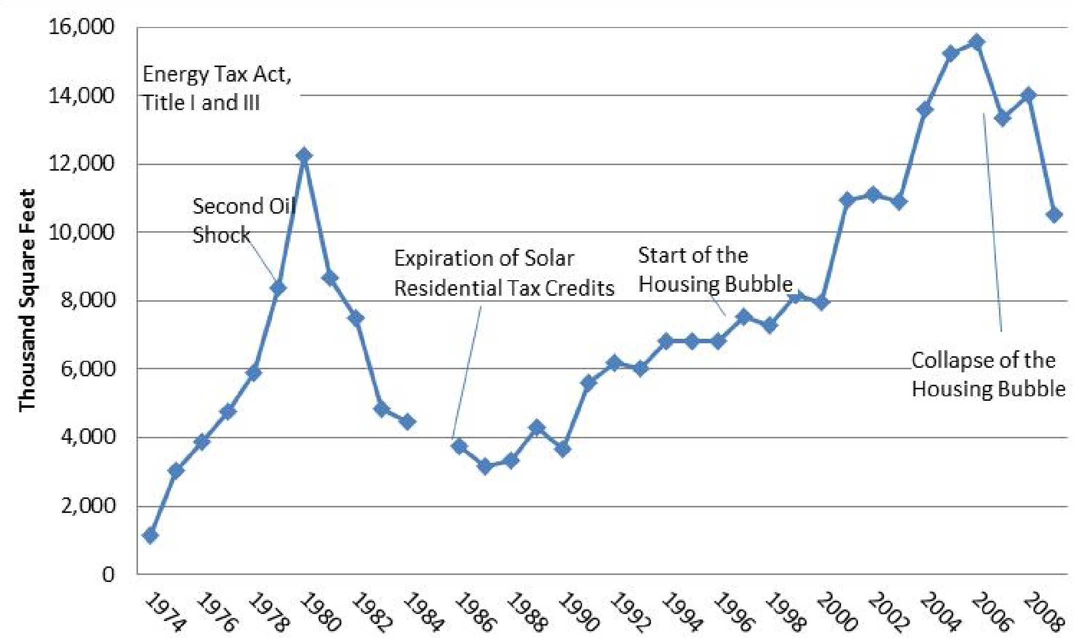
It is important to note that, unlike its nuclear and fossil fuel predecessors, solar resources did not benefit from continuing government commitment through the adoption cycle but only a series of temporary policies. Figures 2-17 and 2-18 show annual production or installations of solar thermal technologies since 1974.

Solar photovoltaic technology began its adoption process in the 1990s. Figure 2-19 shows cumulative installed grid-connected capacity over the past fifteen years. Figure 2-20 shows annual and cumulative CSP capacity. Both figure show significant increases in capacity in the last few years.



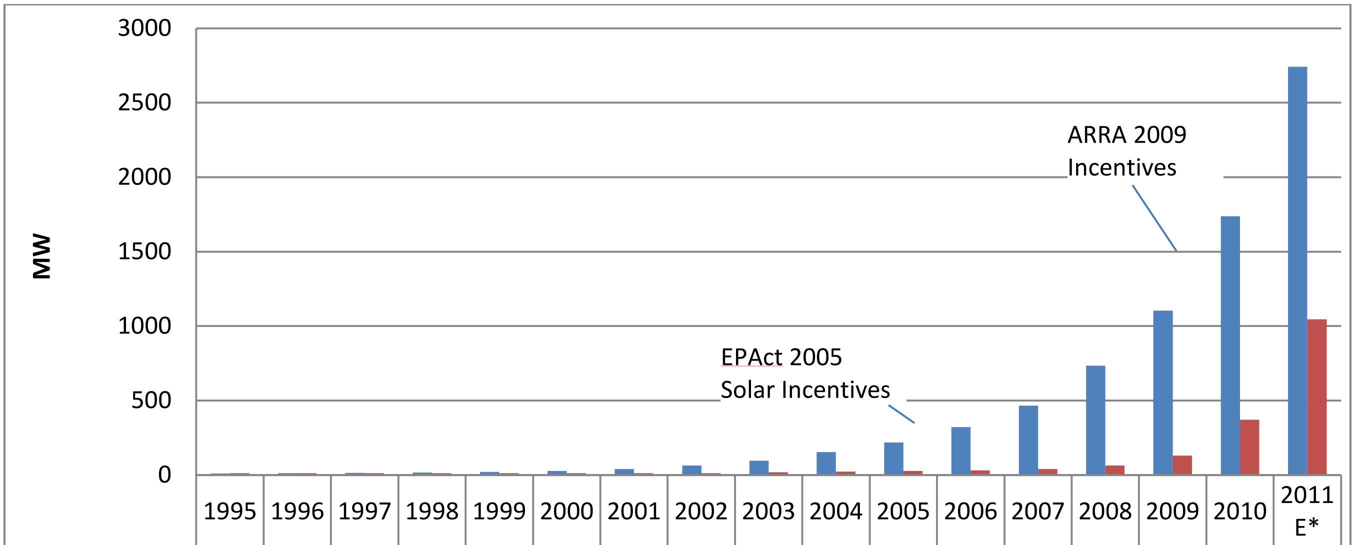
Note: Medium temperature collectors are solar thermal collectors that generally operate in the temperature range of 140° F to 180° F but can also operate at temperatures as low as 110° F
Source: EIA Annual Energy Review

Figure 2-17. Medium-Temperature Collectors



Low-temperature collectors are solar thermal collectors that generally operate at temperatures below 110° F. Primary applications are for residential or commercial swimming pool heating.
Source Data: EIA Annual Energy Review

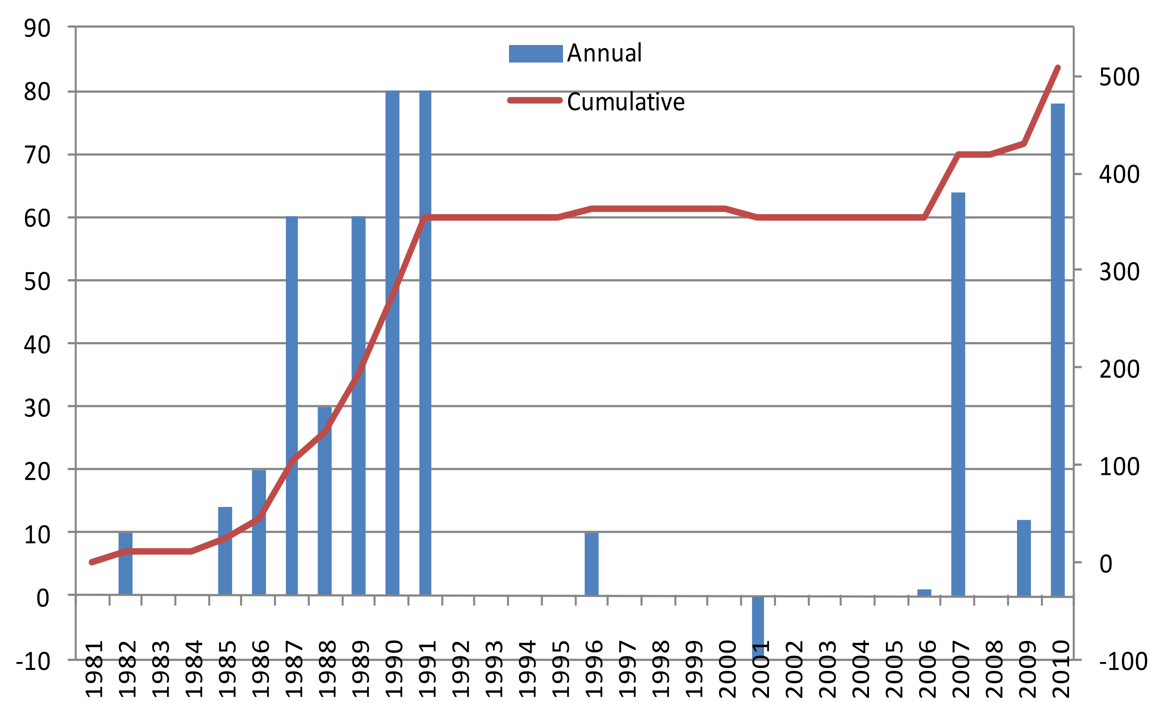
Figure 2-18. Low-Temperature Collectors



	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011 E*
Distributed	9.7	11	13.7	15.9	21.1	28.1	40.6	63.6	95.6	154	219	322	465	735	1104	1737	2741
Centralized	12	12	12	12	12	12	12	12	18	22	27	32	40.5	63.5	130	372	1046

Source: IEA (2011); E* (estimates) from SEIA/GTM Research *U.S. Solar Market Insight* (2011).

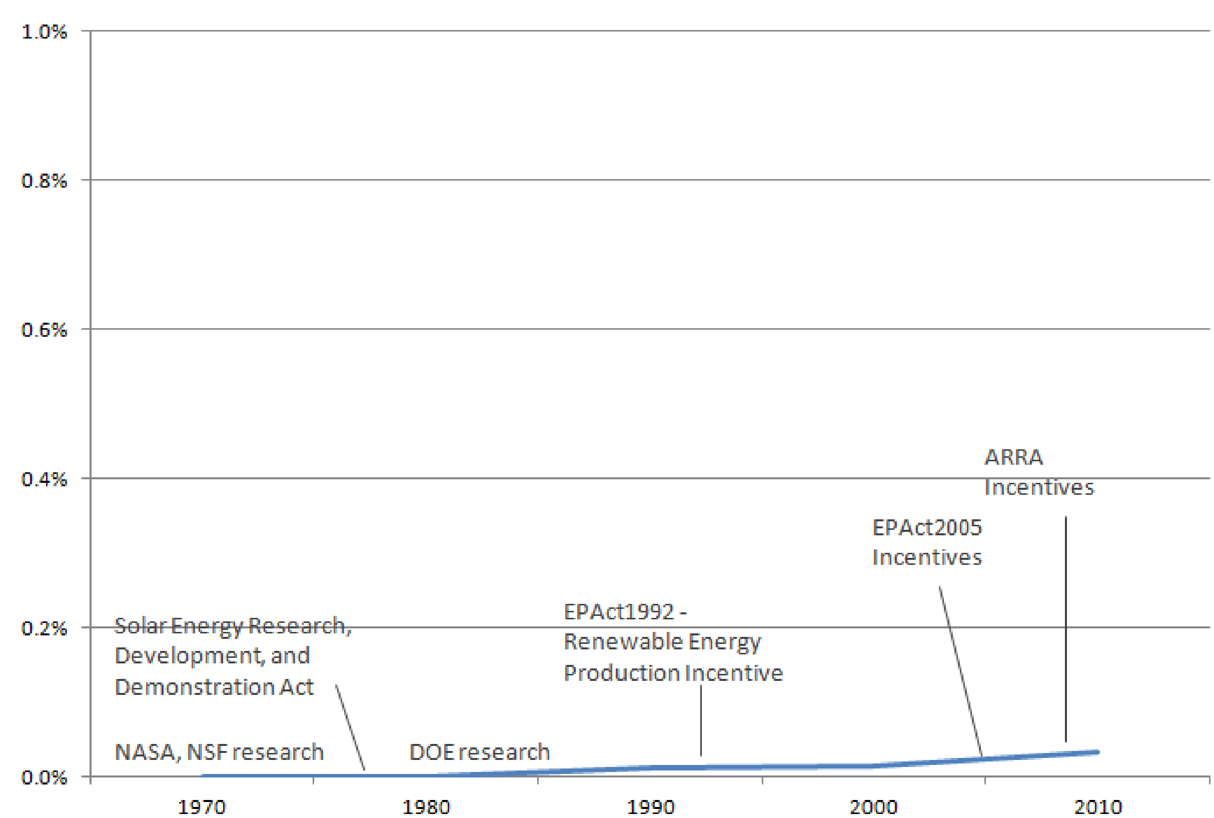
Figure 2-19. Cumulative Installed Grid-Connected PV Power



Source: SEIA

Figure 2-20. CSP Capacity, Annual Installations and Cumulative Capacity

Figures 2-21 and 2-22 show market share for solar resources in the electric utility generation and energy applications markets, respectively, using available data from EIA. EIA data under-represents solar power generation as it includes only electric generation plants larger than 1MWac. Residential capacity (29% of total PV capacity in 2010) and non-utility capacity (40% of PV capacity in 2010) are combined with other co-generation sources.[32]



Note: EIA data reported here exclude non-utility solar generation, including residential and non-utility capacity (29% and 40% of PV capacity, respectively, in 2010.

Source: Electricity Net Generation: Electric Power Sector 1949 - 2010, EIA

Figure 2-21. Solar Market Share, Electric Utility Market

[32] Sherwood (2011).

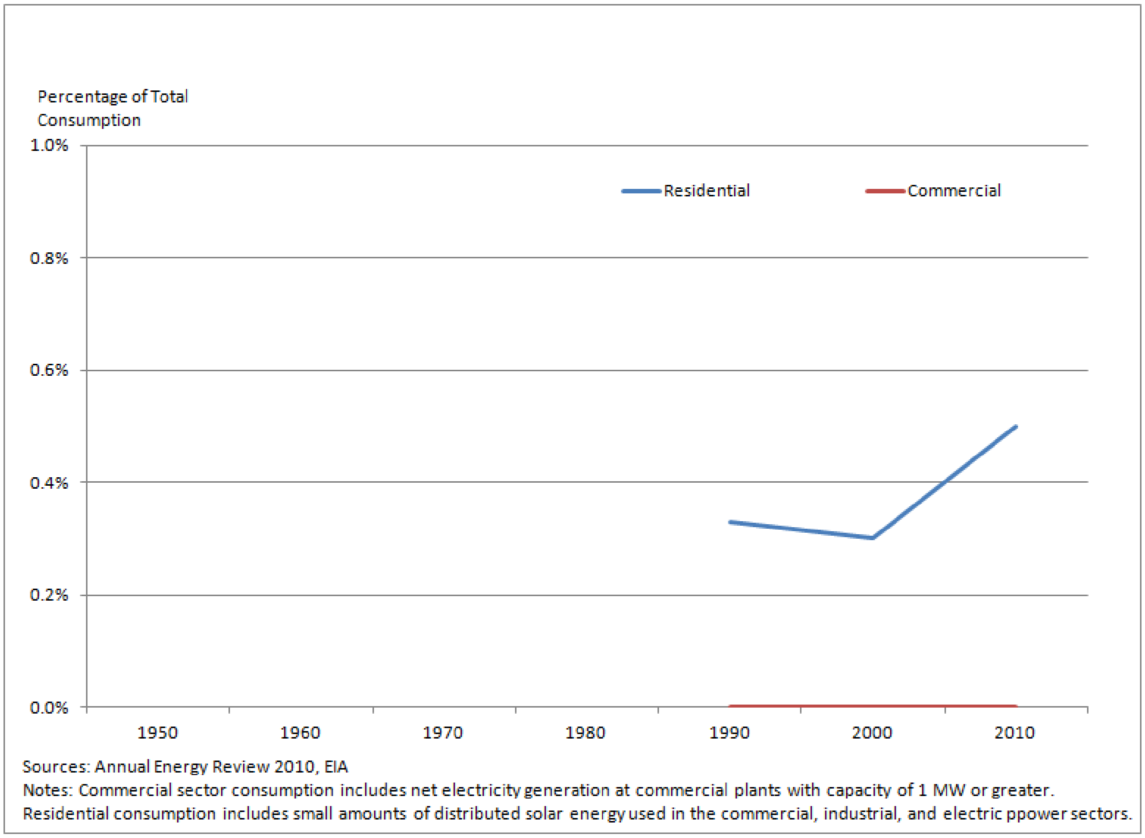


Figure 2-22. Solar Market Share by Sector

CHAPTER 3. ANALYSIS OF FEDERAL INCENTIVES IN ENERGY MARKETS

In this chapter we analyze incentives along three dimensions:

1. the technology adoption stages, along with the mature stage once the technology has progressed through the adoption cycle;
2. the intended effects of encouraging or discouraging supply or demand in energy markets; and
3. the individual markets that comprise the energy value chain.

Our analysis incorporates the rapidly expanding literature on incentive accounting. To understand the effects of incentives on technology adoption, however, we augment the incentive accounting literature with an understanding of other government interventions in energy markets, such as regulations. We also analyze the current portfolio of incentives along the adoption curve, providing a policy framework for understanding differences in total incentive costs by energy resource. We divide our analysis into three sections, starting with the a review of both existing federal incentives and the changing nature of federal intervention in energy markets, followed by lessons from past incentives, and concluding with a comparison of U.S. versus international incentives for solar adoption.

3.1 Estimates of Federal Incentives in the Energy Sector

Interest in government incentives in the energy sector, while longstanding, has undergone a renaissance as a result of the G20 commitment to "rationalize and phase out over the medium term fossil fuel subsidies that encourage wasteful consumption"[33] on the international front and domestic budget issues in the United States. While once there may have been a shortage of analysis of the federal government's role in energy markets in the U.S., information now is voluminous and interpretations of the information sometimes conflicting. A detailed analysis of the variables that contribute to the divergent estimates of federal incentives is outside the scope of this work, but some of the important variables are

- Methods, e.g., price gap analysis vs. budget analysis;
- Time frames, e.g., "snapshots" of a particular year vs. time series encompassing all incentives from inception vs. an initial period of incentivization;
- Definitions and interpretations of incentives, e.g., including or excluding each of these: tax treatments that are not specific to a particular fuel type; regulatory costs; risk management costs, public insurance programs, etc.

Energy agencies, the GAO, industry groups, national laboratories, investment funds, and policy-watchdog groups have issued estimates of federal incentives. These estimates are summarized in Table 3-1.

[33] G20 (n.d.).

Table 3-1. Overview of Estimates of Federal Incentives to Energy Markets*

			Fossil Fuels						Renewables					
Study's short name	**Time period**	**Total Federal Invest-ment [a]**	**Petroleum/ Oil**	**Natural gas**	**Coal**	**Carbon capture**	**Fossil com-bined [a]**	**Nuclear**	**Geo-thermal**	**Hydro**	**Wind**	**Solar**	**Bio-fuels**	**Renew-ables com-bined [b]**
Multiple-year estimates														
MISI (2011) [c]	1950 - 2010	$837B	$369B	$121B	$104B			$73B	$7B	$90B				$74B
Pfund and Healy (2011)	1918-2009	na	$4.86B annually					$3.5B annually					$1.08B annually	$0.37B annually
ELI (2009)	FY2002-FY2008	$112.7B				$2. 6B	$10.0B	na					$18.7B	$13.6B
Dooley (PNNL; 2008)	1961 - 2008	$198.2B, R&D only					$30.0B	$70.3B						$30.0B
GAO (2000)	1968 - 2000	na	$133.4B - $149.6B										$7.7B - $11.7B	
Goldberg, REPP (2000)	1947-1999	na					na	$186.8B			$1.5B	$5.7B		
Single-year estimates														
EIA (2011) [d]	2010	$17.9B in 2007; $37.2B in 2010	$2,820M		$1,358M			$2,499M	$273M	$216M	$4,986M	$1,134M	$7,761M	
EIA (2008) [e]	1999, 2007	$8.6B in 1999; $17.4B in 2007	$2,254M		$3,464M			$1,329M						$5,114M
Koplow (1993) [f]	1989	$20.7B – $35.1B	$8,771M	$3,445M	$8,913M			$8,748M	$407M	$605M	$62M	$253M	$1,273M	

Notes: Table 3-1.

* All works cited here are included in the bibliography.

[a] Estimates in each study have been converted to 2010$ using U.S. gross domestic product price deflators as cited in MISI 2011. ELI (2009) presents data compiled from 2002-2008in unadjusted dollars. To adjust the dollars to 2010$, we assumed equal distribution across the eight years covered in the study and inflated the dollars accordingly. The original studies presented data as follows: MISI, Pfund and Healy and EIA (2011) used 2010$; Dooley used 2005$; EIA used 2007$; GAO used 2000$; Goldberg used 1999$; and Koplow used 1989$.

[b] The "Fossil combined" and "Renewables combined" columns are for data presented in the studies only in the aggregate. These are not totals of individual fossil fuels or individual renewable incentives. So, for example, MISI 2011 data for renewable combined includes solar, wind and biofuels, but does not include hydro and geothermal which are identified separately.

[c] Management Information Services, Inc. (MISI) issued a comparable study in 2008 covering the period 1950-2006. Because the 2011 study includes these years as well as more recent years, only the more recent study is presented here. Roger Bezdek, who authored the MISI studies, also published similar results covering data through 2003 in a 2007 journal article.

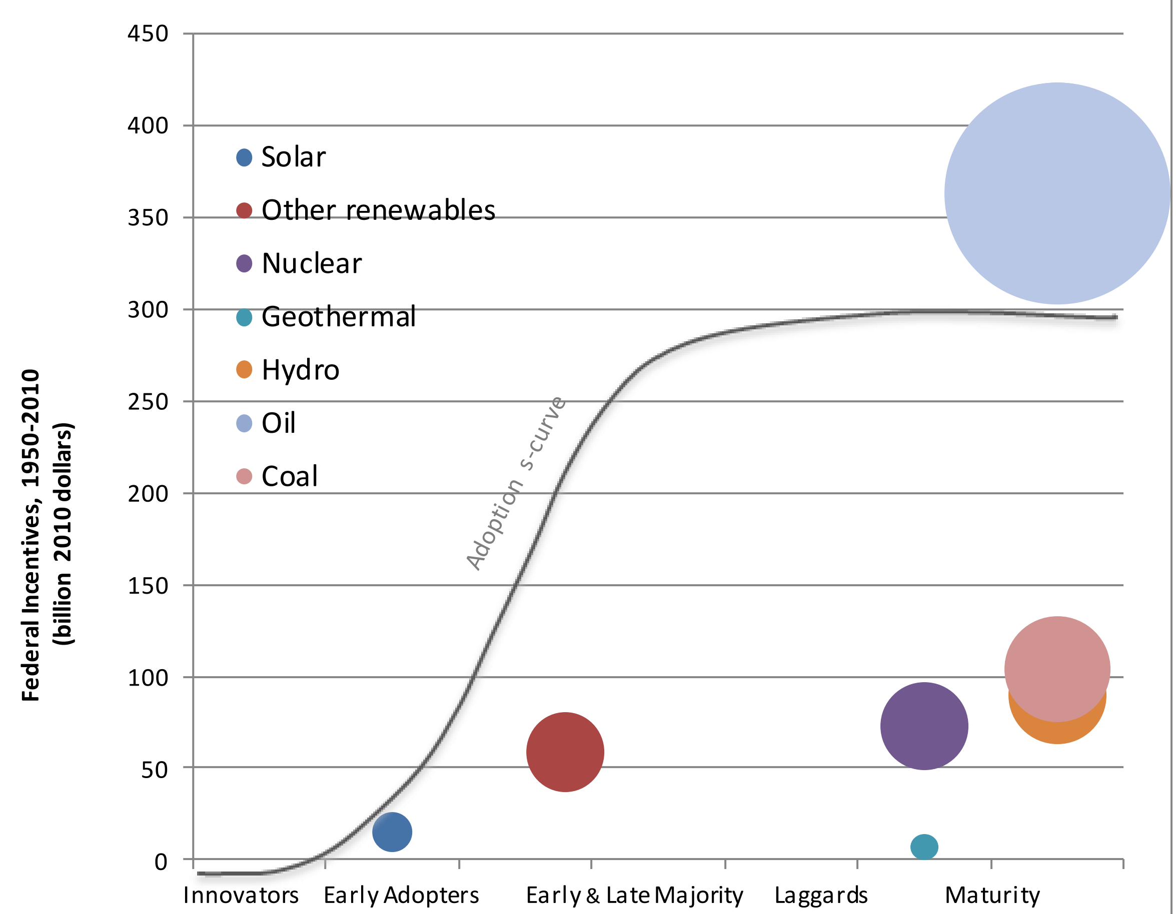
[d] Of the $37.2B in energy subsidies and support EIA records for 2010, $21.35B is fuel specific. Another $15.8B is not fuel-specific and includes $6,597M in conservation; $971M in transmission/distribution; and $8,241M in end-use activities..EIA points out that $14.8B of the total is funding through the American Recovery and Reinvestment Act (ARRA), of which $6.2B was devoted to renewables.

[e] Of the $16.6B in energy subsidies and support EIA records for 2007, $11.6 is fuel specific. Another $3.9B included is not non-fuel specific and includes $1,235M for electricity transmission, $926M for conservation, and $2,828M for end-use activities.

