Forecasting the Future of Alternative Energy Technologies Using Economic Payback Curves

Gary A. Nowakowski and Michael P. Hahn

ABSTRACT

Calculating a payback period for new or improved energy technologies is a simple economic function. However, the very nature of its simplicity tends to mask underlying dynamic characteristics that provide valuable insight into the interpretation of its results. Use of graphics to illustrate the payback function provides an expanded perspective on payback and its sensitivity to energy rates, product cost/pricing and efficiency/technology improvements. This article describes the use of payback curves and provides examples of how these curves can be utilized to gain an understanding of the natural evolution of both high-efficiency products and renewable energy products; provide an indication on the sensitivity of product economics to energy prices, product cost, and efficiency improvements; and ultimately forecasts the future market prospects for new or improved technologies and products based on economic merit.

Keywords: Alternative energy technologies, economic merit, forecasting, payback

INTRODUCTION

Payback period is a widely used economic criterion for evaluating investment alternatives, including energy efficiency and renewable energy technologies and products. Payback period for energy technologies is the length of time that elapses before the net operating savings from a project investment, or between alternative investments, accrue to equal the project's first cost, or first cost differential between alternatives. When comparing projects, the payback period provides an indication of investment risk—how long it will take for one project to recover, in net annual

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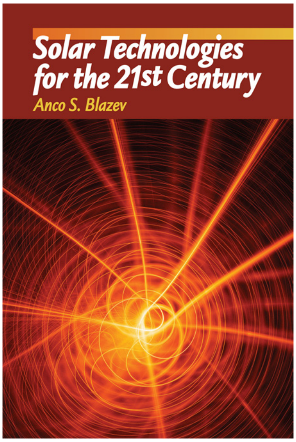

A detailed and insightful examination of both current and emerging solar technologies, this book evaluates both the practical and technological potential of each. The reader gets a clearer understanding of the logistics of deploying solar energy as a viable and sustainable way to solve urgent energy, environmental, and socioeconomic problems. Discussed in detail are solar power generation, solar thermal, silicon PV, thin PV, 3D solar cells, nano PV, organic solar cells and more. Among the many topics examined are solar successes and failures, solar markets, and solar energy's environmental impact. The book serves as both a guidebook for beginners as well as an outline for the debates on solar power technologies.

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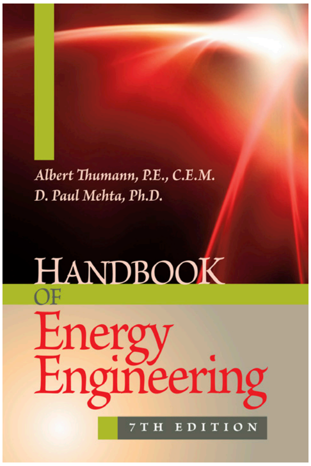

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savings, its first cost premium over another project. Simple payback period does not account for the time value of money. Even with this shortcoming, it is widely used to screen project investments because it is simple and straightforward to calculate, yet offers a good first approximation of a project's economic merit. Discounted payback takes into consideration the time value of money by discounting future cash flows and is utilized in this article to evaluate the economics of various energy technologies.

The discounted payback period function can be expressed as the first cost difference between two projects divided by the net annual savings between the two projects. A discount factor is applied to annual cash flows. It can be written as equation 1.

$$PP = \sum_{1\text{-}n} [FCP_n (1+DR)^n / NAS_n] \quad (1)$$

Where PP is the payback period in years, FCP is the first cost premium in USD, and NAS is the net annual savings in USD per year. A 7% discount rate, DR, typical for power generation companies and utilities, was utilized in this study. In addition a 2.5% inflation factor was assumed and applied to cash flows.

Economic merit is the ratio of additional energy that could be saved or generated per incremental cost through efficiency improvements or innovation/cost reductions. When discounted payback period is plotted against the economic merit of a technology, a set of curves can be generated which illustrate the dynamics of payback as affected by changing fuel prices, product prices and technology efficiency improvements. Comparing payback periods between successive generations of products and technologies and tracking this information graphically can be utilized to reveal critical insight into the below three areas which will be discussed further in this article:

- an understanding of the natural evolution of high-efficiency products and products that use renewable energy fuel sources;
- an indication of the sensitivity of product economics to energy prices, product prices and efficiency improvements; and
- an identification and forecasting of where additional RD&D investments in renewable energy and energy efficiency should be targeted.