[f] Koplow presents high- and low-end estimates. The low-end estimates are included in the per-fuel breakdown. Koplow also estimates $166M for supply efficiency, $567M for end-use efficiency, and $345M for waste-to-energy, mixed supply, and "other" including hydrogen. Koplow's ethanol and non-ethanol biomass are combined here as a biofuels estimate. Koplow (2004) issued an updated total federal subsidy estimate for 2003 of $35B to $64B, not segmented by energy sector. This estimate includes energy externalities, the largest of which is energy security. The 2004 estimate updates Koplow & Martin (1998) that issued an estimate of $5.2B - $11.9B for petroleum subsidies in 1995, without the cost of defending oil supplies, and $15.7B - $35.2B including the cost of defending oil supplies.

3.2 Incentives Along the Adoption Curve

Figures 3-1 and 3-2 show the energy fuels according to their position in the adoption process. Federal incentives for different energy sources in the energy portfolio over the last 60 years are shown in Figure 3-1, derived from Management Information Services, Inc (MISI, 2011), with some disaggregation by the authors. This figure shows the relative size of incentives: larger incentive totals are associated with mature energy technologies and sources that have been receiving incentives for the longest period of time. Federal investment in solar technologies has been modest in a long-term historical context relative to other energy technologies.



*Other renewables include wind, biofuels, biomass, and other minor fuels
Source: MISI (2011) and University of Tennessee Howard H. Baker, Jr. Center estimates based on MISI (2011) and EIA (2011)

Figure 3-1. Portfolio of Government Incentives Along the Adoption Curve, 1950-2010, by Energy Resource

Figure 3-2 shows cost estimates of the current (2010) portfolio of incentives for each energy source along the adoption curve.[34] Since the cost to the government of many of the incentives is variable rather than fixed by design, with the variable portion an increasing function of the number of adopters, we would expect the total cost of incentives for an energy resource to increase as the resource goes up the adoption curve. In other words, since resources that are still early in their development have a small number of adopters, we would expect the total cost of incentives to be smaller compared with resources that are farther up the adoption curve. In the case where this pattern is inverted, it would suggest either that

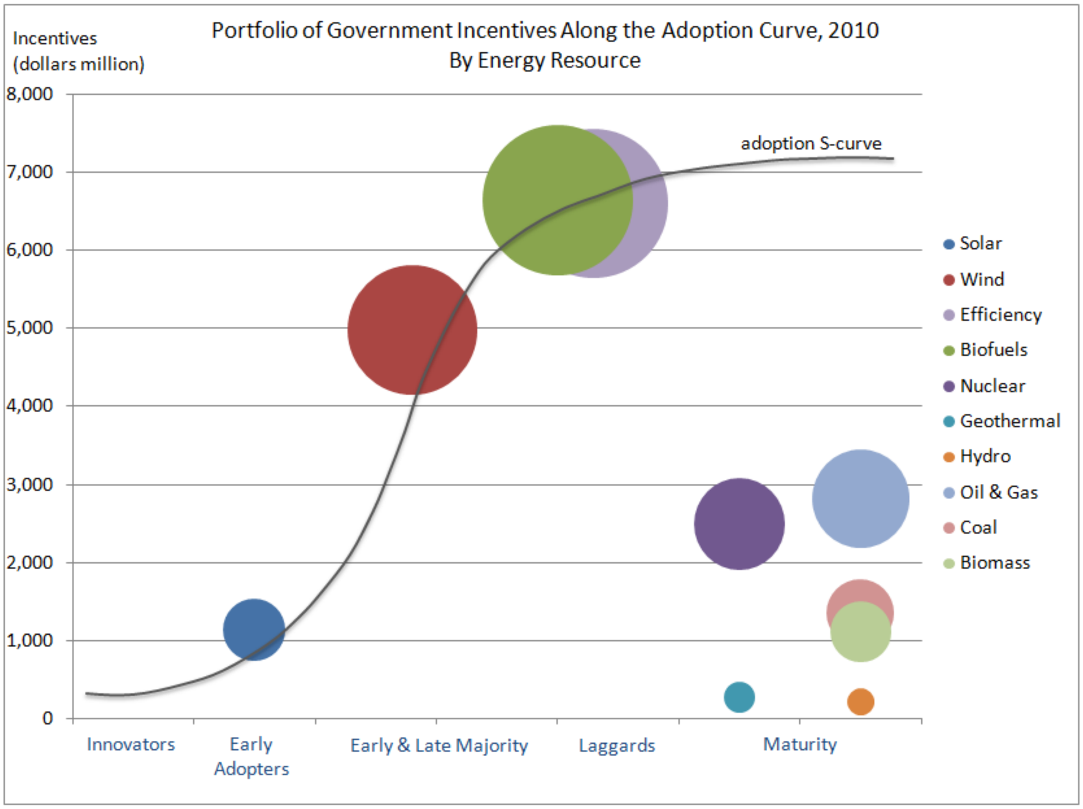
- the resource at the early adoption stage receives relatively more incentives per adopter than other resources, or
- the incentives for the energy resources moving up the curve are not available, effective, and/or utilized.

We would also expect that incentive levels would be reduced as the industry becomes mature and self-sustaining across short-term market downturns and with respect to self-funding of a continuing productivity innovation cycle. Note that here we use the adoption cycle for the energy resource recognizing that for mature industries such as oil and gas, technological innovation continues even in the maturity stage of the industry strives for productivity gains. The difference from a public interest perspective is that during maturity, companies have sufficient profits and cash flow to fund this continuing innovation.

As shown in the Figure 3-2, the current portfolio of energy incentives contains a mix of incentives for new energy resources as well as for mature resources. There are also incentives for energy efficiency, which have the effect of being disincentives for energy resource demand. Clearly, the graphic shows the results of policies that are consistent with the current era in which economic development depends on efficiency and sustainability, along with incentives related to industrial and economic development policies of the past.

The pattern of incentive costs is consistent with expectations along the adoption curve. Solar, which is early in the adoption process, has a lower total incentive cost than wind, ethanol or energy efficiency industries, which are further along the adoption path. We would expect the incentives in the mature industries to raise the overall cost of government incentives to bring these new resources up the adoption curve. If the mature industry incentives declined and prices in these markets rose, then the new energy

[34] The incentive costs presented in the graphic are from U.S. Energy Information Administration *(*2011, July).



Data source: US Energy Information Administration, *Direct Federal Financial Interventions and Subsidies in Energy in Fiscal Year 2010*, July 2011.

Figure 3-2. Portfolio of Government Incentives Along the Adoption Curve, 2010, by Energy Resource

resources would need less incentive for the adopters to jump in to the market.[35] For the case of solar, which competes in the electricity generation market, the current level of incentives would be expected to yield a greater adoption impact if incentives for primary competing energy resources, such as coal and nuclear, were reduced; inversely, if incentives for these energy resources were increased, we would expect the solar incentives to have less of an impact on solar adoption. The cost-effectiveness of incentives to move a technology up the adoption curve, in other words, depends on the current and past portfolio of incentives in the specific technology adoption markets in the energy value chain.

In addition to this policy cost dimension, policymakers may wish to weigh the advantage of rebalancing the portfolio more towards development of new energy resources for both economic development and sustainability reasons. From an economic development perspective, innovation that creates new industries is the source of growth in an economy

[35] Depending on own and cross price elasticities of demand, the relative rate of adoption may change if all incentives are lowered proportionately across energy resources.

compared to mature industries. History suggests that mature industries tend to lose jobs over the long term as new innovations eventually displace mature technologies. From an economic development perspective, a portfolio weighted towards mature industries will tend to maintain profitable industries and suppress new industries, while a portfolio weighted towards industries in the adoption stage will tend to advance adoption of new industries. In terms of economic sustainability, adding new energy resources to the portfolio will also have the effect of lengthening the life of the country's other energy resources making them available for their most valuable uses, creating a more sustainable economy for future generations.

3.3 The Changing Nature of Federal Incentives in Energy Markets

In the prior chapter we briefly discussed the adoption of fuels for those energy sources that had gone through the adoption cycle or, in the case of nuclear, were still in the adoption phase prior to the oil embargo in the 1970s. We also discussed the development of solar technology, which occurred primarily after the oil embargo except for initial research by federal agencies such as NASA and NSF that dates back to perhaps as early as 1946.

The federal actions in energy markets prior to the oil embargo include breaking up monopolies and holding companies, regulating interstate commerce and prices, leasing of and direct investment in federally-owned natural resources, import/export policy, and incentives for domestic exploration and production of natural resources. These actions are indicative of industrial and economic policy, with a commitment to competitive markets, exploration of natural resources for national security, and building a bigger and better America.

Following the oil embargo, the federal government began implementing very targeted incentives across energy sources that both encouraged and discouraged demand or supply in specific markets in the energy value chain. So for petroleum, what was debated in the 1920s and 1930s was finally implemented in the 1970s—discouraging less efficient uses of oil. In addition, targeted environmental policies also affected energy markets in specific ways. For the legacy fuels, the commitments to competitive markets and industrial policy continued with President Reagan's deregulation initiatives, while the new energy and environmental policy incentives created complex dynamics in restructuring energy markets.

Unlike the policies that emerged during the adoption of the fossil fuels, the new post-oil-embargo incentives for solar and other renewable fuels are indicative of energy and environmental policy in an era in which efficiency and sustainability are critical for economic growth. For fossil fuels, the federal government spent considerable resources on regulating the development years of these industries, as these industries had a natural tendency towards monopolization; for renewable fuels, the government is also spending resources during the adoption phase; although the nature of the federal engagement has changed to reflect the reality of the economic environment.

Figures 3-3 through 3-9 organize the federal actions according to whether the intent is to encourage or discourage demand or supply of an energy source. Whether driven by industrial and economic policy or energy and environmental policy, all interventions in markets either encourage or discourage supply or demand. Interventions established to assure the industry's safety or environmental quality, e.g., Mine Safety Regulations or the Clean Air Act, are issued without intent either to encourage or discourage supply or demand. Rather they are intended to assure certain standards are adhered to in providing the supply or meeting the demand. Because compliance can impose a cost on either the industry or the public through its government's implementation of the standards, these types of interventions are included with those that discourage supply, although this type of interventions may have no direct effect on supply. The first set of tables show government interventions along the adoption cycle through the mature industry stage.

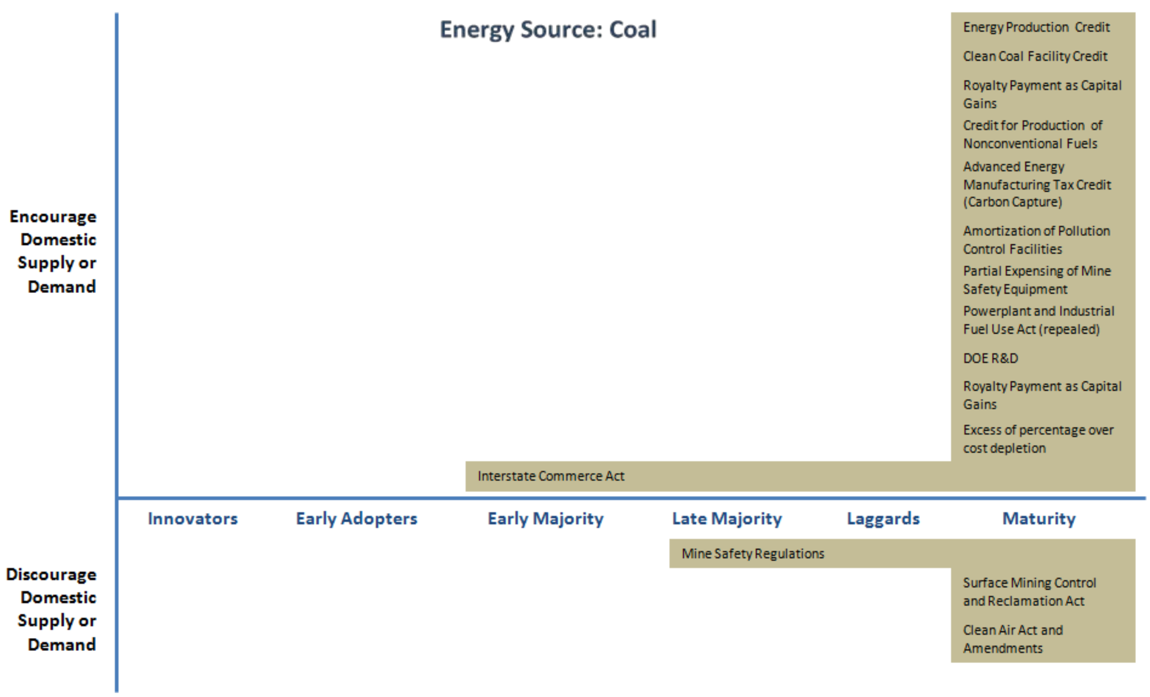


Figure 3-3. Portfolio of Selected Federal Interventions for Coal by Anticipated Market Effect along the Technology Adoption Curve

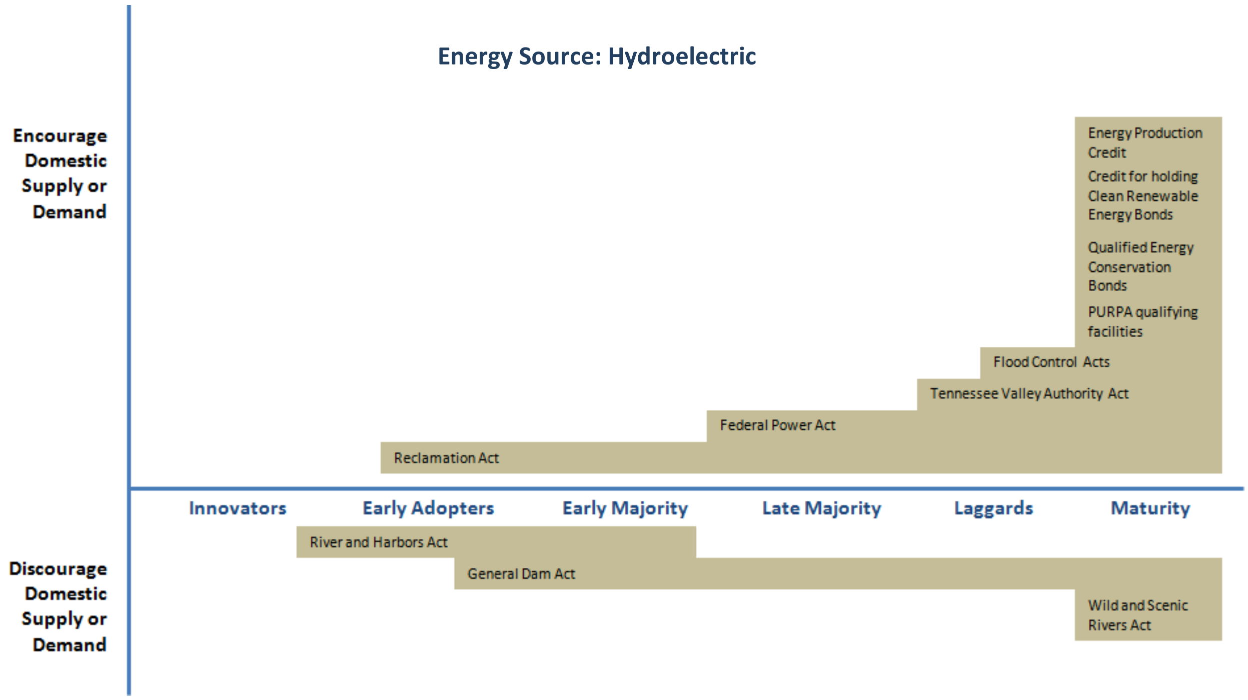


Figure 3-4. Portfolio of Selected Federal Interventions for Hydroelectric by Anticipated Market Effect along the Technology Adoption Curve

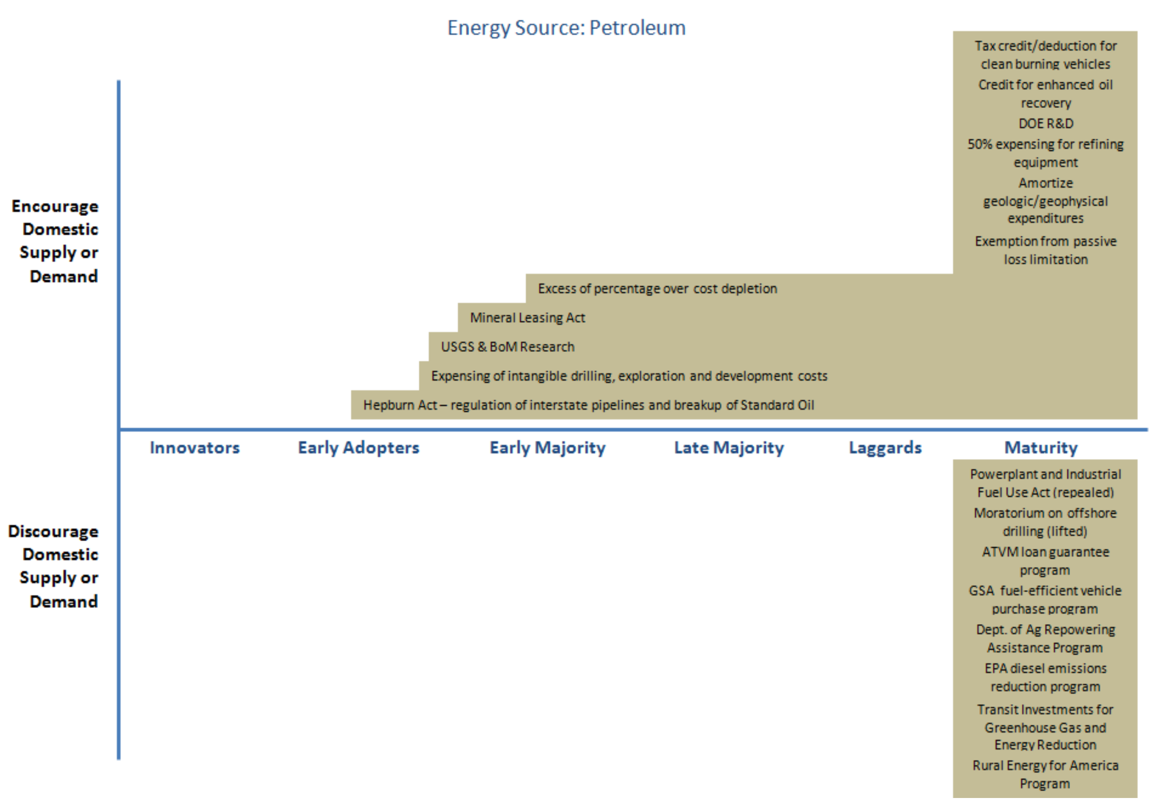


Figure 3-5. Portfolio of Selected Federal Interventions for Petroleum by Anticipated Market Effect along the Technology Adoption Curve

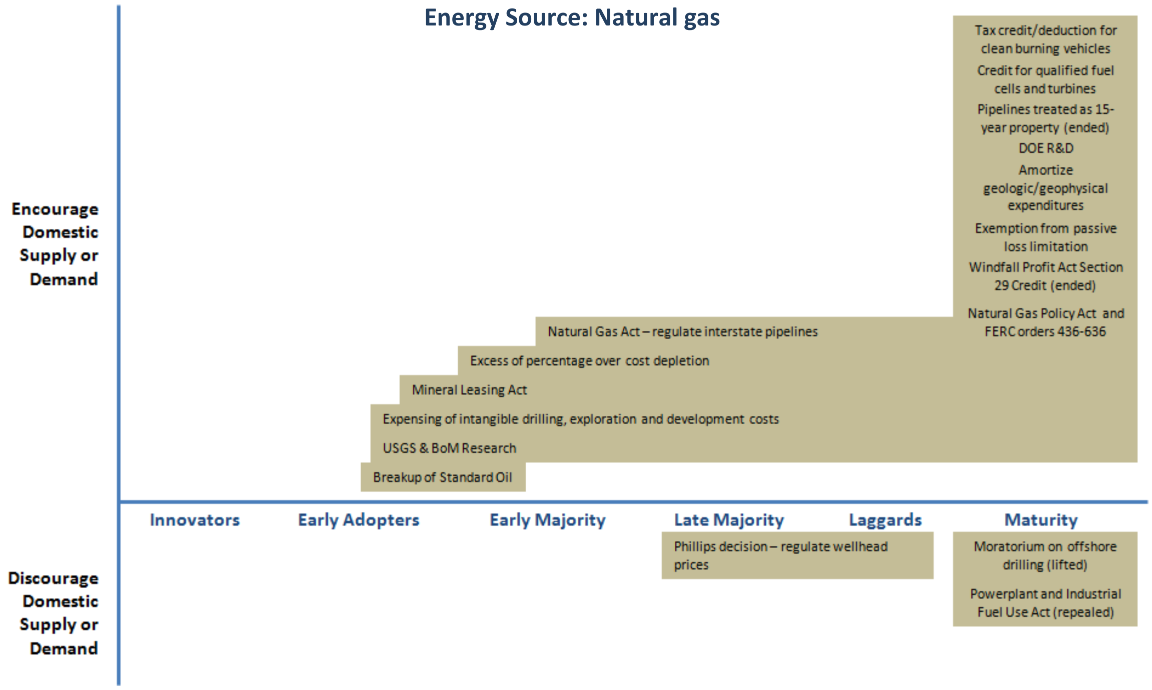


Figure 3-6. Portfolio of Selected Federal Interventions for Natural Gas by Anticipated Market Effect along the Technology Adoption Curve

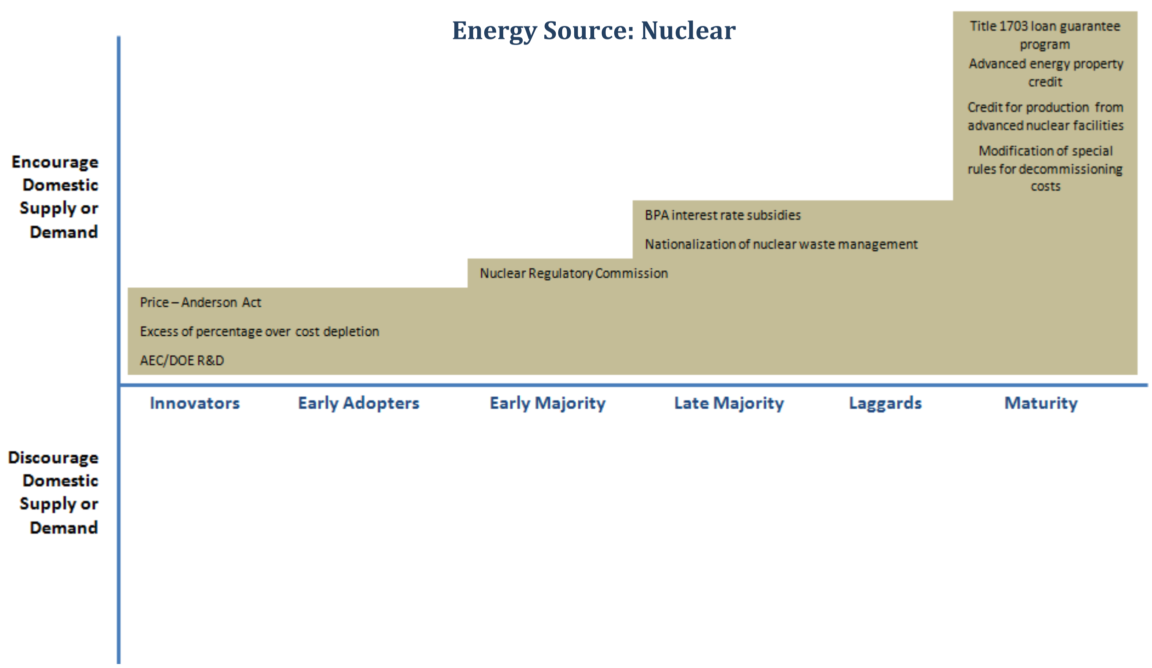


Figure 3-7. Portfolio of Selected Federal Interventions for Nuclear by Anticipated Market Effect along the Technology Adoption Curve

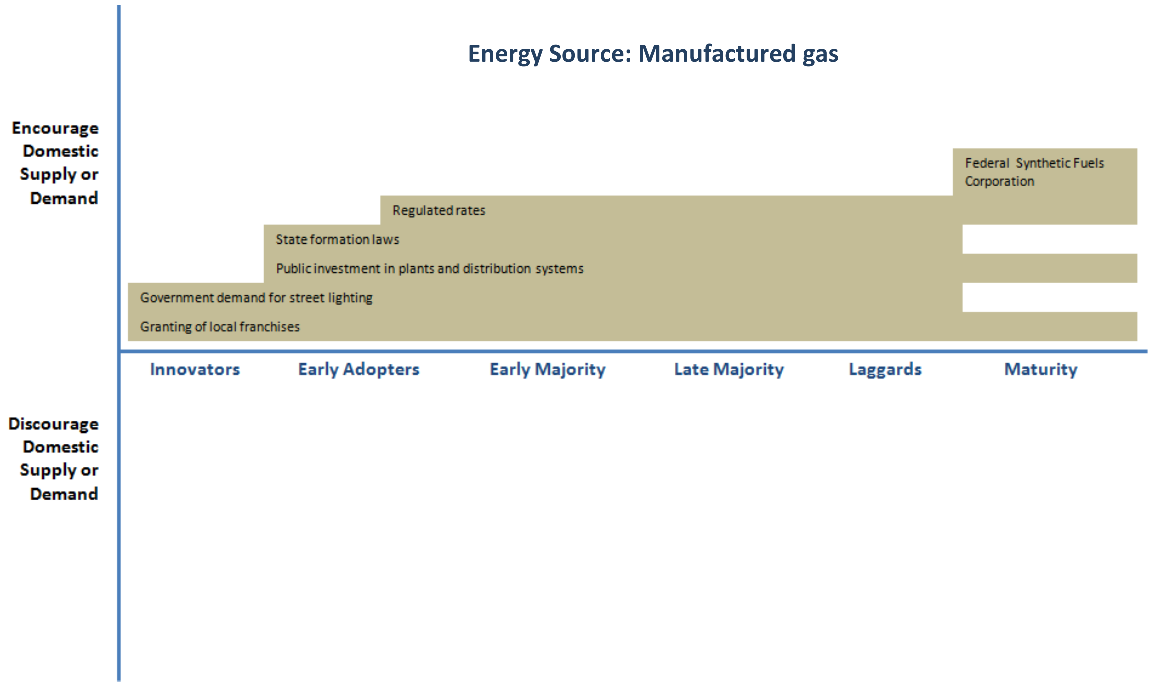


Figure 3-8. Portfolio of Selected Federal Interventions for Manufactured Gas by Anticipated Market Effect along the Technology Adoption Curve

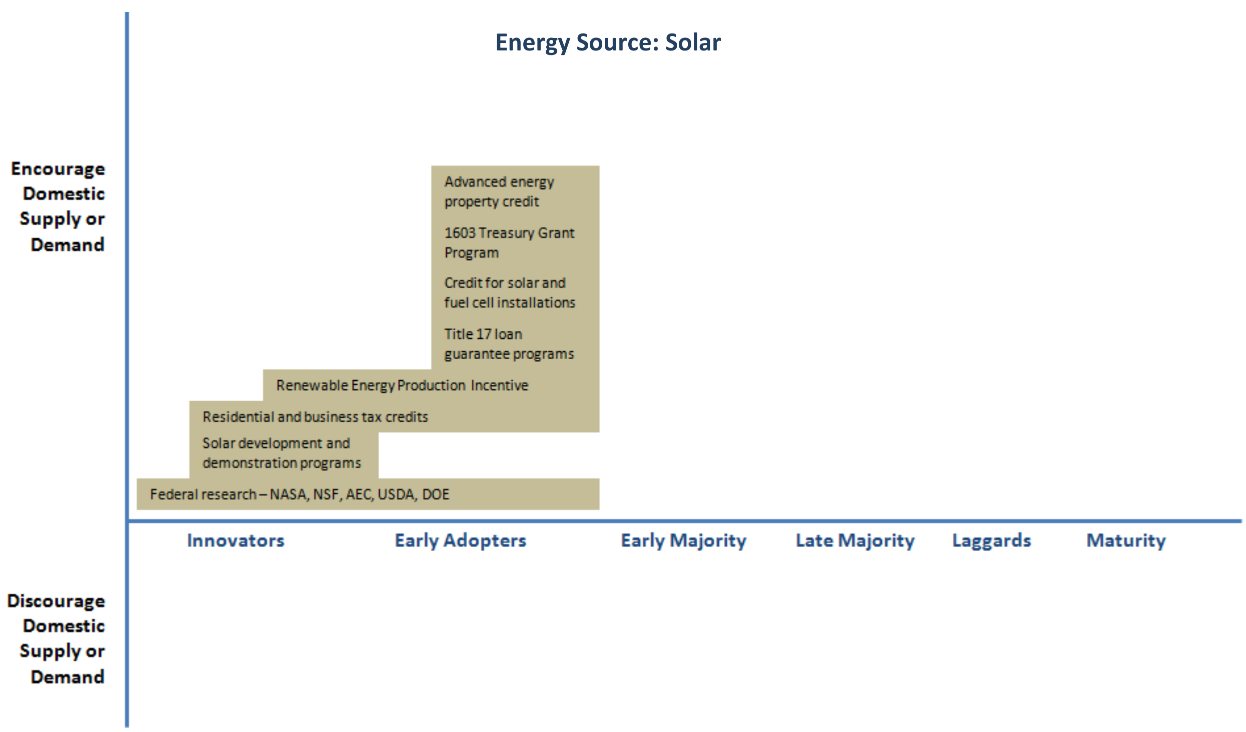


Figure 3-9. Portfolio of Selected Federal Interventions for Solar by Anticipated Market Effect along the Technology Adoption Curve

The next set of graphs (Figures 3-10 through 3-21) shows federal actions across the individual markets in the energy value chain for the pre- versus post-embargo periods. Note how the interventions in the fossil fuel markets changed post-embargo to include the electricity generation and energy applications markets that apply to solar and wind. This change has created a complex dynamic across and within the energy markets in the energy value chain.

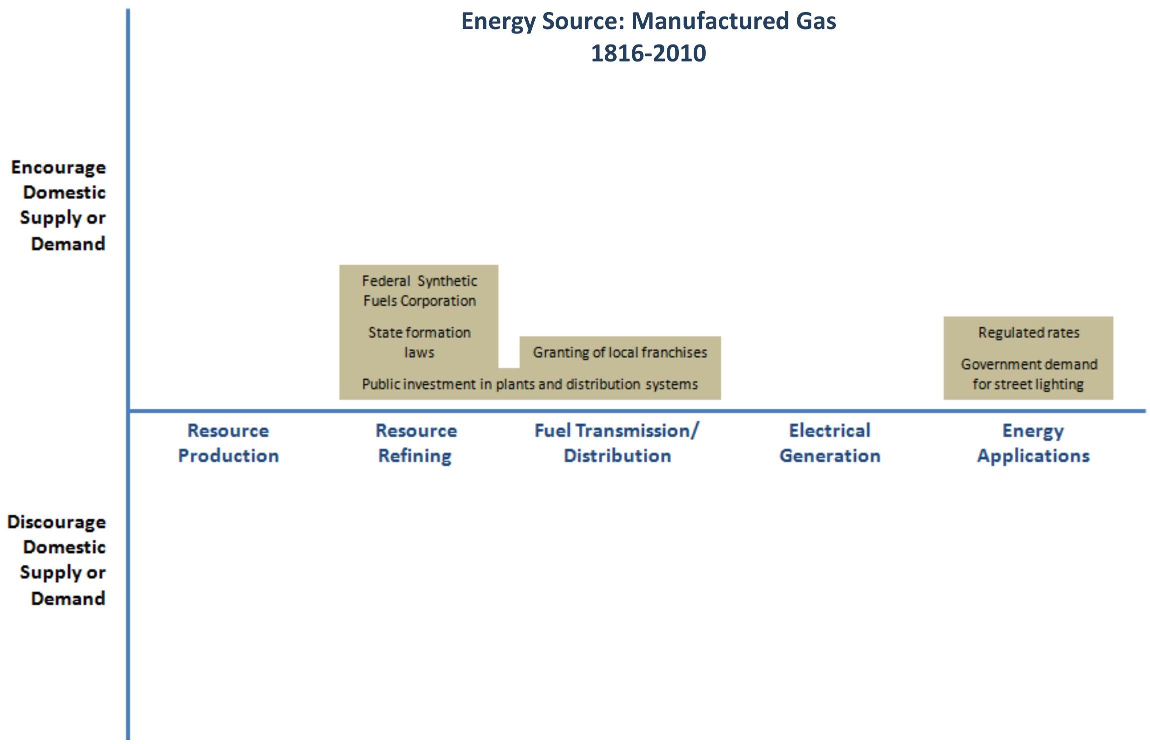


Figure 3-10. Portfolio of Selected Federal Interventions for Manufactured Gas by Anticipated Market Effect along the Energy Value Chain, 1816-2010

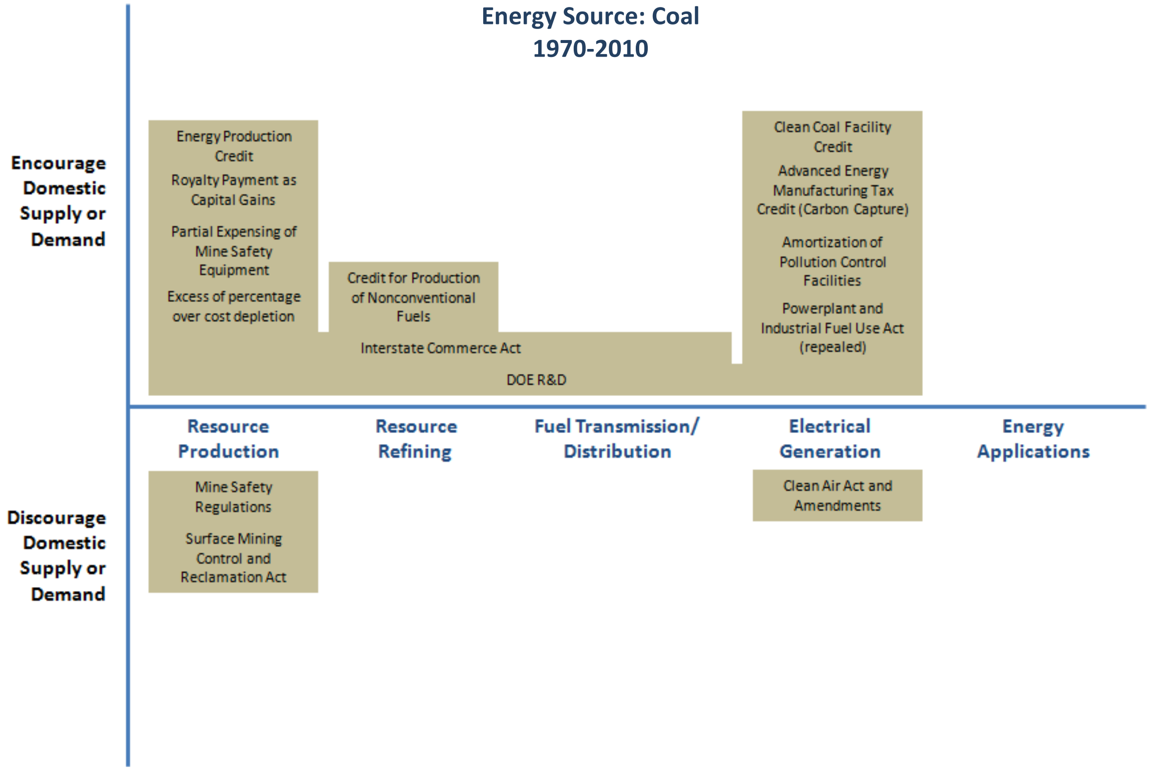


Figure 3-11. Portfolio of Selected Federal Interventions for Coal by Anticipated Market Effect along the Energy Value Chain, 1970 - 2010

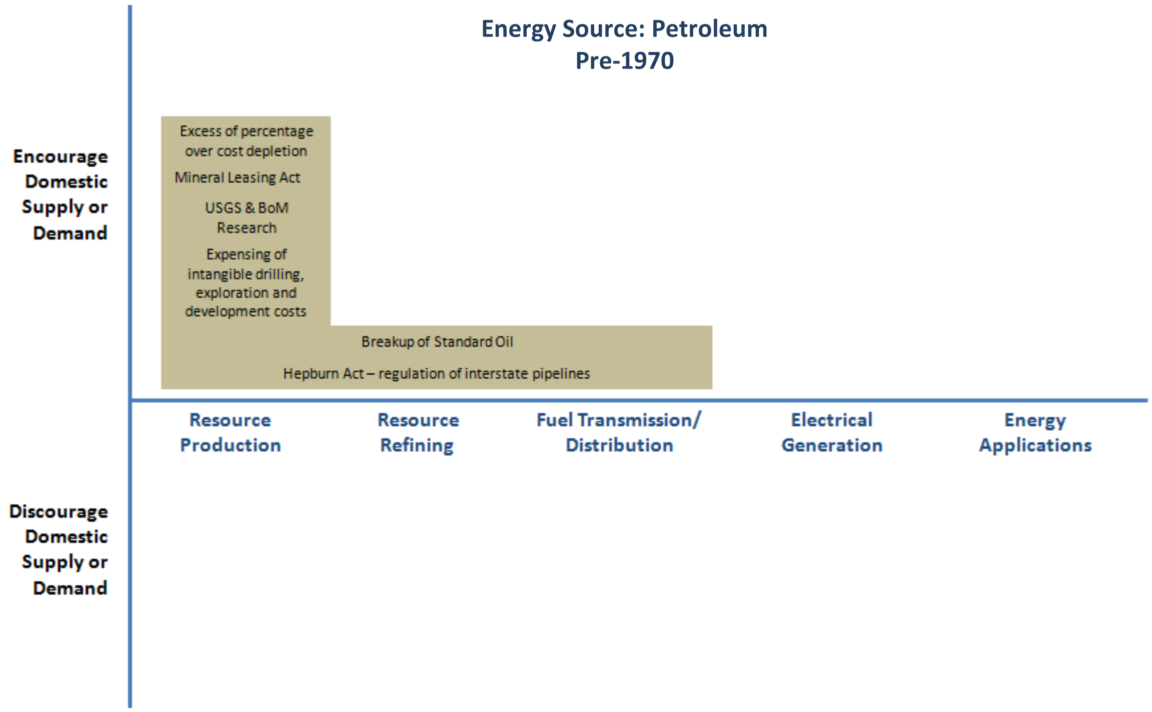


Figure 3-12. Portfolio of Selected Federal Interventions for Petroleum by Anticipated Market Effect along the Energy Value Chain, pre-1970

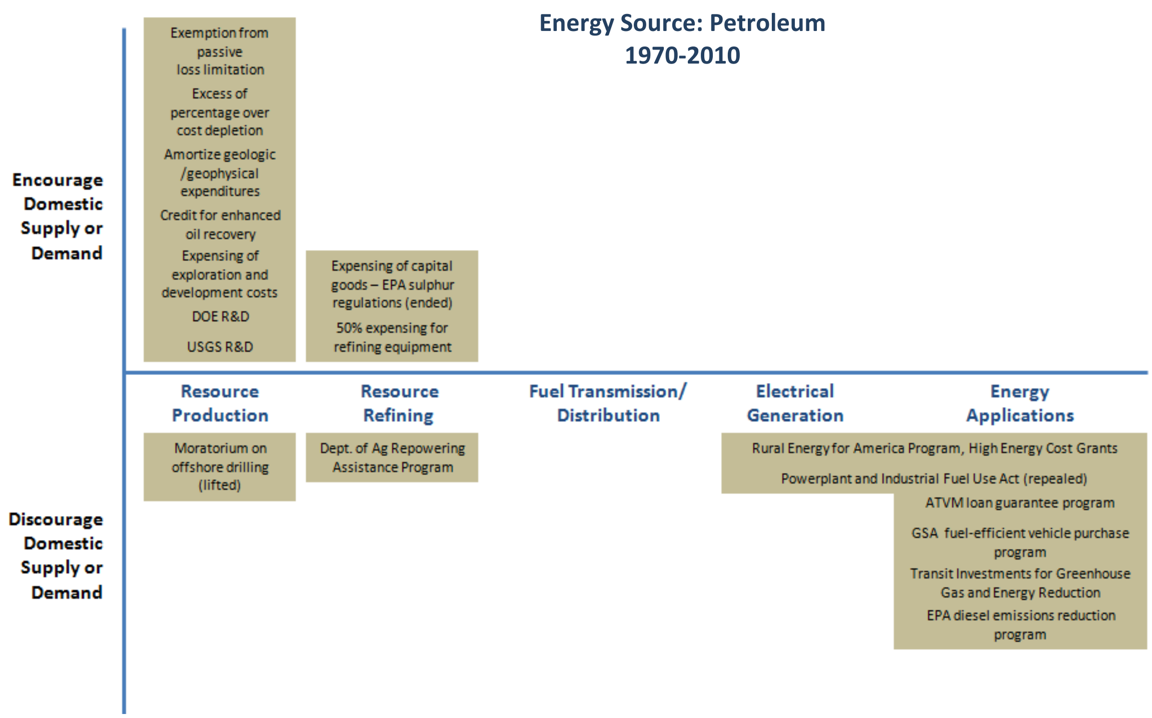


Figure 3-13. Portfolio of Selected Federal Interventions for Petroleum by Anticipated Market Effect along the Energy Value Chain, 1970-2010

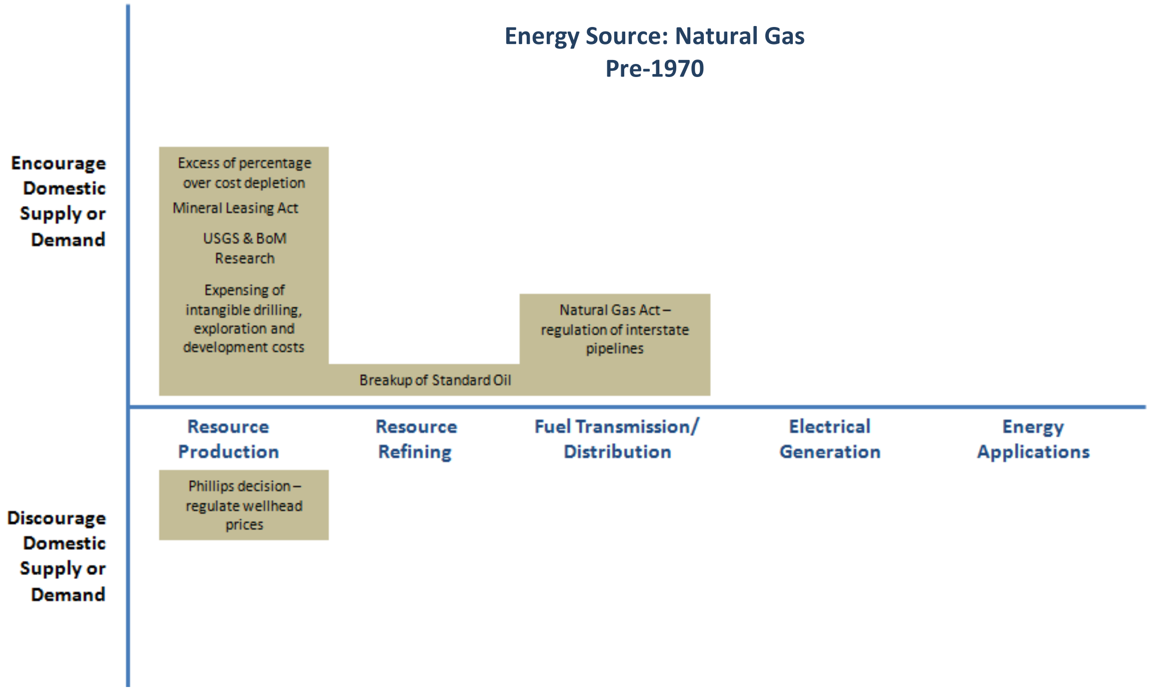


Figure 3-14. Portfolio of Selected Federal Interventions for Natural Gas by Anticipated Market Effect along the Energy Value Chain, pre-1970.

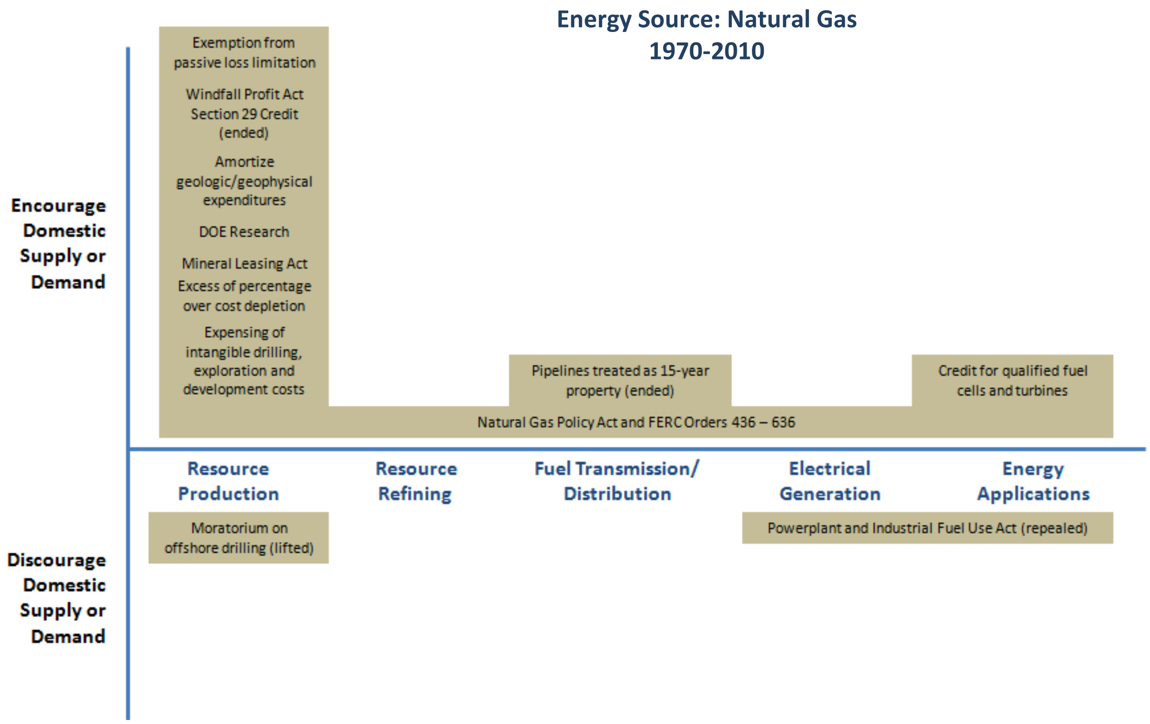


Figure 3-15. Portfolio of Selected Federal Interventions for Natural Gas by Anticipated Market Effect along the Energy Value Chain, 1970-2010.