The economics represented in this article are based on average U.S. energy prices. It should be noted that while the average residential electric rate is approximately 11 cents per kW-hr, there are many highly populated areas where the electric rates are 50% higher such as California, New York, New Jersey, and New England. Residential electric rates are also high in many other countries exceeding 20 cents per kW-hr in the U.K., Italy, Spain, Ireland, Japan, Portugal, Denmark and El Salvador. These higher energy rates act as a significant industry incentive for the advancement of energy efficient and renewable energy technologies.

DYNAMIC CHARACTERISTICS

Both simple and discounted payback are hyperbolic functions in which the payback period monotonically increases with the first cost premium and decreases with net annual savings. For illustration purposes, simple payback, as a function of annual savings and first cost premium, is plotted in Figure 1. The remainder of this analysis uses discounted payback which accounts for the time value of money. Several salient observations can be drawn from the graph. The gradient at long payback periods is extremely steep, so we have coined the term slippery slope for this region. At long payback periods, a slight decrease in the first cost premium or slight increase in net annual savings will dramatically shorten the payback period. At short payback periods, the payback period function is very flat, hence the region flat lands. To get any reduction in the payback period, large decreases in first cost or increases in annual savings are necessary.

Understanding where the payback period between two product generations, or two competing technologies, fall on the payback curves (on the steep curve or on the shallow part of the curve) provides an indication of the potential for improved economic merit due to continued R&D, increased manufacturing volume production or increasing energy prices. The dynamics can be very different depending on whether the analysis involves an energy efficient product versus an evolving renewable energy product. As an example, an energy efficient product with a short payback period has the opportunity to be enhanced and provide greater energy savings and still fall within an acceptable payback period, albeit a longer one, to the marketplace. Natural gas furnaces have evolved following this product development path resulting in successive generations of more efficient products. Conversely, a renewable energy technology such as solar photovoltaics with a long payback period falling on the steep part of the

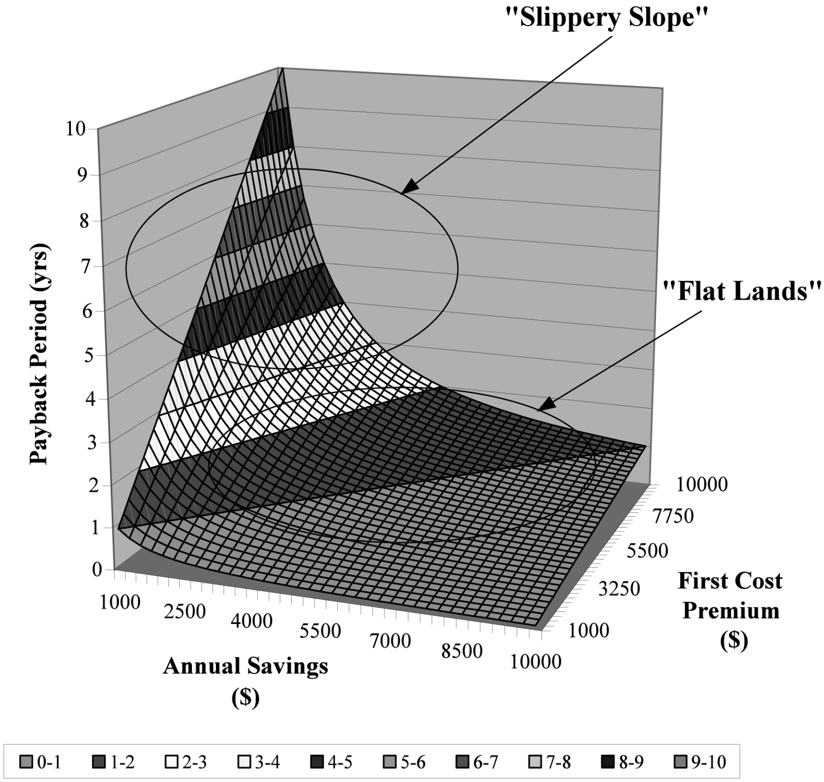

Figure 1. Payback Function

payback curve will have a high sensitivity to payback factors and vastly improved economics can be achieved with relatively small increases in retail electricity prices and product cost reductions resulting from increased volume production and technology development.