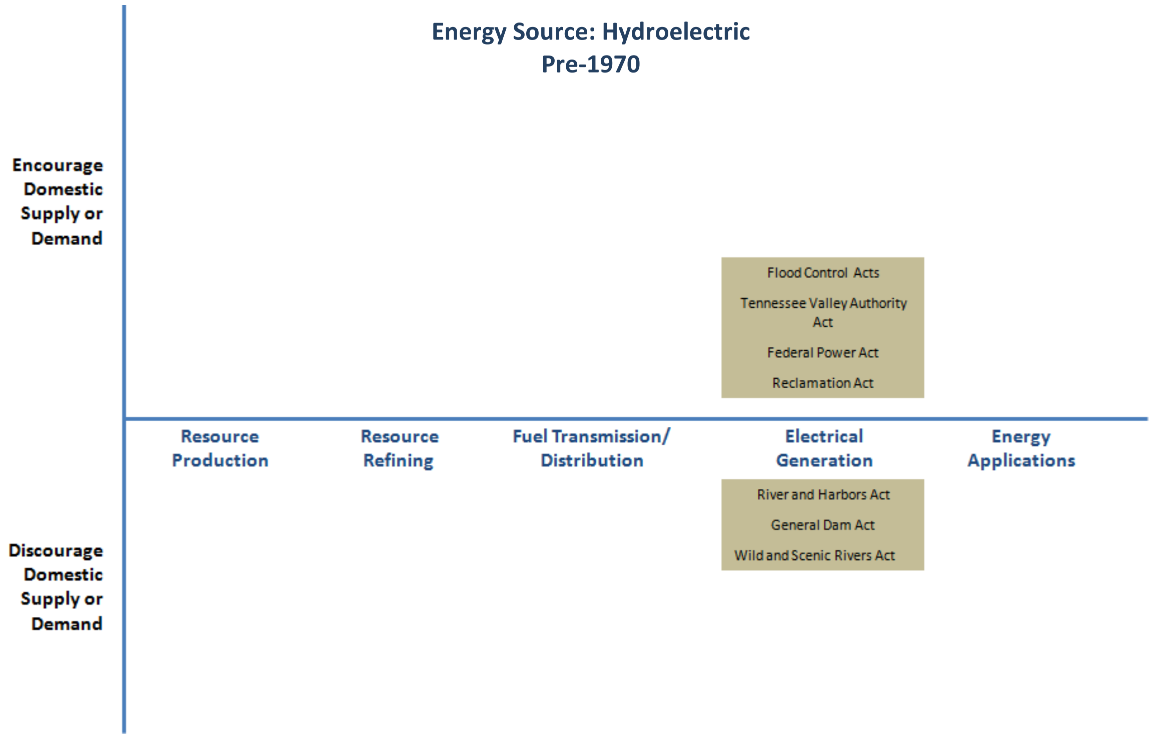


Figure 3-16. Portfolio of Selected Federal Interventions for Hydroelectric by Anticipated Market Effect along the Energy Value Chain, pre-1970

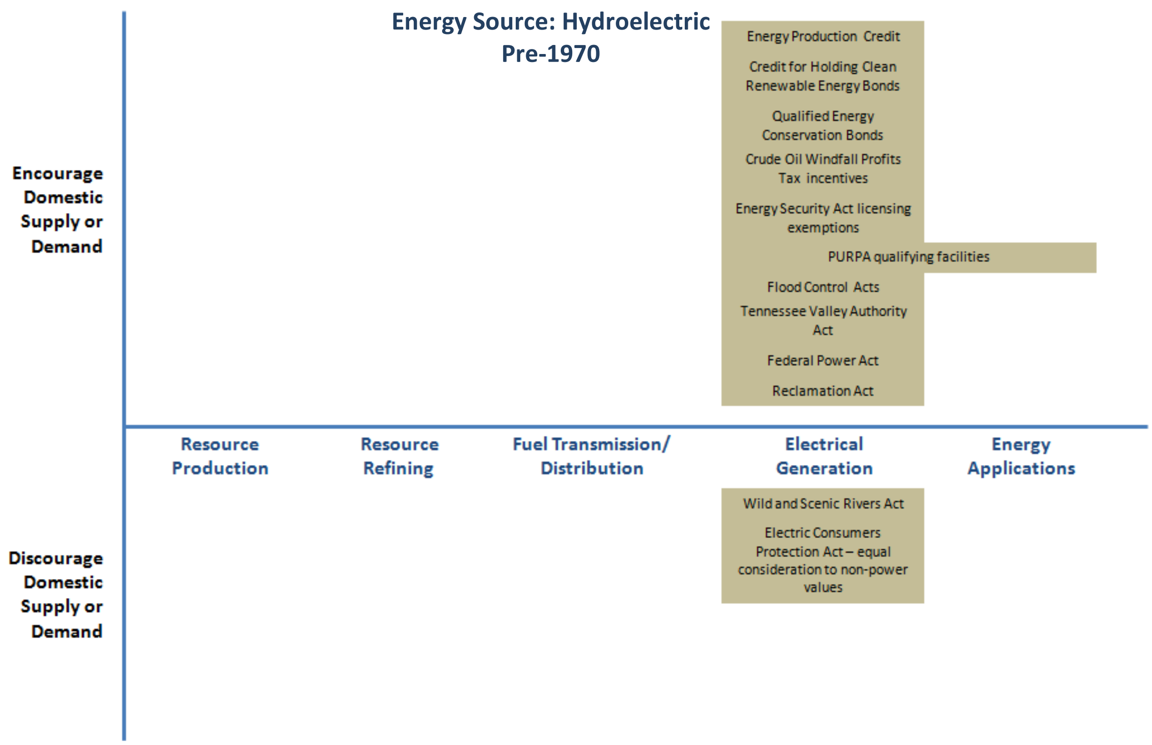


Figure 3-17. Portfolio of Selected Federal Interventions for Hydroelectric by Anticipated Market Effect along the Energy Value Chain, 1970-2010

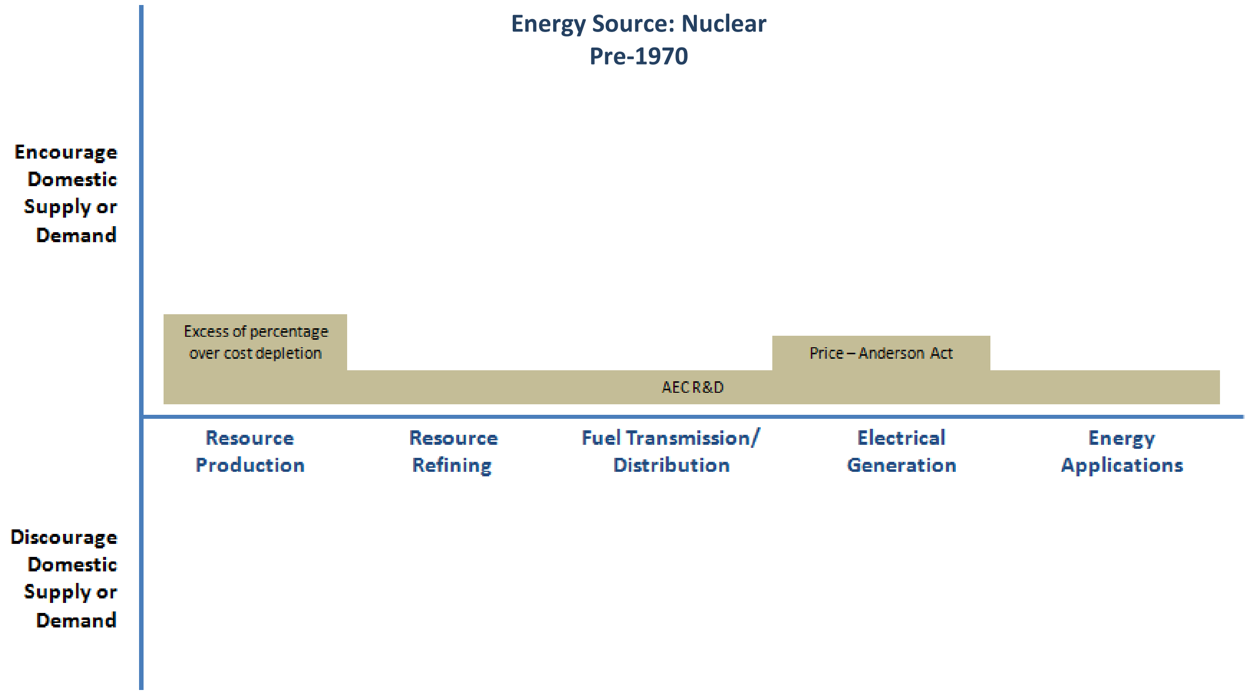


Figure 3-18. Portfolio of Selected Federal Interventions for Nuclear by Anticipated Market Effect along the Energy Value Chain, pre-1970

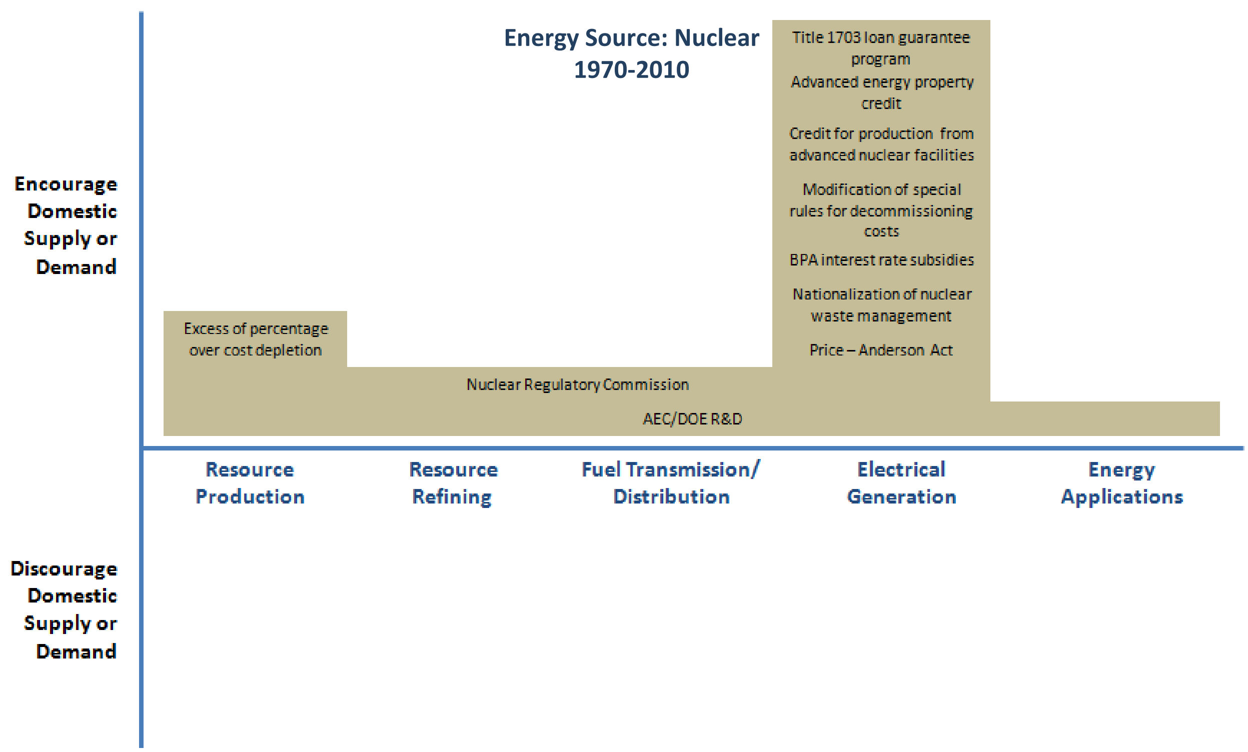


Figure 3-19. Portfolio of Selected Federal Interventions for Nuclear by Anticipated Market Effect along the Energy Value Chain, 1970-2010

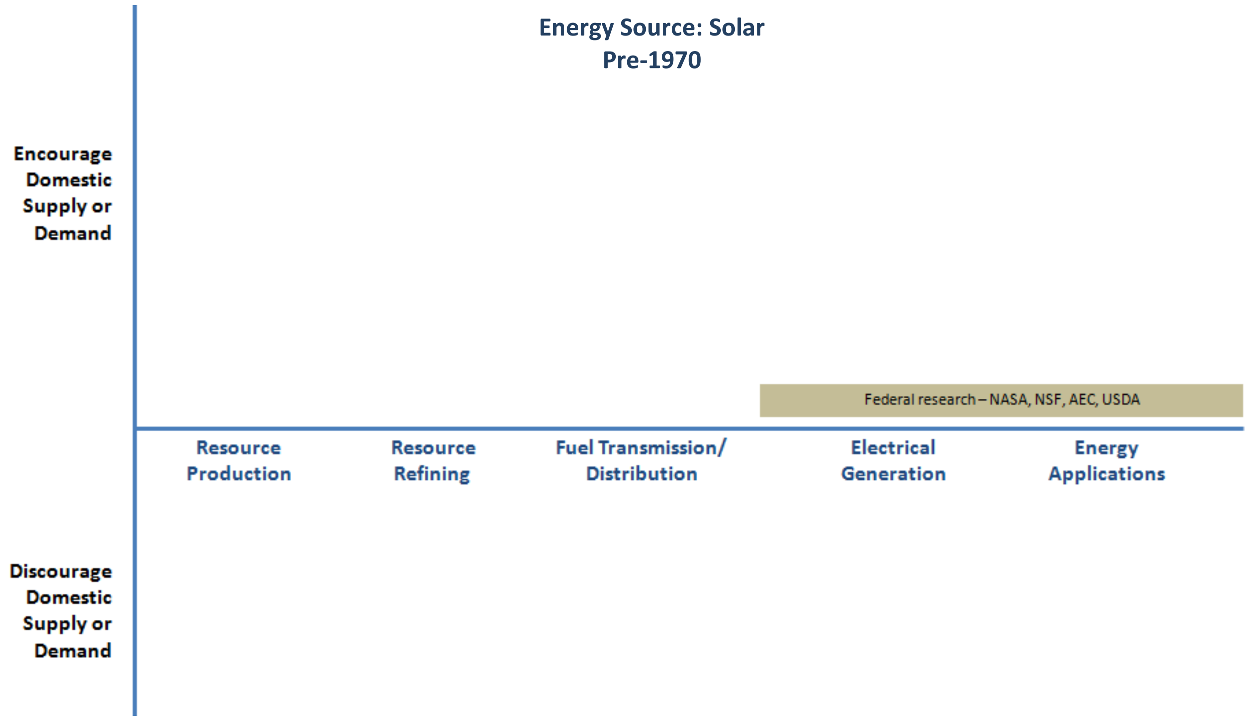


Figure 3-20. Portfolio of Selected Federal Interventions for Solar by Anticipated Market Effect along the Energy Value Chain, pre-1970

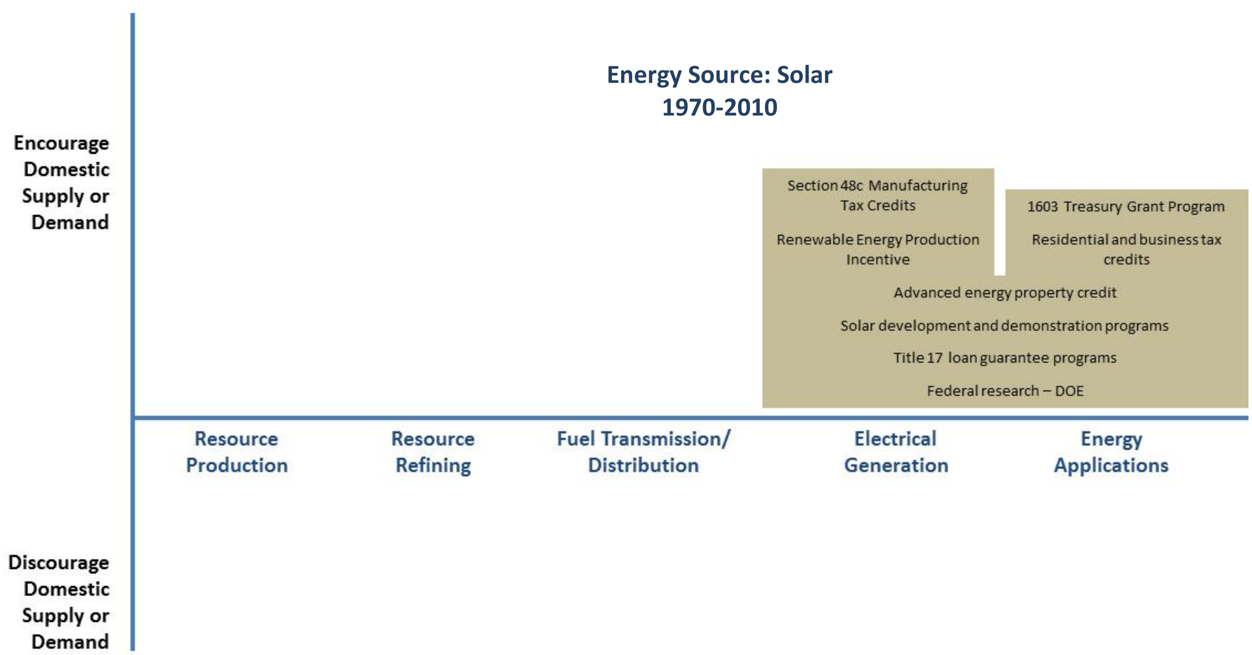


Figure 3-21. Portfolio of Selected Federal Interventions for Solar by Anticipated Market Effect along the Energy Value Chain, 1970-2010

The assessment of incentives along the adoption curve and along the energy value chain are methods for looking at incentive levels to spur development. Another method is to compare incentives per unit of energy reserves.[36] Reserves are the link to sustainable economic development over generations, like we saw in the prior century in the U.S. when we invested heavily to develop the country's hydroelectric and nuclear reserves. For energy resources that are flows rather than exhaustible stocks, the challenge is to bind a timeframe for those flows. For hydro, which is a flow rather than an exhaustible stock, we used annual flows for 150 years to calculate reserves, corresponding to the seven generation sustainability concept using a generational length of around twenty-five years in the U.S. Geothermal reserves were estimated based on a thirty year life.[37]

For solar we have used the feasible deployment pattern in A Solar Grand Plan as an estimate of the recoverable U.S. solar reserves.[38] As with hydro, we used a term of 150 years to convert annual solar resources from the National Renewable Energy Laboratory study to reserves.

The following chart shows the level of incentives in 2010 per unit of reserves by energy resource. This chart was developed using published estimates of reserves for current proven reserves. Reserves were converted to megawatt-hours of electricity using the average heat rate for coal,[39] and using consumption of uranium per gigawatts-hour for nuclear power to convert uranium reserves.[40] Hydro reserves measured in gigawatts of capacity were converted to megawatt-hours of electricity using average generation per capacity.[41]

[36] Per the Congressional request, the 2011 EIA report on energy incentives computes the incentives per unit of production metric, not incentives per unit of reserves. Historically, however, the government has looked at the level of reserves rather than production when making incentive decisions in the market. For the petroleum debate in the early part of the 20th century, the concern was that we were depleting our oil reserves when the government intervened with exploration incentives and efforts to invest in foreign reserves; for hydro and nuclear, the direct investments by the government were made to tap into undeveloped reserves.
[37] Petty and Porro (2007).
[38] Zweibel et al. (2007).
[39] U.S. Energy Information Administration (2010, November) and (2010, October).
[40] U.S. Energy Information Administration (2010, July).
[41] U.S. Department of Energy (2004) and U.S. Energy Information Administration (2011, July).

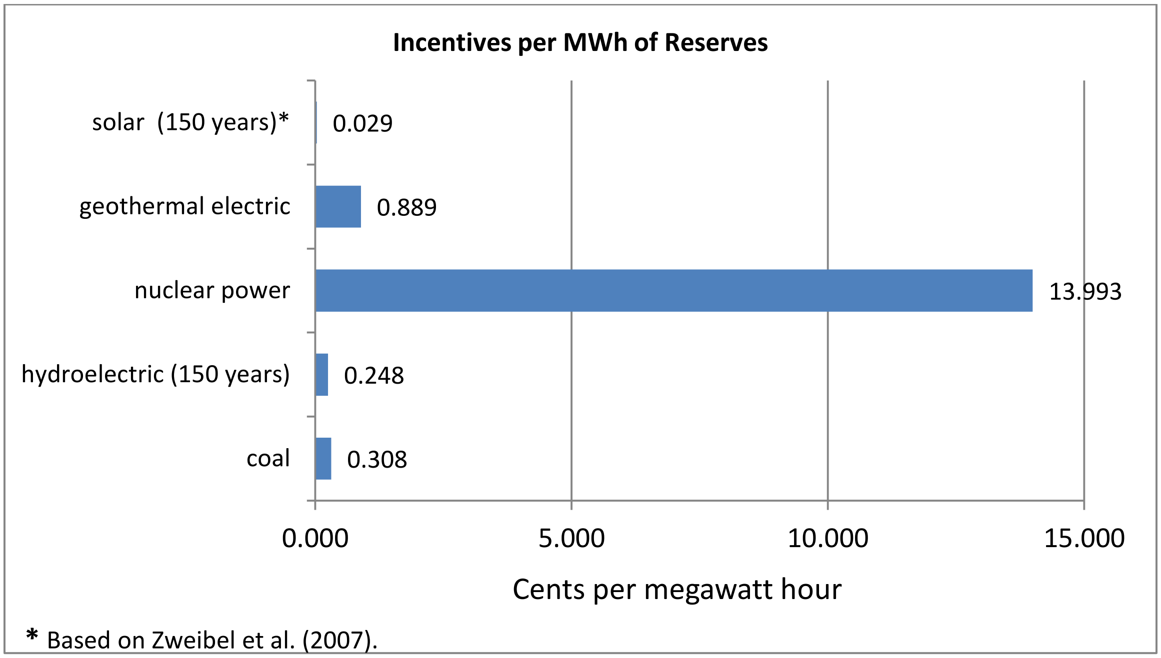


Figure 3-22. 2010 Federal Incentives by Energy Resource per MWh of Reserves

On a comparative basis, all of the resources except nuclear receive under a penny of incentives per megawatt hour of reserves. Nuclear has the lowest amount of reserves but received the largest amount of incentives among these fuel sources in 2010. The incentives per MWh of reserves for solar are less than any other fuel source by a factor of 10, suggesting that the investment value of solar incentives is potentially greater than that of other resources.

3.4 Learning from Past Incentives

Looking at past incentives and technology adoption, we begin to see a few patterns of successes and failures in supporting adoption in energy markets.

- Incentives that target specific barriers have been successful, as have incentives that by design include a commitment to "cross the chasm."
- Failing to commit to the twenty-plus year adoption cycle, especially when competing energy market prices are characterized by boom-and-bust cycles, results in failure. New technologies cannot live through short-term periods of low prices for competing fuels unlike mature industries that have sufficient balance sheets to survive.

- The increasing complexity of the portfolio of federal incentives across energy sources has created situations in which incentives for one energy source are unintentionally countered by incentives in competing markets, resulting in failure of the incentivized technology to hit the high growth part of the adoption curve.[42]

Targeting specific barriers

One way to support adoption is to remove a specific market barrier to adoption of the technology. Two successful examples are discussed below.

Price-Anderson Act and Nuclear Waste Policy Act. Early on in the research and demonstration phase, liability in the event of a nuclear accident was identified as a significant barrier to adoption of nuclear power by the electric utility industry. The Price-Anderson Act of 1957 limited the liability of investors in nuclear power plants, paving the way for private sector investment and the start of the industry. As the industry grew during the 1970s and following the Three Mile Island accident, the government nationalized waste management for the industry, providing a solution to an industry problem that enabled the industry to complete the adoption path.

Investment Tax Credit Program and Section 1603 Treasury Program. Solar is a free resource but requires significant capital investment to begin production. The Energy Policy Act of 2005 allowed a 30% federal investment tax credit (ITC) for residential and business applications. Commercial solar projects with construction start dates between 2009 and 2011, were eligible for the now expired Section 1603 Treasury Program that allowed a 30% grant, in lieu of the ITC, reducing initial capital outlay. With these programs in place, and in the context of other factors such as less expensive PV and State Renewable Energy Standards, a near 77% annual growth in installed capacity has occurred in recent years (see Figure 3-23). The programs illustrate how targeting specific barriers can lead to immediate adoption impacts. Grants may accelerate adoption of solar power as the cash is immediately available to leverage investment relative to the delay that occurs when having to claim a future tax credit that might otherwise be spread over several years in the absence of adequate tax equity financing. Yet the ITC, scheduled to remain in place through 2016, is an example of a long-term stable instrument that can contribute to market adoption.

[42] Another possible situation is that an especially effective incentive can bring a new energy source to significant market share and cause a decline in demand for the displaced fuels, driving down the price of those fuels until equilibrium is reached. That poses a challenge for higher penetration of the new energy source.

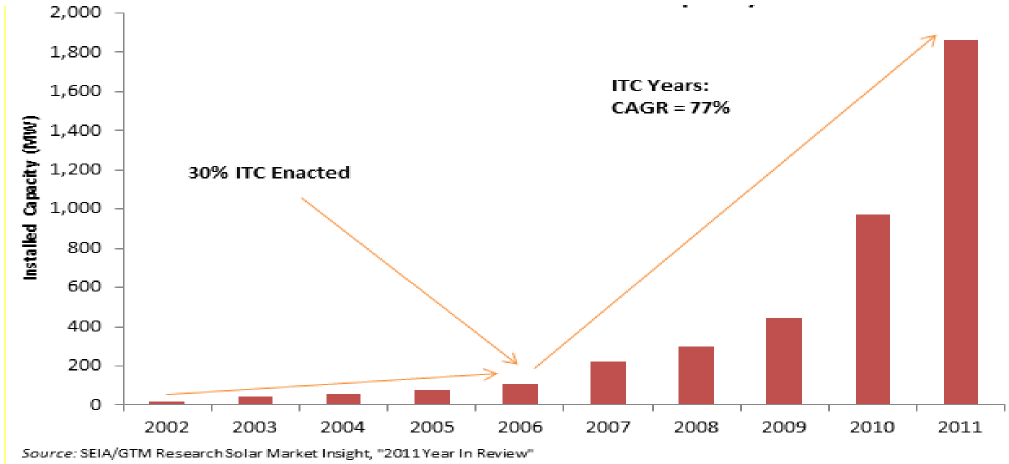


Figure 3-23. Annual Installed Solar Electric Capacity, 2000 – 2011

Committing to cross the chasm

Until an energy source reaches the point in its development in which it jumps to the growth portion of the adoption curve, the fledgling industry lives a precarious life in which market demand may never develop and private sector investment may not be sufficient to carry it through market perturbations. Two examples are provided below.

Windfall Profit Tax Act Section 29 tax credit and unconventional gas adoption.[43] The Windfall Profit Tax Act of 1980 provided tax credits for production from unconventional tight gas sands, coal bed methane, and shale gas wells. The production credit lasted until 2002 for wells that qualified by the end of 1992. This design provided certainty for private sector investment in new technology and exploration. By the end of 2002 when the production credit expired, unconventional gas technology had crossed the chasm and developed to the point of sustainability. The following chart shows the production growth for unconventional gas technology.

[43] Kuuskraa. and Guthrie (2002).

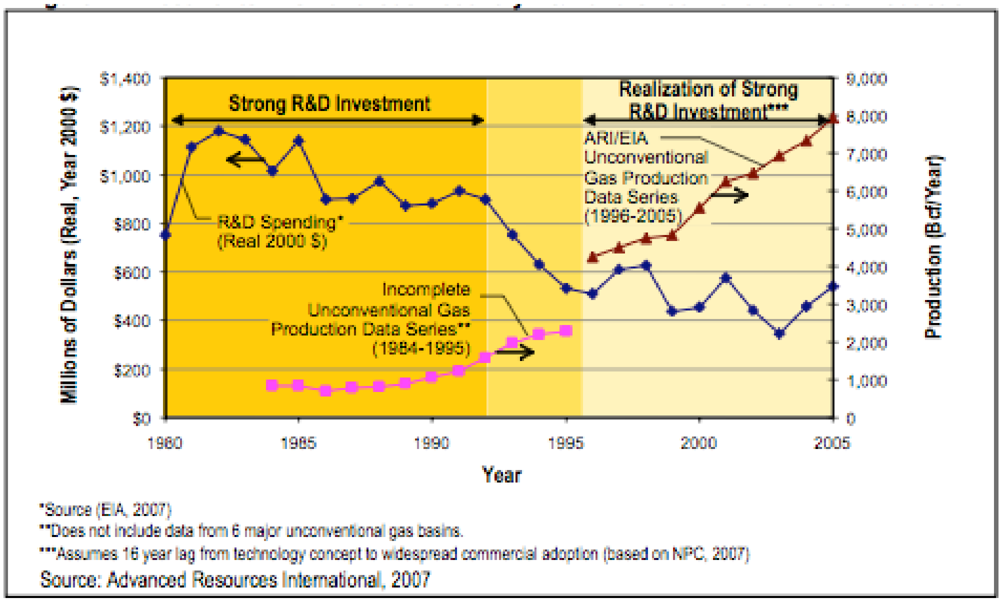


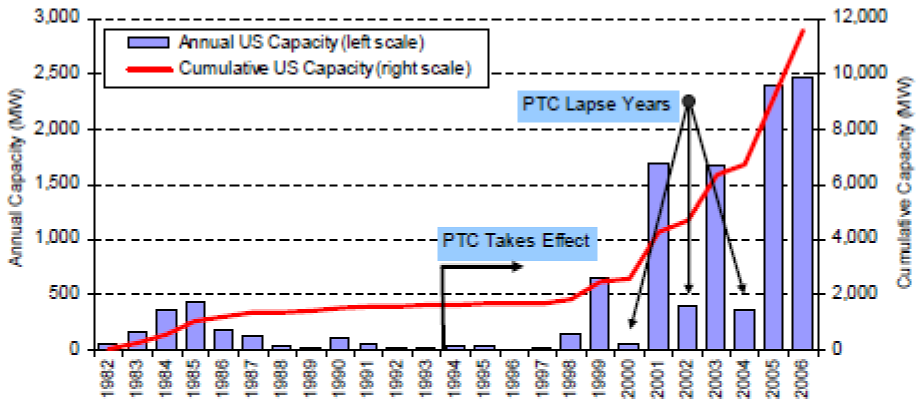
Figure 3-24. Investments in Oil and Gas Recovery R&D and Unconventional Gas Production, 1980-2005.

Uncertainty of production tax credit and wind adoption.[44] Since the adoption of the production tax credit in 1992, the policy has been intermittently renewed with several time lapses over its nineteen year existence. However, in contrast to the Section 29 production tax credit for unconventional gas production, which was written for a twenty-year period, the production credit for wind has been subject to expiration time frames between one and five years, and on three occurrences has been allowed to lapse. So in the end, while we have a tax credit that is spanning almost twenty years of the adoption cycle, the design of the policy, with short-term expirations, has created uncertainty regarding long-term wind investments. As shown in Figure 3-25, the result is a choppy adoption path that did not maximize the potential benefit of the incentives.

Limiting unintended consequences across markets

Unintended consequences can result with an increasing number of unintentionally competitive government actions across energy sources and markets. For new technologies with precarious lives, it may be that a well-designed incentive can fail to support technology adoption if unintentionally negated by the portfolio of policies that support other technologies.

[44] Wiser, Bolinger, and Barbose (2007).



Source: Wiser, Bolinger, and Barbose, 2007.

Figure 3-25. Annual and Cumulative Installed Wind Power Capacity in the U.S., 1982-2006

An example of these interactive effects is the coal syngas technology adoption in the post-embargo period. The U.S. government invested in research, development, and demonstration of technologies, and with the Synthetic Fuels Corporation Act in 1980 created a publicly-funded corporation to finance commercial coal gasification. At the same time, however, the government intervened in natural gas markets to deregulate wellhead prices and encourage unconventional oil and gas exploration and production as well as discourage demand with a portfolio of energy conservation initiatives. Not discounting the impact of the management issues at the corporation,[45] these counter incentives in the competing natural gas market, along with the short-term world-wide drop in energy prices, resulted in incentives that were unable to counter the market effects. In this case, providing a production tax credit similar to the Section 29 tax credit for unconventional natural gas production would have helped counter the interaction of the policies within the gas market. Or, following the example of the unconventional oil incentive which is tied to the market price of oil, a syngas fuel incentive could have been tied to the market price of natural gas, such that as the price of natural gas falls during the adoption period, the subsidy would increase keeping the level of subsidy comparatively the same. This would help ensure that a new industry could survive price swings in the market due to changes in policy or market conditions.

3.5. Learning from International and State Solar Adoption Policies

International adoption and government incentives

Internationally, the primary mechanism used to drive solar technology demand has been the feed-in tariff (FIT). While there are many varieties (some better than others), in general, a feed-in tariff can be described as a renewable energy policy that guarantees a payment to

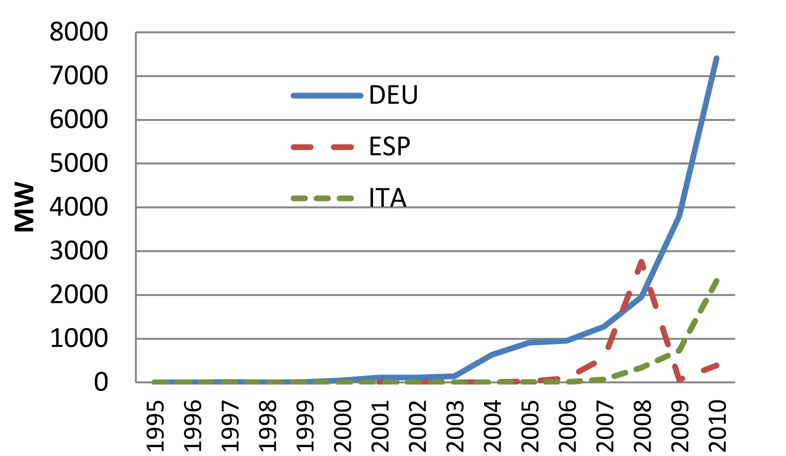
[45] Cohen and Noll (1991).

an owner of a renewable energy resource for the power produced by that resource. Characteristics of FiTs include

- providing a fixed payment guaranteed through a long term contract price;
- setting a tariff that considers the cost of generation of each source of energy relative to the cost of electricity;
- access to the electricity grid through interconnection agreements; and
- tariff degression over time to account for and encourage productivity improvements as the technology matures.

Figure 3-26 below shows the annual installed photovoltaic capacity for the three countries with the largest installed photovoltaic power systems (PVPS) capacity: Germany, Spain, and Italy. The German (DEU) program is generally considered to be the most successful program for accelerating both national and international growth of the solar industry, though it too has come with challenges. The key elements associated with the success of this program are as follows:

- A structured policy framework with a stated renewable energy goal of 30% renewable energy utilization by 2020;
- A tariff that is differentiated by the technology that it serves;
- A guaranteed payment per unit of energy produced for a fixed period of 20 years with a fixed and clearly defined schedule and degression (often based on a reasonable target internal rate of return);
- "Must take" provisions requiring the acceptance of the electricity or energy supply; and
- No capacity limits on technology implementation that would result in implementation uncertainty.



Source: IEA 2011, , Trends in Photovoltaic Applications.

Figure 3-26. Annual Installed PV Capacity: Top 3 IEA PVPS Reporting Countries, 1995-2010

While FiT policies have helped drive massive solar energy deployment and have the potential to exemplify stable, long-term, transparent, and low risk policies, in practice most European FiT policies have proven challenging to implement and maintain. Spain (ESP) experienced a sharp drop in the annual level of installed PV capacity resulting from a poorly designed FiT program (Figure 3-26). The drop in installations in Spain is largely responsible for the plateau between 2008 and 2009 visible in Figure 3-27, which addresses combined annual installed capacity in the top 10 IEA PVPS reporting countries. This kink represents a significant impact on demand, causing a supply surplus (driven by a demand vacuum) that can disrupt industry. More recently, major unplanned FiT adjustments in Germany and Italy have raised the prospect of impacts similar to the "boom then bust" cycle that followed the Spanish FiT adjustment. Therefore it is important to design renewable incentives that result in a consistent policy framework, as consequences can have global implications on the stability and growth of the solar industry.

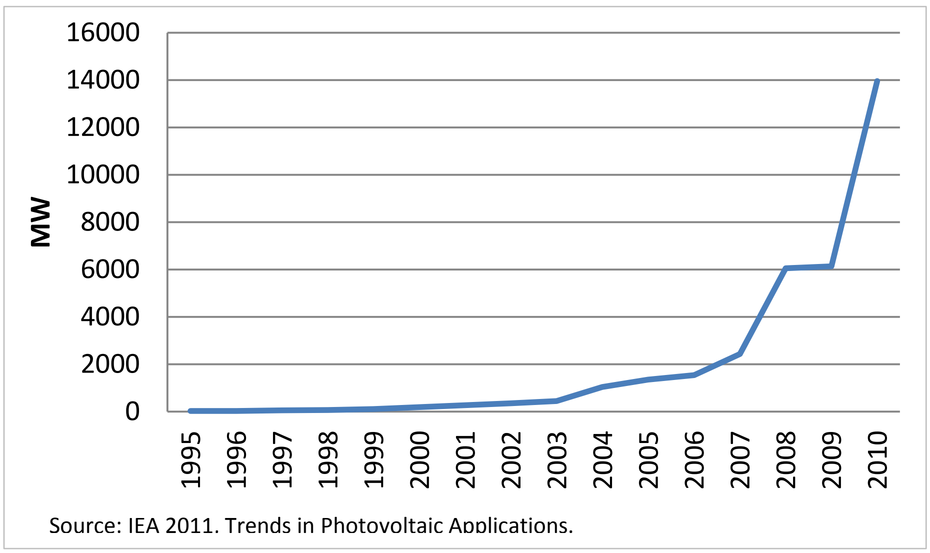


Figure 3-27. Annual Installed PV Capacity: Summary of Top 10 IEA PVPS Reporting Countries, 1995-2010

Like Germany, the U.S. has also seen an increase in installed capacity during the past few years as shown in the following chart. While Germany's level of annual installations has been six or more times greater than the U.S. during the past few years, it has played an important role in the development of the global industry: building industry scale. Massive solar demand in Europe has enabled the growth of large-scale solar manufacturing driving huge economies of scale that have driven the cost of solar energy down rapidly.

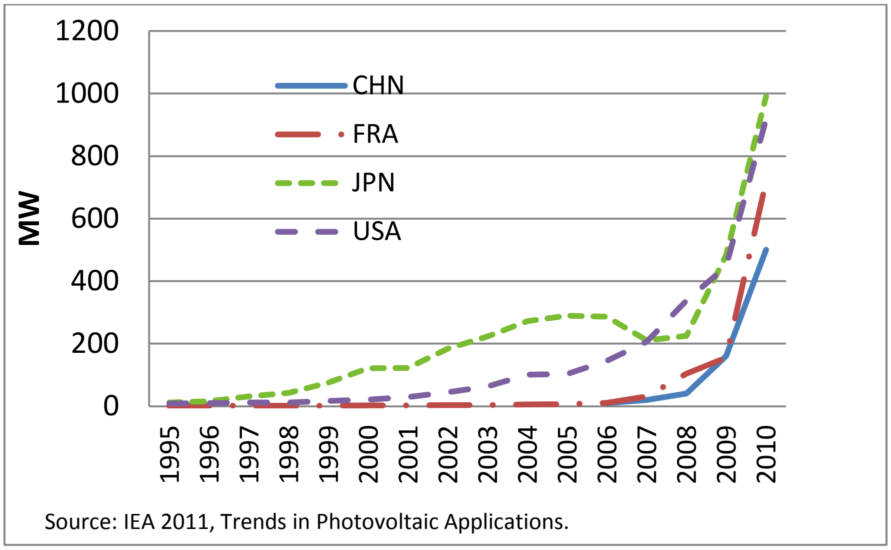


Figure 3-28. Annual Installed PV Capacity: Next 4 IEA PVPS Reporting Countries, 1995-2010

In comparison to the European national FiT programs, the U.S. policy operates within the U.S. federal framework with a mix of federal and state policies designed to accelerate technology adoption to develop the country's solar resources. The electricity utility industry in the U.S. is subject to state regulations with considerable federal coordination. With substantial energy resource and policy variations across the country, grid electricity prices vary significantly by state as shown in the following chart.

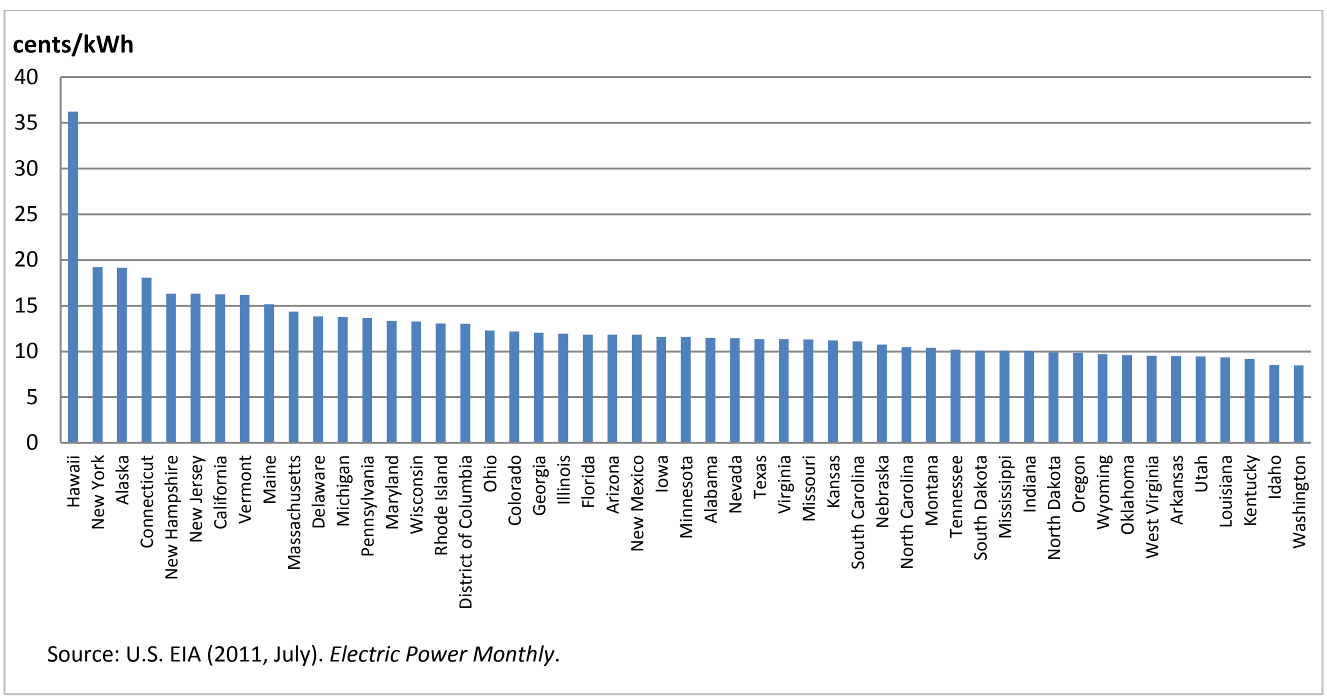


Figure 3-29. Electric Power Residential Rates, July 2011

This federal/state system has resulted in policies that differ when compared to Germany's program. Areas where the U.S. policies differ are as follows:

- No structured federal goal or renewable portfolio standard
- Only short-term financial incentives for renewable energy at the federal level that provide only short windows of opportunity. Lack of tariff differentiation, issues that result from FERC "avoided cost" requirements that under-compensate and under-incentivize the renewable energy resource
- No must-take provisions, disaggregated requirements by state on availability of net metering or interconnection policies
- Funding caps and requirements on implementation of renewable technologies, lack of transparency and complex requirements for some policies which may impose high transaction costs.

State solar adoption and government incentives

Unlike coal, oil, natural gas, hydro, and nuclear – each with their own requirements for federal regulation in energy resource development or refining – development of the country's solar resources places no such burden on the federal government. Development of solar resources can fit with relatively minor adjustment into the existing regulatory environment for the electricity industry, which is a mix of federal and state policies. And, as was seen following the Energy Policy Act of 1992, states play a major role in this market, with many states making significant efforts to deregulate vertically-integrated electric utilities. In doing so, some states began to introduce policies that addressed barriers to adopting solar technology, such as grid interconnection access, and policies that encouraged supply or demand for solar, such as renewable portfolio standards for utilities operating in the state, rebates for solar equipment and incentives for new factories.

In 1996, net metering laws were initiated in many states. This removed one core barrier to entry for the implementation of solar PV installations resulting in a foundation for growth of the industry. In 1997, states began structuring Renewable Energy Portfolio Standards with long-term targets that created a more certain investment environment. These state policies that encourage development of solar resources have started to play a significant role in solar adoption, as solar photovoltaic technology has started up the adoption curve in the U.S. With the additional incentives implemented by the federal government in 2006 and 2009, growth has accelerated.

The following chart shows the growth in photovoltaic adoption in California following state policies enacted in 1998, federal policies in 2005, and the California Solar Initiative.

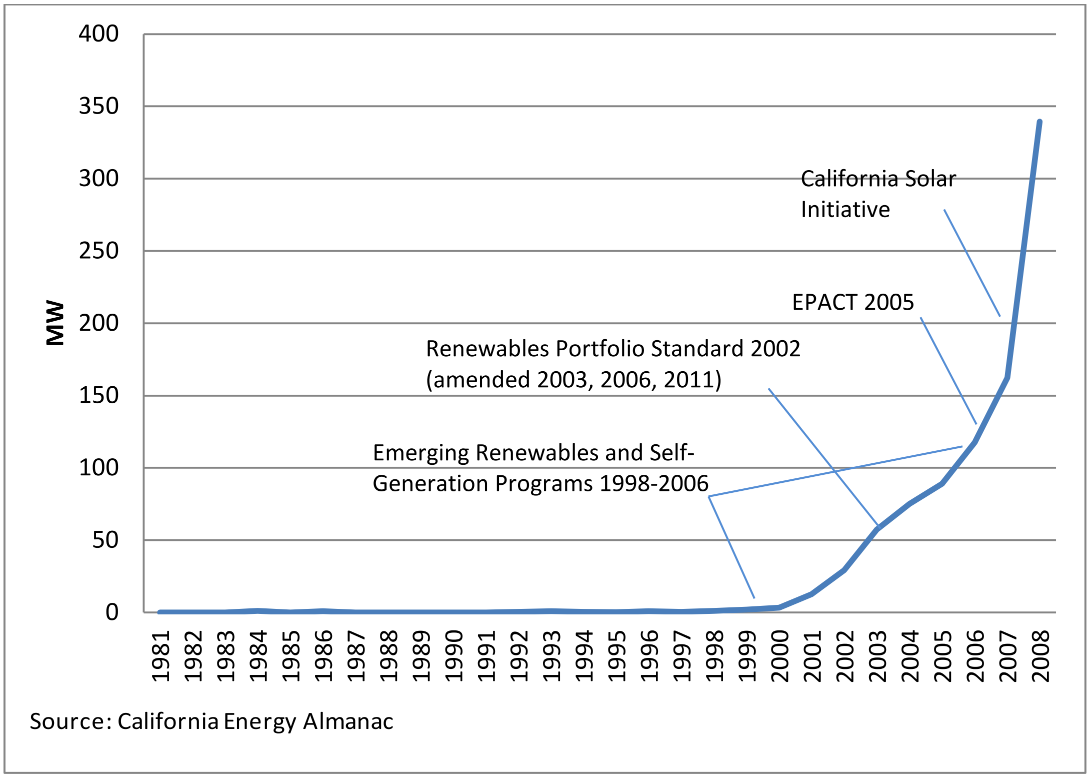
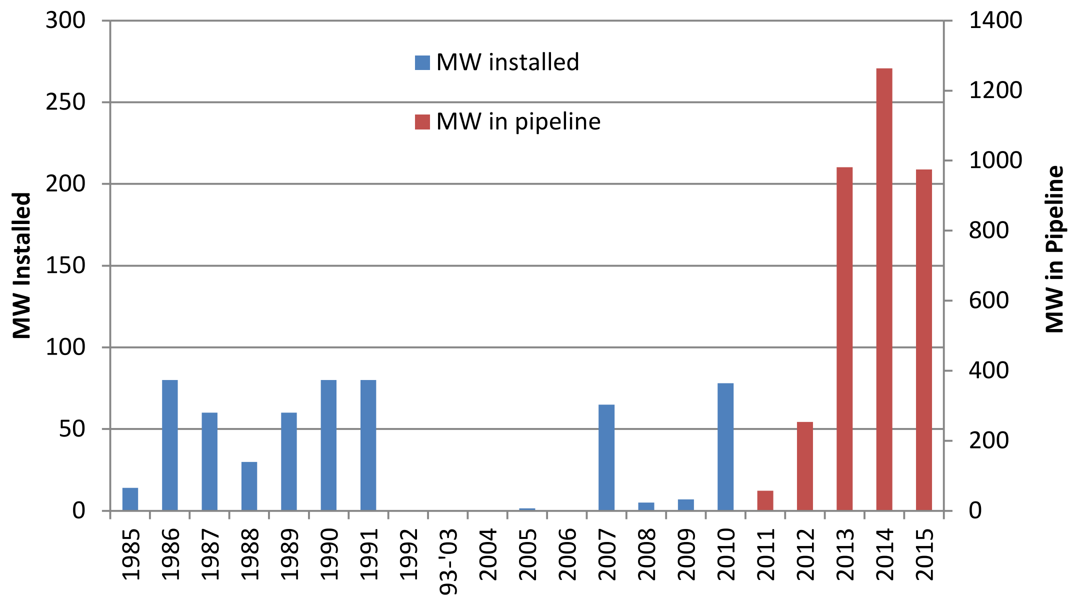


Figure 3-30. California's Annual Installed Capacity, 1981-2008

Other examples of state incentives could be analyzed to show the impacts on adoption at a state level. Like the federal government, one frequent incentive used by states across industries to encourage economic development is tax credits. California provides an interesting case study regarding concentrating solar power and property tax credits. The chart below illustrates the effect of dropping incentives early in the adoption process before the fledgling industry has crossed the chasm. During the initial period of innovators in the market, investment in solar concentrating power plants began to trend upwards, partially driven by California's property tax credits. However, in 1992, California delayed property tax credits which immediately caused investment in this technology to halt. Annual installations of concentrating solar power in the U.S. were nonexistent from 1992 through 2004. Commercial concentrating solar power installations reappear in 2007 on a limited basis which correlates with the start of Energy Policy Act 2005 policies. Given long lead times associated with the design and financing of these larger scale facilities, we are now starting to see the technology begin once again the adoption path. As we discuss in Section 3.3, the lesson is that if policies are enacted but then prematurely removed, the impact can be severe on the adoption process. Energy resource development follows a thirty-year adoption process. In this case, the incentives during the initial period did not have nearly the impact that could have been achieved had there been a commitment to the full adoption process.



Sources: US DOE 2008, Solar Market Technologies Report; NREL 2010, Concentrating Solar Power Projects; SEIA 2011.

Figure 3-31. U.S. Concentrating Solar Power Installations by Year, Existing and In-pipeline

CHAPTER 4. THE SOLAR INDUSTRY'S PROSPECTS AND POTENTIAL

A robust solar industry in the U.S. would not only benefit the environment, but it would also create significant job and export growth, increase efficient peak power production, and reduce electric grid congestion. This chapter reviews recent trends in solar energy worldwide and in the U.S. and then addresses some specific benefits of a strong U.S. solar industry.

A number of short-term issues may impact both supply and demand in the solar power market:

- Declines in housing values make it difficult for individuals to finance long-term cost savings that require upfront investment costs, although new financing options for solar may offset this difficulty somewhat.
- Global budget austerity measures raise uncertainty about government assistance on both the demand and supply side during the transition to industry maturity.
- Federal incentives to the fossil fuel industries disadvantage the market entry of new energy sources unless the new fuels are brought to incentive parity with traditional fuel sources.
- Despite recent federal investment in solar power, historically non-steady commitments to renewable technologies have hindered a smooth and certain path for private investment in solar.
- A global surplus of photovoltaic panels starting from 2010 and into 2012 will create a buyer's market but strain manufacturers.

These pressures will pass. But even a short term break in growth can significantly dampen the momentum needed to lift the solar power industry over the chasm and into a phase of majority adoption.

4.1 World Trends for Solar

Current Status

Aggressive government policy support for solar in Europe has helped push solar across the chasm from early adopters to the beginning of early majority adoption market in some European countries. The European Photovoltaic Industry Association (EPIA) reports installed capacity at the end of 2010 was 30 gigawatts (GW)—of which 13 GW was installed in 2010—with potential production annually of 35,000 gigawatt-hours (GWh) or 1.2% of the European Union's electricity demand.[46]

[46] See European Photovoltaic Industry Association (2011, May).

EPIA attributes the recent growth and a favorable forecast for continuing growth in photovoltaic capacity to underlying changes in the solar market, as well as policy support:

- "Firstly, renewable energy is no longer considered a curiosity. PV has proven itself to be a reliable and safe energy source around the world."
- "Secondly, the price decreases that have brought PV close to grid parity in several countries have encouraged new investors."
- "And finally, smart policy makers in key countries have set adequate FiTs [feed in tariffs] and other incentives that have helped develop markets, reduce prices and raise investors' awareness of the technology."[47]

According to the 2010 BP Statistical Review of World Energy, Germany and the rest of Europe have increased their relative shares of world photovoltaic capacity, while the United States' share has declined.[48] As seen in Figure 4-1, the U.S. solar market has expanded much slower than European markets but is about on pace with other major markets. It appears that the U.S. industry is still negotiating the chasm before full adoption—awaiting stability in policy and movement to grid parity, where the cost of generating electricity from solar energy is the same as or less than purchasing or generating electricity from traditional sources.

The decreasing cost of solar panels—driven primarily by production scale and efficiency as well as new technologies—along with interest and policies that promote the use of low- or no-emission energy has stimulated recent movement of the industry. However, the downturn in the economy and fiscal constraints may retard the speed of deployment in some markets.[49]

Future growth in solar deployment

Worldwide, solar power is expected to grow substantially in the next twenty years. Long term planning in Europe has positioned solar power as one component in renewable energy growth. Binding targets to use 20% renewable energy by 2020 set by the 27 European Union

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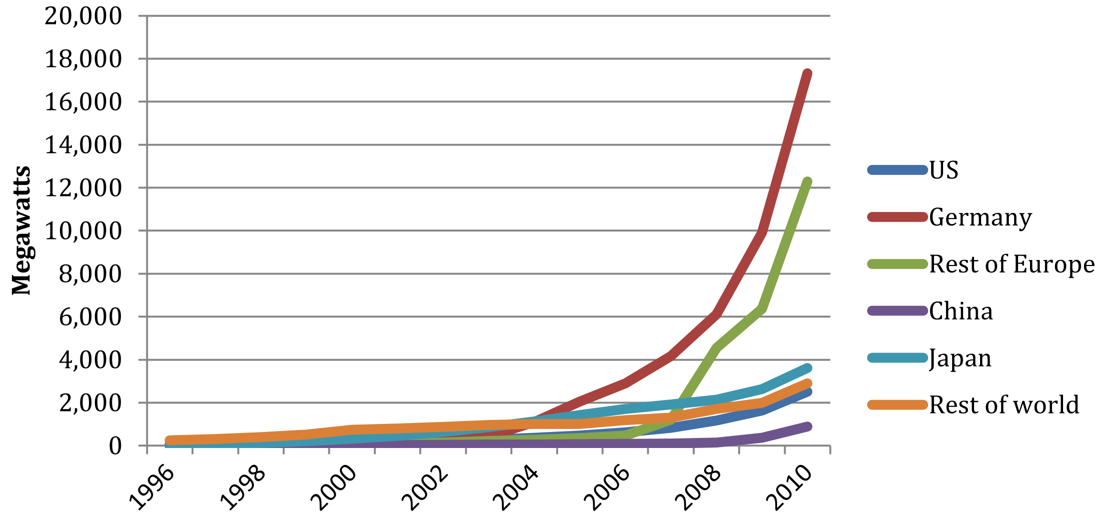
[47] *Ibid.*, p. 39.

[48] See BP p.l.c. (2011).

[49] See Global Studies Initiatives (2010).



Source: BP Statistical Review of World Energy, 2010.

Figure 4-1. Cumulative Installed Photovoltaic Capacity

states are being met by a projected 23.6% annual growth rate in photovoltaic capacity and 31.1% annual growth in concentrating solar power (CSP).[50]

- Dynamic grid parity, the point at which the cost of grid power equals the value of electricity produced from a photovoltaic installation, could occur as early as 2013 in the commercial segment in Italy and then spread out in Europe to reach all types of installations considered in all the selected countries by 2020.
- Solar system prices are expected to decline by 36-51% in next ten years accompanied by a rise in traditional electricity prices.[51]
- Sixteen of the member states are expected to exceed their 2020 targets.[52]

China has selected solar development as one of its paths to future competitiveness. In China, the National People's Congress (NPC) has set a 2020 target for photovoltaics of 30 GW of domestic installed capacity, which the European Photovoltaic Industry Association (EPIA) considers feasible.[53]

[50] European Renewable Energy Council (2008).
[51] European Photovoltaic Industry Association (2011).
[52] European Renewable Energy Council (2011).
[53] European Photovoltaic Industry Association (2011, May).

EPIA has generated short term projections of photovoltaic capacity growth under two scenarios (Table 4.1). The moderate scenario is a "business as usual" set of assumptions that envisions a continuation of current production and policy trends. A second "Policy Driven" scenario assumes that there will be an increase in commitment to photovoltaic power through enhanced feed-in tariffs and other policy commitments.

Table 4.1 Short Term Forecast of the Expansion in World Photovoltaic Capacity 2010 to 2015 (GW)

World Region	Base Year Capacity	Predicted Installed Capacity in 2015 under Alternate Scenarios	
	2010	Moderate Scenario	Policy Driven Scenario
Europe	29,252	69,070	107,625
Asia Pacific	5,706	26,135	37,020
North America	2,727	24,150	35,600
Rest of World	1,844	11,900	15,700
Total World	39,531	131,255	195,945

Source: European Photovoltaics Industry Association (2011).

The Solar Energy Industries Association and GTM Research have developed forecasts for the growth in capacity of both PV and CSP in the U.S. market. Their base case scenarios show continued growth in annual installed capacity through 2015 for the PV market and significant additions to capacity in new CSP installation.[54]

[54] SEIA/GTM, 2011. U.S. Solar Market Insight Report. Q3 2011: Full Report.

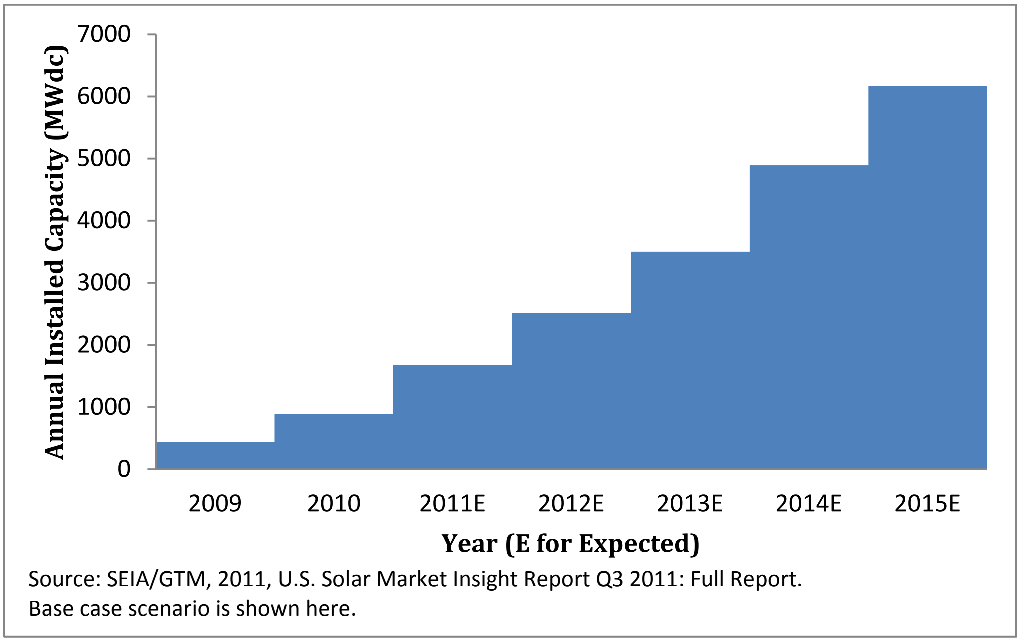


Figure 4-2. U.S. PV Installations Forecast through 2015

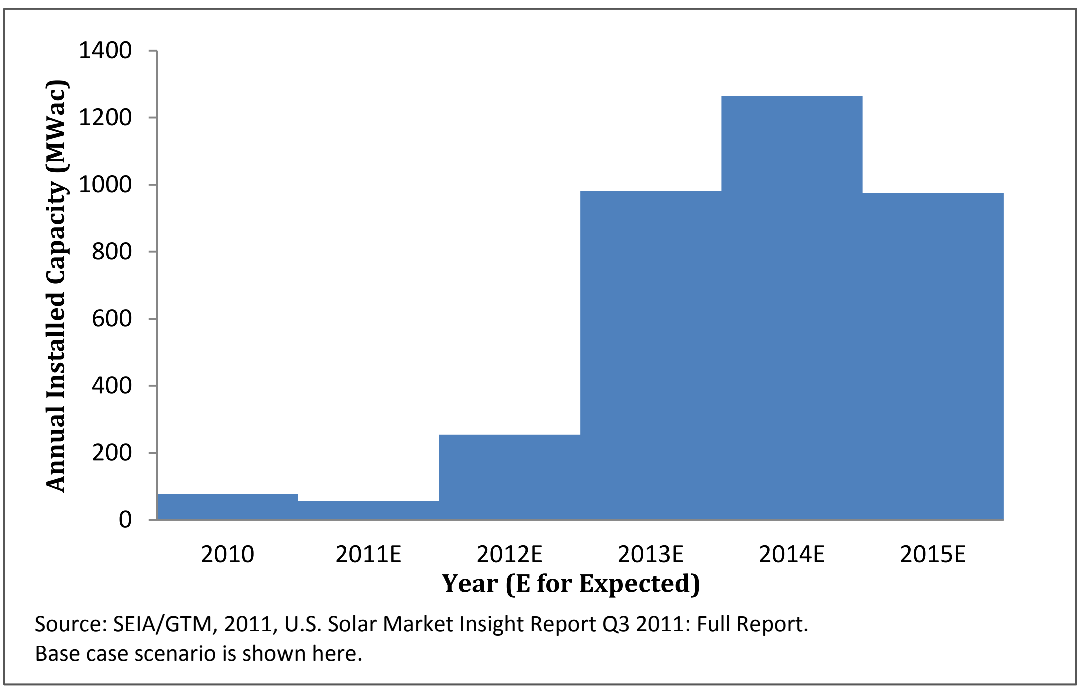


Figure 4-3. U.S. CSP Capacity Additions through 2015

4.2 Long Term Projections of Growth in the U. S. Solar Industry

The increasing role that solar energy can play in the total energy portfolio is addressed in several recent studies, all of which project continued strong growth in the sector. The estimated growth rates vary, however, based on assumptions about levels of policy support ranging from business as usual to very aggressive policy initiatives. A number of growth scenarios are presented in Table 4.2 and discussed here. As a simple way to characterize the scenarios, we use the projected cumulative capacity and calculate the compound annual growth rate to apply between 2010 and the scenario's projected end, to arrive at that capacity. These scenarios provide us a wide range of growth potential which we use to estimate potential employment that could be generated by growth in solar industry (see Section 4.3). More extensive discussion of the scenario selection is provided in the Appendix.

In "Renewable Energy and Energy Efficiency: Economic Drivers for the 21st Century," Roger Bezdek provides several scenarios for growth in renewable energy and energy efficiency. [55] He breaks out base year data on revenues and employment into two solar power categories—photovoltaics and solar thermal[56]—presented in aggregate in Table 4.2. The estimates include only private industry employment. The report presents projections for renewables as a whole. We applied this growth rate to the solar revenue and employment totals in the Solar Census base year to build projections for solar power employment. This assumes that solar will maintain its current share of the renewable portfolio, although the recent rise in solar growth suggests that it may increase its share. Consequently, the estimates used from this scenario may understate the growth in solar employment.

The Energy Information Administration's *Annual Energy Outlook* 2011 (EIA 2011) contains projections for CSP and PV capacity and consumption out to the year 2035.[57] For this estimate, we combined the separate information on CSP and PV capacity for both the utility and end use sectors. The AEO provides a range of projections with variations in the level of solar growth, ranging from 5.6% in its Reference case to 9.1 % in its more aggressive "No Sunset" case. We apply the EIA-projected growth rate in net solar power capacity for the No Sunset to the Solar Census base year employment numbers to generate employment projections for this EIA reference scenario.

[55] Bezdek (2007).
[56] Includes both concentrating solar power (CSP) and solar water heating (SHC).
[57] U.S. Energy Information Administration (2011, April).

Table 4.2 Long Term Growth Rate Projections for U.S. Solar Power Capacity					
Source	**Data year**	**Period**	**Scenario**	**Annual Growth in Installed Capacity (%)**	**Comments**
Bezdek	2006	2012-2030	Base	4.8	Business as usual-no change in policy
			Moderate	8.7	Assumes moderate increments in federal and state renewable energy and energy efficiency initiatives
			Aggressive	12.9	Potential with current technology coupled with aggressive state and federal policies
EIA 2011	2011	2012-2035	No Sunset	9.1	Combined CSP and photovoltaic for utility and end use sectors.
Green Jobs Calculator	na	2009-2030	Base	15.3	Driven by a California Renewable Portfolio Standards scenario
Predicted GNP Growth	2011	2009-2020	na	2.7	Source: Global Insight
20% Growth	na	2012-2030	na	20.0	Commitment to Solar Scenario
SunShot	na	2012-2050	na	26.0	SunShot has high annual growth (26%) through 2030, and moderate growth thereafter
IPCC	na	2007-2030	na	29.0	The 29% level is extremely aggressive and is not reported on further.
* We use the SunShot 26% growth rate since our employment projections do not extend beyond 2030.					

The University of California Berkeley's Renewable and Appropriate Energy Laboratory (RAEL) has synthesized 15 job studies[58] and incorporated the information into its Green Jobs Calculator.[59] The calculator also includes a baseline long-term projection of solar capacity. The goal of the Berkeley project is to estimate the number of jobs that might be generated from renewable energy and energy efficiency programs from Renewable Portfolio Standards programs by 2030. The table includes the Green Jobs Calculator's projections of solar power capacity expansion.

58 Wei, Patadia, and Kammen (2010).
59 Wei, Patadia, and Kammen (2011).

The SunShot Vision Study provides direct solar industry employment estimates based on "best case" solar scenario that includes achieving a 75% cost reduction across residential, commercial, and utility deployments of solar power. Under this scenario, SunShot estimates solar meeting 14% of total electricity demands by 2030 and 27% by 2050.[60]

The Intergovernmental Panel on Climate Change's projection of a robust 30% annual growth rate for U.S. solar power capacity[61] serves here as the upper bound for potential growth. To provide a lower bound, we use a scenario in which solar expands only at the predicted GNP growth rate of 2.7%.

4.3 Long Term Employment Potential

The 2011 Solar Census[62] estimates of solar energy employment are used as a starting point for the employment analysis (Figure 4-4).[63] Fundamentally, the assessment of future employment is made by applying employment multipliers to the projections of solar capacity and annual installations to generate the scenario-related employment. The difficulty is that labor productivity employment multipliers are not readily available. Consequently, for this study we developed employment multipliers that account for labor productivity. The process used to create these multipliers is discussed in the Appendix. Employment multipliers and labor productivity changes can be different by technology (PV, CSP and Thermal) and sector (manufacturing, installation, and operations/maintenance).

Investments in solar photovoltaic capacity generate more jobs per megawatt capacity than any other energy technology.[64,65] The RAEL study reports that solar has 7.45-10.5 jobs per megawatt of installed capacity. This is compared to 1 job for coal and 0.95 jobs for natural gas. The research to support the Green Jobs Calculator reviews the literature on estimates of renewable energy employment and discusses many of the issues in interpreting simple employment-output ratios.[66]

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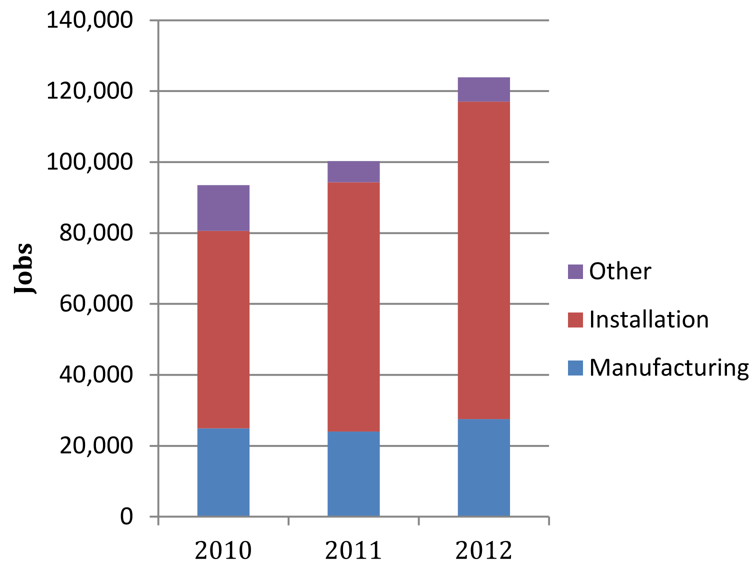
[60] SunShot (2012). "Message from the director of the SunShot Initiative." In *SunShot Vision Study*.
[61] IPCC (2011).
[62] The Solar Foundation (2011).
[63] We follow the definition for jobs that the Solar Census uses, i.e. workers who spent 50% of their time in solar activities are counted as a solar jobs. We combined the Solar Census' categories of installation and sales/distribution into one, installations. This was done to facilitate the allocation process.
[64] Kammen, Kapadia, and Fripp (2004).
[65] Wei, Patadia, Kammen (2010).
[66] Goulding, Marr, and Goulding (2011).



Source: Solar Census 2011
Note that the 2012 figure was a forecast produced in 2011.

Figure 4-4. Estimated U.S. Solar Energy Industry Employment

In order to construct the projections for the current study, we needed a consistent and current data set of industry employment, production (i.e. installations), current capital stock (i.e. cumulative installations), and productivity adjusted employment multipliers for each technology of interest of PV, CSP and Thermal. No current study or report seemed to present such a consistent set of data; therefore, we constructed this dataset. The approach to developing the profile is described in the Appendix.

The basic approach is to project annual installations by technology through 2030. The series of annual installations are then added to the base year capacity to get a series of cumulative installed capacity for each data year. Thus, two time series are created for each technology: installations per year and cumulative capacity for each technology. The cumulative capacity for each year is used to develop employment for operations and maintenance while the series of installations is used to project employment for installations and manufacturing.

To characterize the scenarios we use the projected capacity in 2030 as the endpoint, but do not assume a consistent rate of growth over the projection horizon. If one simply used an annual growth rate to generate the installation series, one would have relatively small levels in the near term and exponentially growing installations in the later years. In a new industry, as discussed early in the paper, one expects annual sales that become increasingly larger in the early years and then taper off as the industry matures, generating an S-curve pattern of growth of annual sales. A procedure was developed to force an S shape to the sales growth and yet target the end capacity. The approach was used on all the scenarios considered except the SunShot scenario which provided actual jobs estimates for 2030 and 2050. We used the SunShot capacity growth rate through 2030 for our analysis. SunShot uses a more aggressive labor productivity growth rate for operations and maintenance sectors than the growth rates we applied to other scenarios.[67]

Because the projections of solar industry growth presented above were derived at different times and used different bases, we have calibrated the projections to be consistent with the most recent Solar Census base estimate of solar employment.[68] The Solar Census, rather than identifying "solar industries" and using the standard industry employment statistics, has derived employment estimates from survey data it collected directly from firms.[69] The Solar Census surveyed firms to identify the number of people that spend at least 50% of their time on solar-related activities. These survey-based estimates are then scaled up to provide a national total of employment. This concept of "direct" employment used in the Solar Census is somewhat different than the standard Input-Output modeling definition and may include industry employment that normally would be part of indirect employment. Conversely, it might also exclude from its direct employment calculations some jobs that normally would be included. It is still desirable to estimate the total of direct and indirect employment that is related to the Solar Census direct employment. To do this we simply used Bezdek's ratio of total employment to direct employment to estimate a base year and projected total employment. This, of course, assumes that the relationship between direct and total remains the same over the projection horizon. Additionally, direct, indirect, and induced labor productivity-adjusted employment multipliers were developed as described in the Appendix.

Using this procedure described in detail in the Appendix, we developed the estimates presented in Table 4.3 and Figure 4-5. Estimates of employment—direct, indirect, and induced—generated by the solar industry in 2030 range from 240,000 to 965,000 jobs.

[67] SunShot (2012).
[68] The Solar Foundation (2011).
[69] The Solar Census used this approach partially because the Bureau of Labor Statistics is in the process of defining the components of the solar industry.

Table 4.3 Projections of Total Direct, Indirect and Induced Employment Supported by the Solar Industry and Related to Growth in Domestic Solar Capacity Thousands of Jobs								
		Bezdek Projections			EIA 2011			
Year	GNP Growth	Base	Moderate	Aggressive	No Sunset	Green Jobs Calculator	20% Growth in Solar Capacity	SunShot
2015	185	187	190	194	191	209	243	236
2020	201	206	220	236	223	295	431	378
2025	219	230	255	287	261	397	653	604
2030	240	254	287	334	295	482	826	965

Note: Excludes employment related to export activity.
Source: University of Tennessee Howard H. Baker Jr. Center for Public Policy analysis.

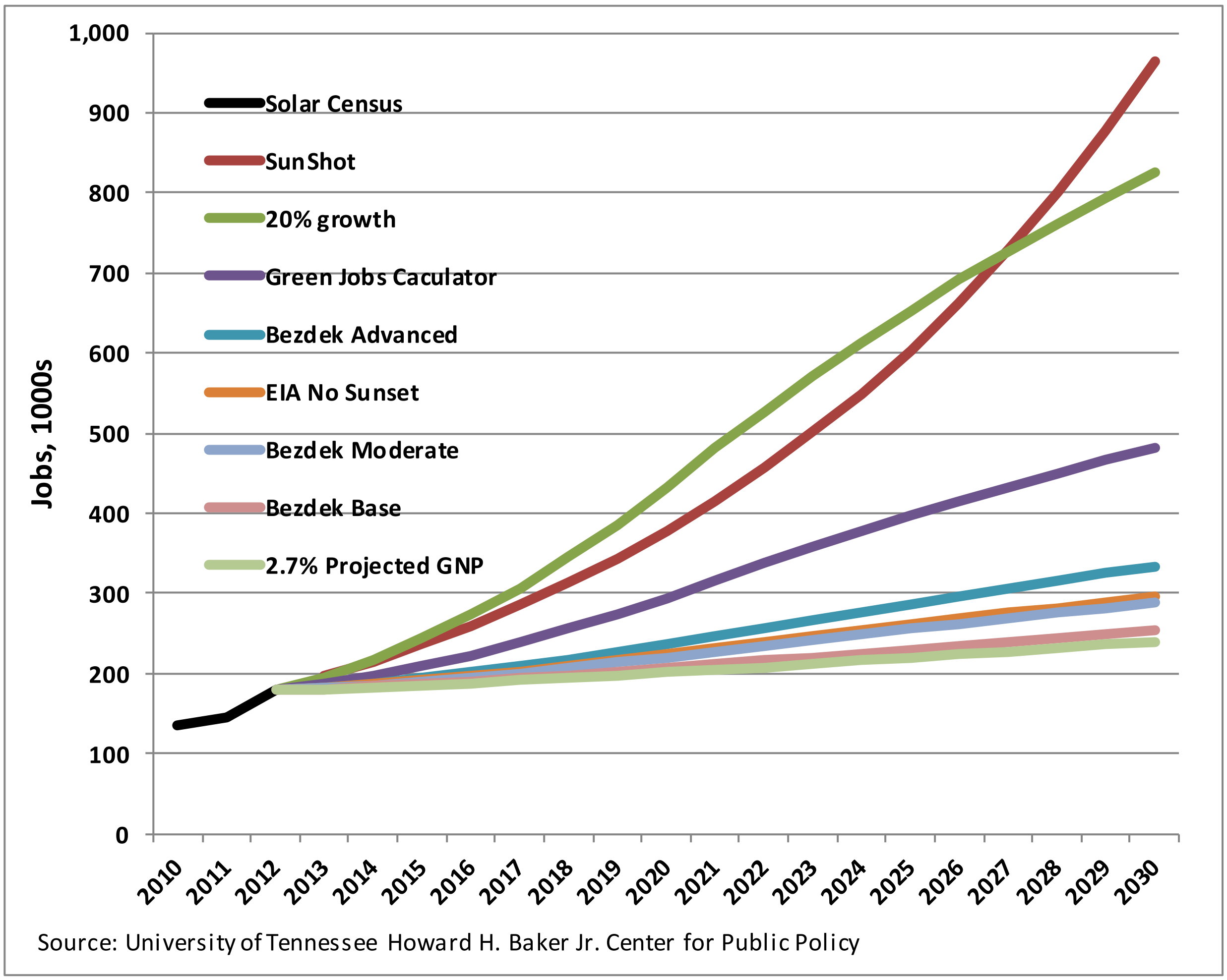
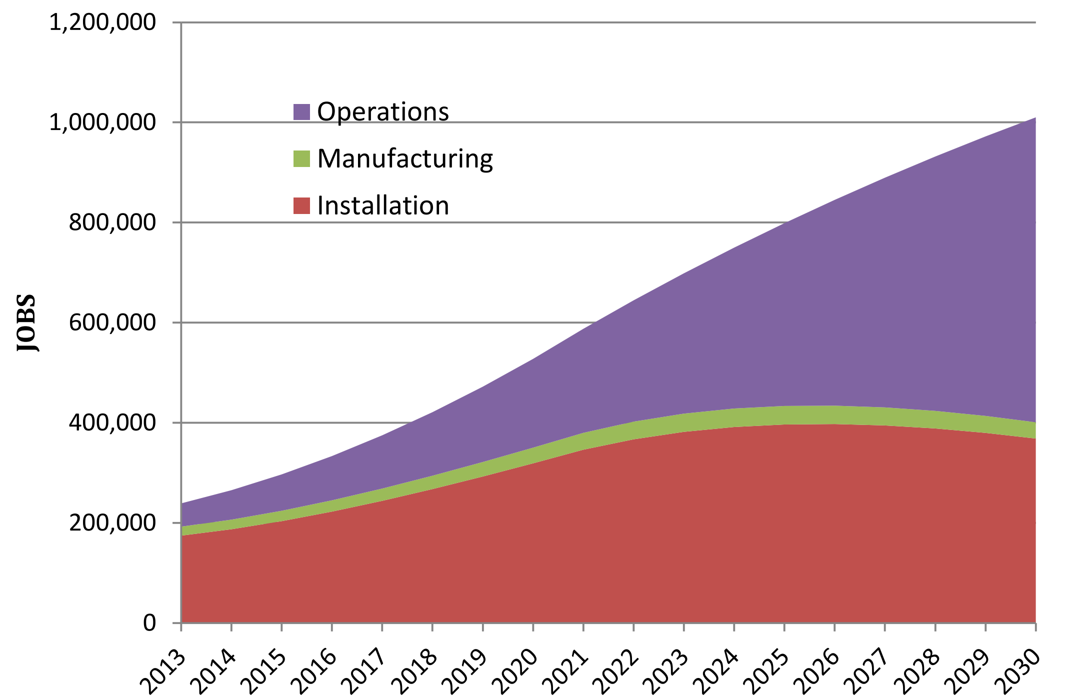


Figure 4-5. Total Employment Growth (direct, indirect & induced) Supported by Domestic Growth in the Solar Industry under Various Scenarios, 2010 – 2030

The employment multipliers (i.e., the ratio of indirect to direct and induced to direct) were computed separately for Manufacturing (of input materials); Installations; and Operations & Maintenance for PV, CSP, and solar thermal. The sectors had different labor productivity factors as well. Consequently, the mix of employment by sector can change over time. An initial observation is that manufacturing employment becomes overshadowed by employment in Installations and O&M. Moreover, as the cumulative capacity expands and the labor productivity improvement in the other two sectors takes effect, O&M becomes the largest sector (See Figure 4-6).



Source: University of Tennessee Howard H. Baker Jr. Center for Public Policy estimates.

Figure 4-6. Distribution of Employment Related to Domestic Growth in the Solar Industry, 2013-2030, with 20.0% Growth in Solar Capacity

4.4 Export Opportunities and Economic Development

With several European countries leading the U.S. domestic market in annual solar installed capacity, there is growing export market potential for U. S. solar manufacturing and materials. However, these European countries, along with China, see their home markets and development of solar technologies as a mechanism for their own export expansion and economic growth.[70] To these ends, there is state intervention in these countries not only to

[70] Pew Center for Global Climate Change (2011).

encourage local consumption but also to assist their renewable energy industries in competing in world markets.[71]

Recognizing both this opportunity and threat, there is growing policy interest in using energy technology to position U.S. export markets as a driver of economic growth and competitiveness.[72] A Pew Research Center brief on job opportunities in energy markets issues this caution:

> U.S. firms are currently lagging behind their foreign competitors and missing opportunities to compete in these markets. Fostering domestic markets will create jobs and give lead industries the initial foothold they need to ultimately better compete in rapidly expanding international clean energy markets—and the sooner these industries can be established, the larger the share of these global markets they stand to gain in the decades ahead.

Competing in foreign markets, especially in China and with China, may require a commitment on the part of U.S. policymakers to increase domestic initiatives to enhance competitiveness of U.S. manufacturing.[73] Fred Bergsten of the Peterson Institute for International Economics argued before a recent House Committee hearing that such a commitment to reduce the U.S. trade deficit by increasing exports could be a way to increase employment.[74,75]

In 2010, the U.S. had a positive trade balance in solar equipment, with the primary export activity in photovoltaic products as shown in Table 4.4. Exports of photovoltaics are heavily weighted to capital equipment ($1.4 billion), polysilicon ($2.55 billion), and modules ($1.2 billion) (although the U.S. is a net importer of modules).

As shown in the export employment data developed above, the major proportion of employment in manufacturing related to solar is export oriented in 2010. Recent slowdown in European installations has reduced this export concentration. However, it is likely with the long-term growth in export markets that the U.S., if it maintains a robust manufacturing of key supply chain products, can build a base for employment growth.

To understand the potential for export-based economic development related to solar technologies, we estimated employment related to exports to various world regions and then prepared projections of domestic employment that would be supported by exports in 2030. The starting point of the export analysis is the U.S. Solar Trade Assessment data

[71] European Renewable Energy Council (2003).
[72] Baily, Katz, and West (2011).
[73] Baily (2011).
[74] Bergsten (2011, September).
[75] Bergsten (2011, October).

shown in Table 4.4. The report also indicates the export value related to domestic content (i.e., net of imports) for PV ($2,133 million) and solar thermal ($431 million). Using the cost and employment multipliers from the earlier analysis, the export related employment was computed to be 4,078 export-related domestic jobs for PV exports.

Table 4.4 Trade Balance by Solar Technology

Technology	Number of Establishments in the U.S.	Distribution of Establishments In the U.S. %	Imports 2010 $M	Exports 2010 $M	Net Trade Balance 2010 $M
Photovoltaic	754	39.4	3,679.3	5,613.5	1,934.2
Solar Heating and Cooling	737	38.5	13.6	16.3	2.7
Concentrating Solar power	240	12.6	57.4	0.0	-57.4
Other	182	9.5	0	0	0
Total	1913	100	3750.2	5,629.8	1,879.6

Sources: Number of establishments and their locations are from The Solar Foundation, National Solar Jobs Census 2011; Trade data from GTM Research, 2011, Solar Trade Assessment[76]

The pattern of dollar value of exports by country reported in the 2011 Solar Trade Assessment was used to distribute the PV and Thermal export employment calculated above. We maintain PV and thermal separately to be consistent with the employment data and the different countries involved in PV and Thermal. Then we applied the solar growth rates for the world region in which each country resided to the base year values of PV and thermal to get the out-year projections. The world region projections are available from the EIA International Outlook.[77] Then the PV and thermal employment figures were summed to get a total export-related employment for each world region in the base year of 2010 and 2030 as presented in Table 4.5. The 2030 raw employment numbers were then adjusted for increased labor productivity using information from the earlier multiplier analysis.

[76] GTM Research (2011).
[77] U.S. Energy Information Administration (2011, September).

Table 4.5 Estimated Solar Growth in Installed Capacity by World Region	
World Region	EIA Projected Solar Growth Rate (%)
Africa	25.40
Asia	11.70
Australia and Oceania	9.60
Central America	12.30
Europe	5.27
North America (Canada)	7.70
South America	12.30
Source: EIA (2011)	

When the EIA growth rates are applied to the export patterns presented in the Trade Assessment we derive the export related employment indicated in Table 4.6. The distribution by country is established in the base year 2010 and is very likely to change over the 30 years. However if the U.S. maintains its market share in the growth of these foreign markets then the pattern below could result. It also is possible that new export markets will develop in other countries as the United States solar industry grows.

Table 4.6 Export Related Employment: Direct, Indirect and Induced		
Country	**2010**	**2030**
All Other	6,545	24,378
Argentina	35	133
Canada	1,557	2,436
China	11,721	13,113
France	517	501
Germany	6,040	5,850
Italy	880	852
Japan	4,253	14,309
Mexico	2,293	3,587
Norway	1,802	1,745
Saudi Arabia	176	593
Spain	161	156
Taiwan	35	119
Grand Total	**36,015**	**67,772**

The projections reflect a "business as usual" scenario for growth of solar exports. The EIA projections of international capacity growth are generally greater than the expected U.S. GNP growth rate. The projections assume that the United States maintains its export share in each market so that the exports grow at the same rate as the foreign country or region's solar installation growth rate—an assumption that depends on the U.S. industry holding its foothold in the international markets. To increase market share, the U.S. would need to gain a comparative advantage globally in enhanced technology and specialty equipment.[78] It is to be noted that while intellectual property can easily be exported, manufacturers of new technology tend to like to co-locate factories and R&D. In light of support other countries make available to their solar industries, the U.S. industry and markets are at a relative disadvantage with limited state support especially at this period on the adoption curve, before the domestic market has expanded enough to reach a scale of aggregate demand that bridges the chasm to market adoption. As discussed in Chapter 1, moving the U.S. domestic solar industry across the chasm will likely require an expansion of long-term supply to enable decreasing cost and a concurrent expansion of long-term demand to provide the market for the increased supply. The current global oversupply of photovoltaic panels comes about because of the mismatch between short-term supply and demand curves.

This industrial development process need not be done in isolation of other goals. With the decline in the overall U.S. manufacturing base, there has been a growing interest in economic development strategies that use "Industrial Clusters" as a driving force for export-based local economic development. The cluster model is an economic development approach pioneered by Michael Porter and his Institute for Strategy and Competitiveness.[79]

The cluster approach centering on green technologies, including solar, has been utilized in a number of local economic initiatives.[80] One prime example of a green cluster with a strong solar component is the New York Renewable Energy Cluster (NYREC) recently funded by Economic Development Agency. [81] EDA has also established the "i6 Challenge—Bringing Innovative Ideas to Market."[82] These recent events build upon a strong local economic planning interest in using green technology to improve regional competitiveness and develop a sustainable local economy. Some other examples of solar energy cluster implementations are Michigan,[83,84] Colorado,[85] Arizona[86], Orange County California, and

[78] Hunt (2011).
[79] Institute for Strategy and Competitiveness (n.d.).
[80] Karlenzig (2006).
[81] Orange County Economic Development (2009).
[82] U.S. Economic Development Administration (n.d.).
[83] The Right Place, Inc. (2007).
[84] HV Insider (2011).
[85] Colorado Clean Energy Cluster (n.d.).
[86] Miller (2011).

Massachusetts.[87] Indeed, the Massachusetts energy cluster accounts for over 10,000 jobs, in which solar is an important component.[88]

Historically, the size and breadth of the U.S. economy has supported new domestic technologies to vie for success and move to the next level of scale, i.e. to cross the adoption chasm. But with a competitive gap forming as foreign countries now lead the U.S. in solar installations and manufacturing, this competitive advantage of the U.S. economy could be lost. From both a regional and national perspective, our analysis suggests that supporting the domestic market could result in export driven economic growth, while failing to support the domestic market could threaten maintenance of economies of scale in production that are needed for domestic produce to compete in the global market.

4.5 Adding Solar Resources to the Electric Generation Portfolio

Since the development of the electricity industry in the U.S., the government has played a direct role in adding new sources of energy to fuel the electrification of America. Now, as economic growth becomes ever more dependent on sustainable energy supplies, policymakers are once again playing a role in developing new resources, such as solar and wind.

Figure 4-7 shows the level of reserves for energy resources for electricity generation that began deployment before the oil embargo in 1973.[89] For comparison's sake, the feasible deployment pattern in A Solar Grand Plan is used as an estimate of the recoverable U.S. solar reserves.[90] The Solar Grand Plan presents the possibility for solar to provide 35% of total U.S. needs by 2050 and 90% in 2100. The Solar Grand Plan was used because it presents a projection of capacity and capacity factors for specific technologies as

[87] Massachusetts Clean Energy Center (2011).
[88] *Ibid.*
[89] Procedures used to estimate the non-solar reserves are addressed in Section 3.3. Information sources used are Denholm and Margolis (NREL) (2008); Petty and Porro (2007); U.S. EIA (2010, November and 2010, October); U.S. EIA (2010, July); U.S. EIA (2011, July); U.S. DOE (2004); Zweibel et al. (2007).
[90] Zweibel et al. (2007).

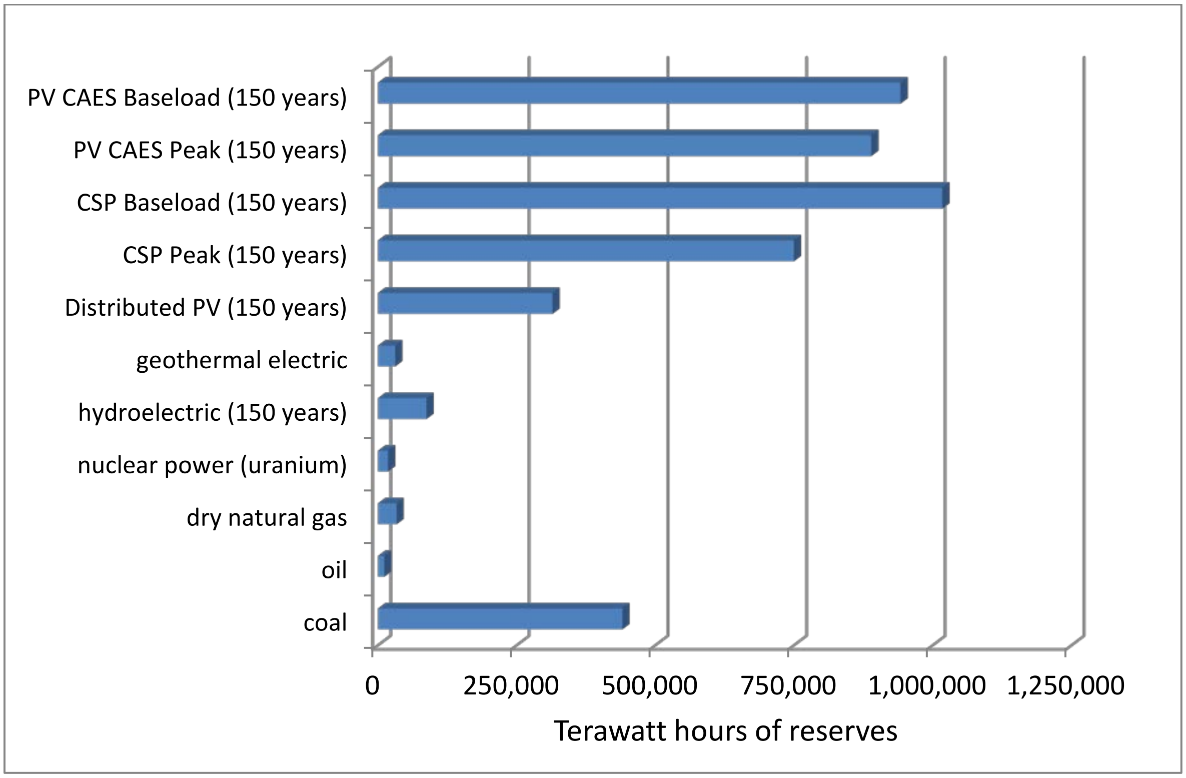


Figure 4-7. U.S. Energy Resource Reserves for Electricity Generation (undeveloped reserves)

compared to the wide range of values from other sources that are based solely on inferences from available solar radiation.[91] This solar future is based on a range of technologies but has no further technological development after 2020. The study assumes utility PV power generation is enhanced with compressed air energy storage (CAES) to provide base load generation. The Solar Plan's deployment pattern was used to develop a time series of electricity generation by technology that is used as the estimate of recoverable reserves. To generate the full 150-year time period used in this analysis, the published data were extended beyond the year 2100 using the year 2100's generation values. We use a 150-year period to calculate reserves for inexhaustible resources that are energy flows rather than stocks, corresponding to the seven-generation sustainability concept.

Each of the solar technologies adds a significant amount of reserves to the portfolio compared to many of the traditional energy resources; hence we include each independently in Figure 4-7. In total there are 3.9 million terawatt-hours provided by the combined set of technologies over the 150-year period considered for the reserve base of

[91] Arvizu, et al. (2011).

renewables[92][93]. These solar reserves could be especially important if the United States, for policy reasons, puts more emphasis on non-fossil resources. Seen from this perspective, developing solar resources not only has a direct effect on employment and economic growth in this country, it also can play an important role in supporting economic growth in other sectors that are dependent on reliable electricity supplies.

4.6 Solar Power, Peak Demand, and Merit Order Effects

The merit order effect is the benefit generated by low marginal cost renewable energy. In a merit order (or economic dispatch) approach to electricity generation, producing units are ordered by marginal production cost, from lowest to highest.[94] This generates a supply or dispatch curve, as shown in Figure 4-8. As demand increases during the day, the generation moves along the dispatch curve, with greater production cost occurring at peak demand. The addition of low marginal cost renewables to the front of the dispatch curve shifts the curve out providing cheaper peak rates. Given the low marginal cost of solar energy as an input into the power production process, solar power plants that are feeding into the grid

[92] Perez and Perez (2009) provides a world-wide estimate of 23,000 TWH per year, giving around 3.5 million TWH for 150 years, based on an estimate of solar radiation.
[93] Harvey (2010) calculates that the western deserts of the United States could generate 127,000 TWH per year. This provides 19.11 million TWH for a 150-year period. This estimate is based on assuming an average daily efficiency of 14% from available solar radiation.
[94] Philibert (2011).

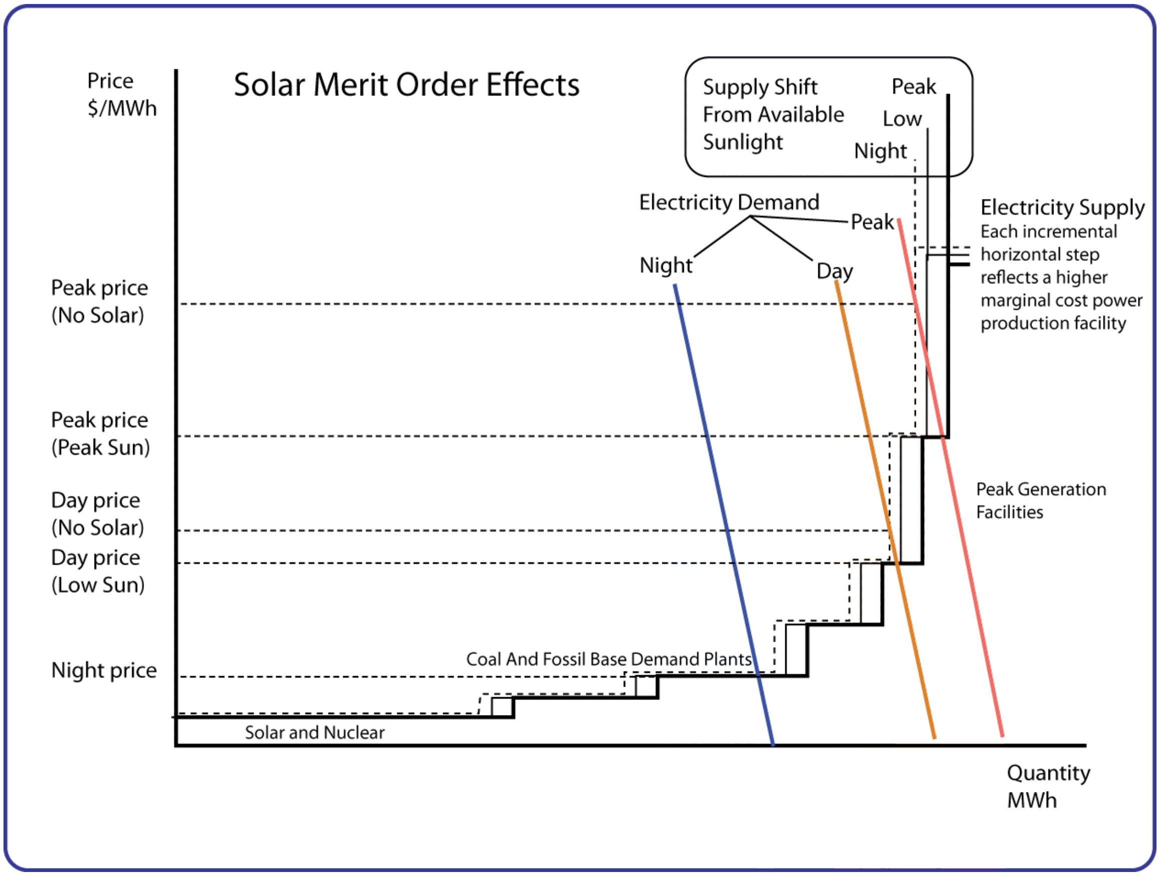


Figure 4-8. Solar Merit Order Effects

can have a significant impact on the marginal price of electricity production at peak demand by reducing the requirement to bring high marginal cost producers on-line.

Renewable energy resources including solar and wind have low operation and maintenance costs relative to power plants that require fossil fuels for electricity production. Renewable energy supplies are typically freely available whereas fossil fuels must be purchased and consumed to produce electricity. Additional costs, such as carbon costs, associated with the use of fossil fuels to generate electricity to satisfy peak demand requirements may also be assessed. The merit order effect takes into account the low marginal cost of production per MWh for renewable resources and their capability to offset and reduce the usage of generating capacity with significantly higher costs of operation.

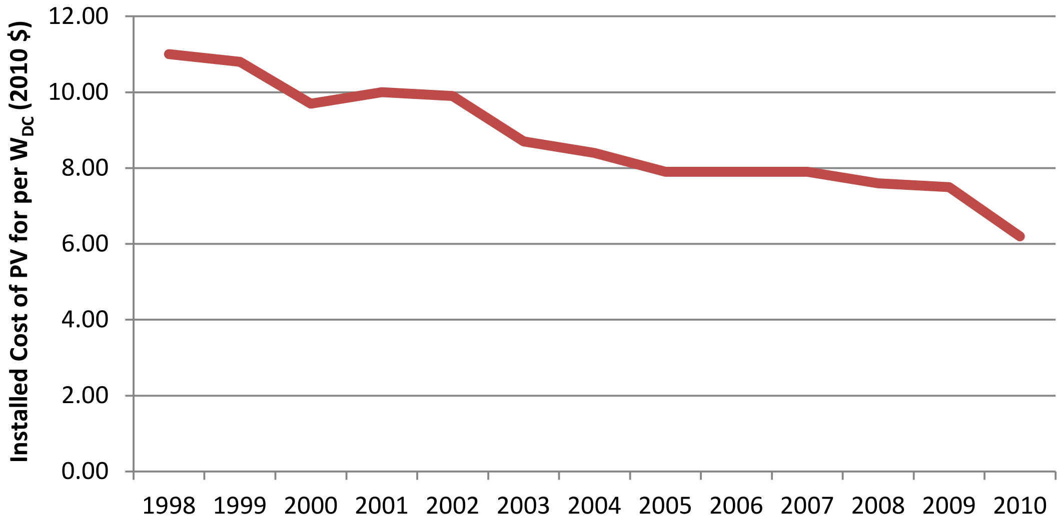
The merit order effect can be seen in the graphic as the supply curve is pushed out from the night curve above, to the average curve reflecting non-peak solar radiation, to the peak supply curve where the highest rates of insolation are available. In the supply curve, the shift resulting from night to peak derived supply curves will reflect the total MWh of generating capacity associated with solar electricity production. Therefore, as the number of MWh produced increases based on increased solar insolation, the average and peak supply curves will diverge further to the right from the night supply curve, essentially increasing the merit order effect.

Electricity demand is generally held to be independent of shifts in supply relating to the merit order effect. Additionally, the price elasticity of demand is generally inelastic in the short term, resulting in a steep demand curve; thus, large changes in electricity price will have small effects on demand. Therefore, an outward shift in supply resulting from the introduction of lower marginal cost solar-derived electricity will reduce the need for higher marginal cost electricity supplies. This means reduced need to operate existing, and build new, high-operating cost, peaker plants.

One advantage of solar energy is that there is a close correlation between electricity demand and peak power demand. One example of this close correlation relates to space cooling requirements: air conditioning demand in the summer drives peak electrical demand to some of the highest levels. This is both a consequence of thermal energy generated by the sun, and a benefit derived from the increased availability of solar energy. Energy demand is also highest during the day as people in general are more active and exploit energy resources at a greater rate during the day. Therefore, both supply and demand will shift in the same direction as indicated in the graph above.

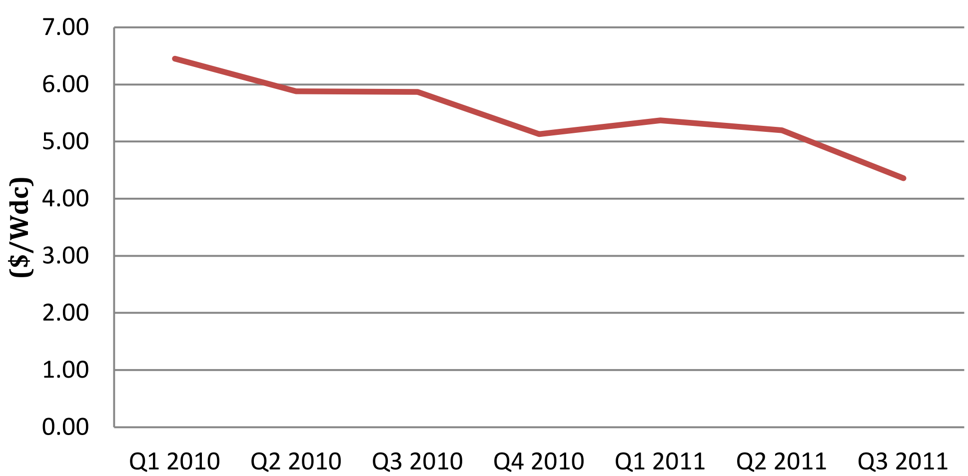
Some seasonal effect may be observed as well as the rightward supply shift will increase during the summer when there is greater insolation, and decrease during the winter when less solar energy is available. Demand may also shift left during these periods based on the reduced amount of electricity required for space cooling activities, though there may be some offset for other demand requirements such as heating or lighting.

The merit order effect does not address capital costs associated with electricity generation. While capital costs are currently relatively high in developing solar electric generation capacity, they have been falling rapidly, and it is expected that these costs will continue to be reduced as the technology matures (Figure 4-9 and 4-10). Similar efficiency gains can be seen throughout this study as generating capacity for other energy resources such as coal and natural gas have been developed. Solar technologies and facilities are still in a relatively early stage of development, and it is anticipated that further significant advances in both technology and economies of scale will be realized as have been for fossil and other electrical power generating technologies.



Source: Barbose et al. (2011).
Note: Costs are capacity weighted average costs.

Figure 4-9. Declining Cost of PV Installations, 1998-2010



Source: SEIA/GTM, 2011, U.S. Solar Market Insight Report Q3 2011: Full Report.

Figure 4-10. Recent Quarterly Blended Average Installation Costs of PV in the U.S., 2010-2011

Several studies have been completed on the benefits of the merit order effect in the context of renewable energy portfolios. These studies include both solar and wind generation and the effects of the deployment of these portfolios. Specifically, a decrease in peak prices, due to the reduction of new electricity supply from high marginal cost supplies. An example is a study and literature review by Frank Sensfuß et.al that reviews the merit order effect in the German market and concludes that, in 2006, price reductions from the widespread deployment of renewable resources may account for approximately 3-5 billion Euros through the reduction of high marginal cost peak production electricity, offsetting the cost for renewable support that is paid by consumers.[95] When reviewing the merit order effects of solar energy relative to all renewable resources, consideration must be made for the diurnal and seasonal constraints that are associated with the use of solar energy relative to other renewable resources such as wind. Wind energy is more closely associated with geographical and climate drivers. Solar power requires sunlight, and therefore is most efficiently exploited during the day. However, advances are quickly being made in the storage of thermal capacity in CSP facilities to allow for generation to continue far into the evening. Existing facilities in Spain and one under construction in the U.S. include storage capacity.

[95] Sensfuß, Ragwitz, and Genoese (2007).

Chapter 5. Conclusions

Energy is central to the U.S. economy and, as such, the federal government has a strong interest in maintaining stable, secure and affordable energy markets. Federal engagement in the sector has historically been focused on policies designed to maintain competition, provide for national security, and promote economic development. More recent federal policy has placed some emphasis on energy security.

Experience from other fuel sources and non-fuels industries in the United States shows diffusion of solar energy technology in the energy markets is consistent with the less-than-smooth paths that many American industries have traveled. Experience also shows that stable, long-term programs that reduce risk, level costs in such a way that private markets see long-term opportunity, or provide stable future markets have contributed to fuels' successful leap across the chasm between early adoption and full market penetration. Historically, each energy resource has approximately a thirty year period of innovation and early adoption before leaping to full market adoption. Since various estimates consistently show that the federal government currently incentivizes every major energy production market, incentive programs directed at solar power allow it to compete on par in the other incentivized fuels. From an economic development perspective, a portfolio of federal incentives weighted toward mature energy resources will tend to maintain those resources and suppress new industries.

A maturing solar power industry can provide employment benefits and global market opportunities. Depending on the growth rate, we estimate the solar industry will provide between 240,000 to 965,000 direct, indirect, and induced jobs by 2030, taking into account the productivity improvements that will occur over time. The export potential for U.S. solar manufacturing and materials provides potential benefit to the economy, as would the additional 67,700 direct, indirect and induced jobs that would be added to the existing solar industry employment by 2030 if the U.S. maintains its share of the solar market.

Solar power is a substantial resource to provide baseline power and to meet peak power demand at minimal marginal cost. Reserves of solar energy tapped using CSP and PV with compressed air storage could provide 3.9 million terawatt hours to the U.S. energy portfolio over a 150 year time period. This amount is larger than that estimated for all other traditional energy reserves combined. The "merit order" effect of electric power dispatch, where generating facilities are dispatched based on their marginal cost of production, results in solar plants being dispatched first. This has the impact of shifting supply and demand curves in ways that tend to result in electricity price reductions for peak power periods, a significant benefit for all electricity consumers.

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APPENDIX

PROCEDURES TO DEVELOP LABOR-PRODUCTIVITY-ADJUSTED EMPLOYMENT PROJECTIONS

The goal of this activity was to develop a consistent set of scenario projections that include the effects of increased labor productivity and provide a perspective of the potential employment that could be generated by a dynamic solar industry. The basic approach uses projected annual installations and adds each additional year's capacity to the current cumulative base. This produces two data series—annual investments and capital stock—to which we apply appropriate employment multipliers in order to obtain the employment generated by manufacturing and installation of the new capacity and the operations and maintenance of the growing stock.

Several scenarios of dynamic growth of the solar industry were obtained from recent studies. To characterize the scenarios we use the annual growth rate required to meet the study's projection of capacity in 2030. Of interest is also the growth path of installations. If one simply used the growth rate to generate the installation series, one would have relatively small levels in the near term and exponentially growing installations in the later years. In a new industry, as discussed early in the paper, one expects annual sales that become increasing larger in the early years and then taper off as the industry matures, generating an S-curve pattern of growth of annual sales. A procedure was developed to force an S shape to the sales growth and yet target the end capacity. The approach was used on all the scenarios considered.

Two projected growth rates for the U.S. economy are used as a reference for solar growth scenarios, assuming the solar industry only grows as fast as the economy. Recent estimate of GNP trends from Global Insights is 2.7% per year.[96] A higher figure of 4.7% was used by the Congressional Budget Office in reviewing the 2011 Budget Proposal.[97]

The Department of Energy's Energy Information Administration (EIA) makes an annual projection in its Annual Energy Outlook.[98] EIA runs a wide variety of solar capacity growth scenarios ranging from 5.6% in its reference case to 9.1 % in its more aggressive "No Sunset" case. Roger Bezdek and the University of California's Renewable and Appropriate Energy Lab (RAEL) provide more expansive scenarios for renewables and solar. [99] Bezdek

[96] IHS (2012).
[97] Congressional Budget Office (2010).
[98] U.S. EIA (2011).
[99] Bezdek (2007).

provides several scenarios for renewables and energy efficiency, including a base case, a moderate case, and an aggressive case with 4.8%, 8.7%, and 12.9% annual growth, respectively. The report only presents projections for renewables revenues as a whole. We use this renewable rate for our solar industry growth rate. This assumes that solar will maintain its current share of the renewable portfolio, although it is more likely that solar will have an increasing share. Thus, the Bezdek projections may understate the growth of solar capacity relative to his overall scenario growth.

The University of California Berkeley's Renewable and Appropriate Energy Laboratory (RAEL) has synthesized 15 job studies[100] and incorporated the information into its Green Jobs Calculator.[101] The study uses a 15.3% growth rate as a reference for their projections. The Intergovernmental Panel on Climate Change has the most robust projection of 30% for U.S. solar power.[102] While this projection seems optimistic, we do use rates of 20% and 25% as upper levels given the recent growth of the industry in the U.S. These scenarios provide us a wide range to explore the potential employment that could be generated by growth in solar industry.

Once the scenario projections of capacity and annual installations are generated, it is a simple matter to apply the appropriate multipliers to generate each scenario's employment estimates. The difficulty is that labor productivity employment multipliers to capture gains in productivity over time are not readily available. Consequently, we developed productivity multipliers for this study. Employment multipliers and labor productivity changes can be different by technology—PV, CSP and thermal—and sector—manufacturing, installation, and operations/maintenance. In order to do this, a consistent and current data set of industry employment, production (i.e. installations), and current capital stock (i.e., cumulative installations) for each technology of interest is required. Since no current study or report seemed to present such a consistent set of data, again we determined a need to construct one.

To develop the base employment estimates, we first developed a profile of expenditures for material (manufactured goods) and labor (installation) for the development of a typical installation in each technology. Expenditure patterns for each technology were available from a recent study.[103] The report presented total costs and cost spent in the U.S. as "Total value created in the U.S." For our procedure we used domestic cost and domestic installations to focus on domestic employment and net out impacts of export and imports. Value of U.S. exports for PV and thermal are also presented in the study. The expenditures on domestic installations and the export earnings are both considered in the determination of employment patterns.

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[100] Wei, Patadia, and Kammen (2010).
[101] Wei, Patadia, and Kammen (2011).
[102] IPCC (2011).
[103] GTM (2011).

SEIA information from the 2010 Solar Market Insight[104] on cumulative capacity and installations for each technology (see Table A1) were used to escalate the expenditures for typical units to annual total installation expenditures for each technology.

Table A1. Base Capacity and Annual Production Estimates			
	PV	CSP	Thermal
	100 MW	100 MW	Million Square Feet
Cumulative Capacity 2010	20.953	5.153	12.7
Installations in 2010	8.78	0.7757	2.426
Source: SEIA (2011).			

The total annual expenditures were then used to allocate industry total employment derived from the Solar Census.[105] For the purpose of this study, it is assumed that the Solar Census captures both the direct and indirect employment. The distribution between direct and indirect employment to the Solar Census was derived using indirect multipliers available in the literature. Induced multipliers were available as well. A baseline estimate of solar industry employment in 2010 by technology (PVC, CSP, Thermal) by sector (Manufacturing, Installations, and Operations and Maintenance) for employment category (direct, indirect, and induced employment) were then developed and depicted (Table A2).

Navigant[106] used and reported indirect and induced multipliers developed by S. Grover using the NRL JEDI model.[107] The JEDI economic multipliers are calculated using IMPLAN regional economic modeling software. The employment multipliers (i.e., the ratio of indirect to direct and induced to direct) were reported separately for Manufacturing, Construction and Operations & Maintenance (O&M) for the three technologies. The ratios are used to generate the employment distributions in the Table A2 and the per-capacity multipliers presented in Table A3.

[104] SEIA (2011).
[105] The Solar Foundation (2011).
[106] Navigant (2008).
[107] Grover (2007).

Table A2 Solar Industry Employment Profile in 2010					
		Jobs			
		PV	CSP	Thermal	Totals
Manufacturing	Direct	1,922	386	159	2,538
	Indirect	2,789	158	223	3,170
	Induced	4,184	282	334	4,800
Installation and Distribution	Direct	21,010	1,825	1,117	23,952
	Indirect	29,414	748	1,564	31,726
	Induced	44,121	1,332	2,346	47,799
Operations	Direct	5,464	1,836	815	8,116
	Indirect	2,732	1,653	408	4,792
	Induced	4,371	551	652	5,574
Manufacturing Exports	Direct	7,388	0	615	8,003
	Indirect	10,343	0	862	11,204
	Induced	15,515	0	1,292	16,807
Total		149,326	8,771	10,385	168,402
Total Direct and Indirect		81,134	6,606	5,762	93,502
Solar Census					93,502
Scale Parameter to adjust to Expenditures into Jobs based on Solar Census					4.502
Source: Howard H. Baker Jr. Center for Public Policy compilation from various sources					

Friedman,[108] citing New Energy Finance (2009), provides jobs per MW for 2008 and 2025 by component activity from which we developed operation, manufacturing, and installation labor productivity growth rates. He assumes no change in unit labor cost for O&M activities. EPRI has recently reviewed best practices and the comparative benefits of using in-house or out-source staff in dealing with O&M of PV.[109] It seems reasonable to assume that there will be some learning-by-doing improvements, so we allow for a small increase in labor productivity.

108 Friedman (2009).

109 Electric Power Research Institute (EPRI) (2010).

Table A3. Employment Scenario Projection Parameters				
		PV	CSP	Thermal
Base Year Employment Multipliers				
		Jobs/100 MW	Jobs/100 MW	Jobs/million square feet
Manufacturing	Direct	224.63	498.17	65.52
	Indirect	314.48	204.25	91.73
	Induced	471.72	363.67	137.60
Installation	Direct	2,368.67	2,352.11	356.33
	Indirect	3,316.36	964.36	644.68
	Induced	4,974.21	1,717.04	967.01
Operations	Direct	260.78	356.33	64.05
	Indirect	130.39	320.73	32.03
	Induced	208.63	106.90	51.24
Base Capacity Estimates				
		100 MW	100 MW	Million Square Feet
Cumulative Capacity 2010		20.953	5.153	12.7
Installations in 2010		8.78	0.7757	2.426
Labor Productivity Annual Adjustment Factor				
Manufacturing		0.946	0.946	0.946
Installation and Distribution		0.957	0.957	0.957
Operations		0.995	0.995	0.995
Source: University of Tennessee Howard H. Baker Jr. Center for Public Policy				

To implement the labor productivity estimates, we used productivity adjustment factors that indicate the percent of labor in a prior year that is still required in the following year. These can be multiplied directly times the employment multiplier to get a labor productivity adjusted multiplier that is used in the projections. The key parameters for the projections are shown in Table A3. The projections are made for each year, scenario, technology, sector, and employment category. A summary by scenario is presented in Table A4 and graphed in Figure A1. The distribution of sector employment over time for the 20% scenario is presented in Figure A2. The employment presented in Table A4 and the accompanying figures are for employment associated with domestic installations and does not include employment driven by exports which are handled separately.

Table A5. Scenario Projections of Solar Employment - Direct, Indirect and Induced by Year (Thousands Jobs)									
Growth Rate by Scenario									
		26.0%	20.0%	15.3%	12.9%	9.1%	8.7%	4.8%	2.7%
Year	Solar Census	SunShot	20% growth	Green Jobs Caculator	Bezdek Advanced	EIA No Sunset	Bezdek Moderate	Bezdek Base	Projected GNP
Employment Projections by Scenario									
2010	135								
2011	144								
2012	178		178	178	178	178	178	178	178
2013		196	195	186	183	182	182	181	180
2014		215	217	197	188	186	186	184	183
2015		236	243	209	194	191	190	187	185
2016		260	273	222	201	196	195	190	188
2017		285	307	238	208	202	201	194	191
2018		313	344	255	217	209	207	198	194
2019		344	386	274	226	215	213	202	197
2020		378	431	295	236	223	220	206	201
2021		415	480	317	246	231	227	211	204
2022		456	527	338	257	239	235	216	208
2023		500	571	358	267	246	242	220	212
2024		550	613	378	277	254	248	225	215
2025		604	653	397	287	261	255	230	219
2026		663	691	415	297	268	262	234	223
2027		728	727	433	306	275	268	239	227
2028		800	762	450	316	282	275	244	231
2029		878	795	466	325	289	281	249	236
2030		965	826	482	334	295	287	254	240

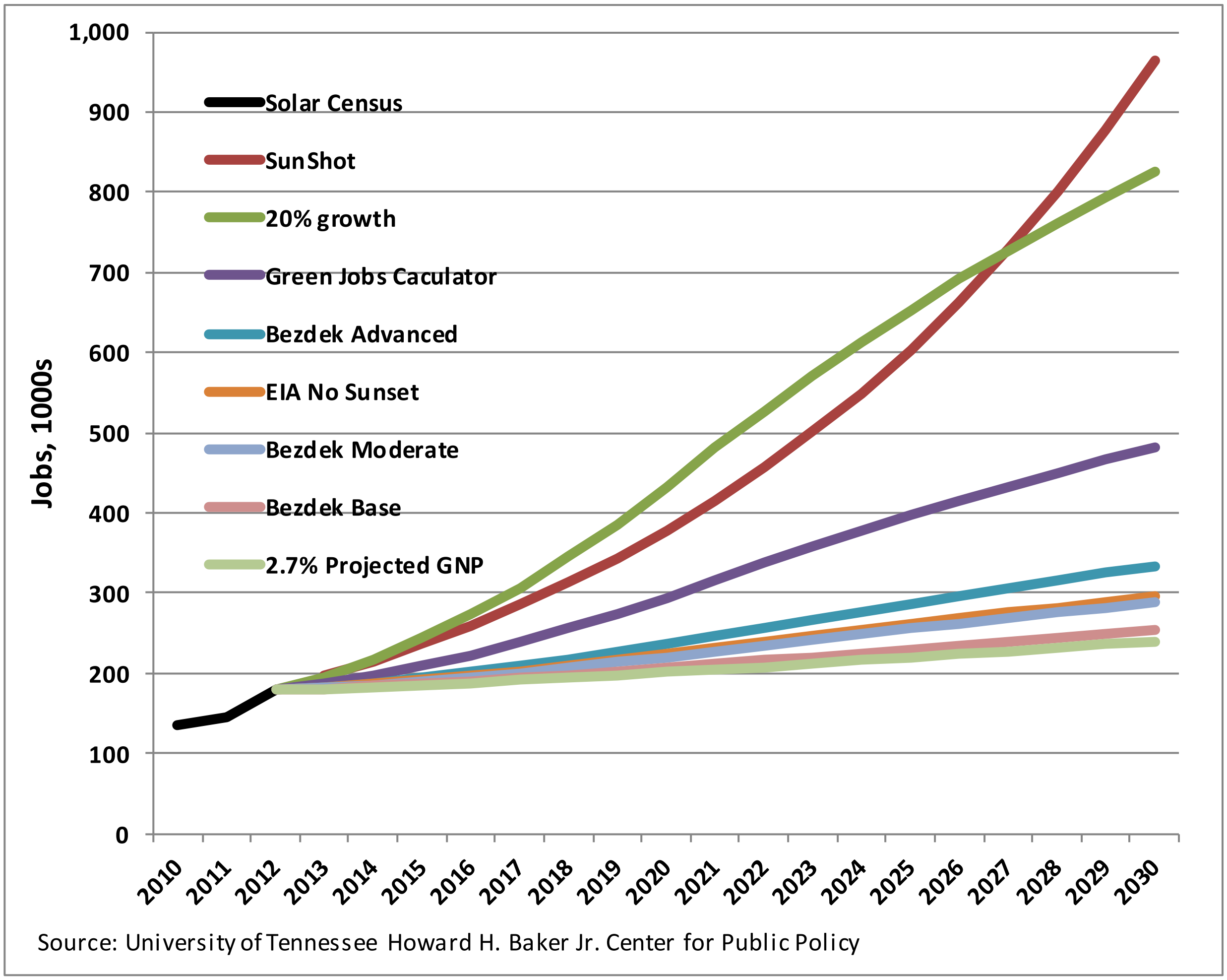
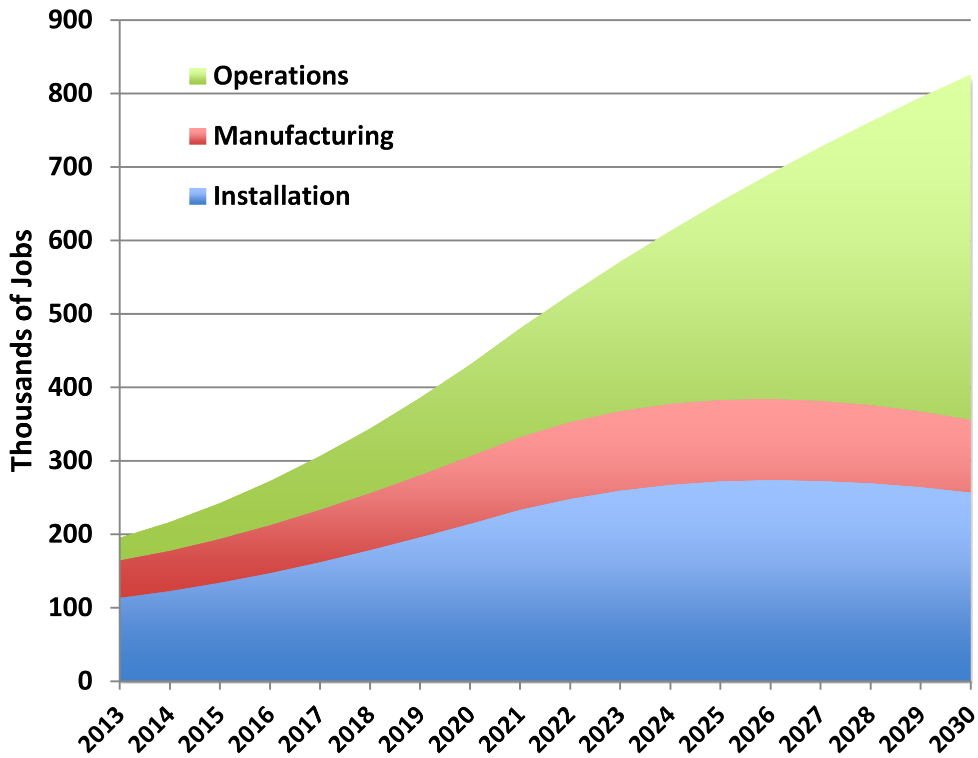


Figure A1. Employment Growth under Various U.S. Solar Growth Scenarios
Direct, Indirect and Induced



Source: University of Tennessee Howard H. Baker Jr. Center for Public Policy estimates

Figure A2. Distribution of Employment Related to Domestic Growth in the Solar Industry, 2013-2030, with 20.0% Growth in Solar Capacity