ECONOMIC MERIT

The economic merit factor (R), for energy technologies, represents the amount of additional energy that could be saved, or generated, on an annual basis through product advancements. It indicates how much more energy (in MMBtu) can be squeezed out of a product efficiency improvement for an incremental increase in product price; or for power generation technologies, how much additional energy can be produced through product advancements.

Discounted payback period, when plotted versus economic merit, (shown in Figure 2), can be used to evaluate the attractiveness of energy technology products. It is a function of prevailing energy prices, product price premium and annual energy savings.

EFFICIENT PRODUCT EVOLUTION

Products such as furnaces, insulation, air conditioners, windows and heat pumps have evolved since their introduction in the marketplace to high efficiency levels. When these products were initially introduced, the first efficiency improvements resulted in high R-values, which indicated that there was additional room for original equipment manufacturers to increase the product's cost in order to achieve higher efficiencies.

As products improve in efficiency, the R-value declines. This results in less favorable economics, i.e. longer payback periods. As products become more efficient, the law of diminishing returns makes it more difficult to achieve economical efficiency gains. In other words, efficiency gains become more expensive to achieve. For example, there is decreasing logarithmic annual energy savings associated with incrementally increasing the amount of insulation, or its thermal resistance, in the attic of a residence, as plotted in Figure 3. Continuing to increase the insulation thickness results in diminishing energy saving returns for each successive dollar invested. So, for products demonstrating high R-values and short payback periods, original equipment manufacturers, OEMs, often develop a range of advanced products and offer product lines consisting of good, better and best products representing a range of product efficiencies.

The "best" product may be the most efficient, but will not necessarily have the best economic return and the shortest payback period. Nonetheless, demand exists in the marketplace for these "best" products as long as the payback period is within an acceptable range, generally five years or less.

RENEWABLE ENERGY PRODUCT EVOLUTION

Unlike products that move from high R-values to lower R-values as they evolve through successive generations of efficiency improvements, renewable energy technologies such as photovoltaic and wind turbines

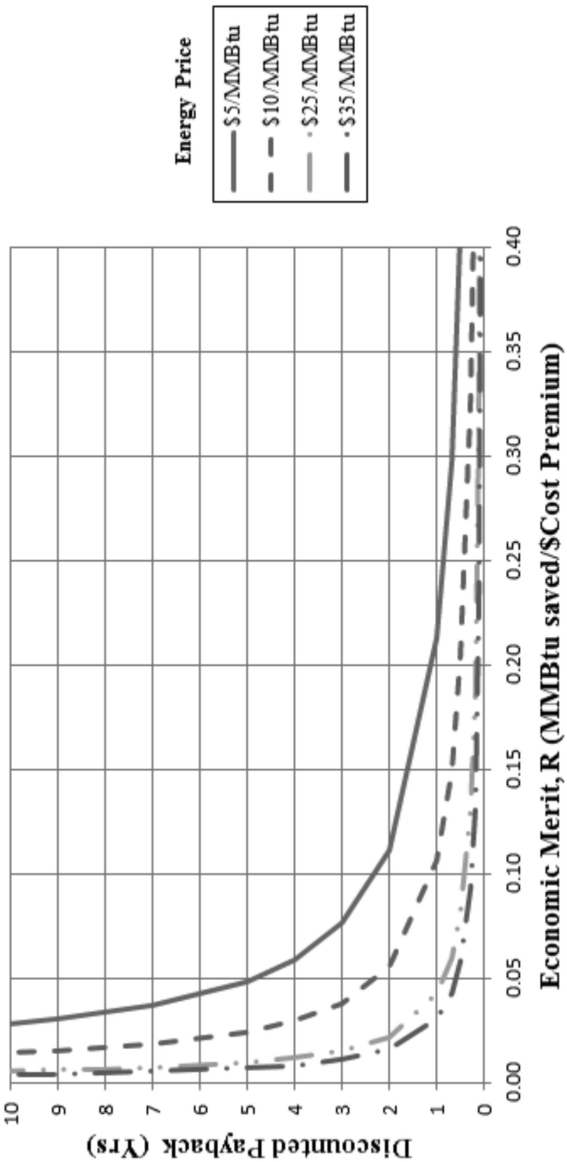

Figure 2. Discounted Payback Period versus Economic Merit

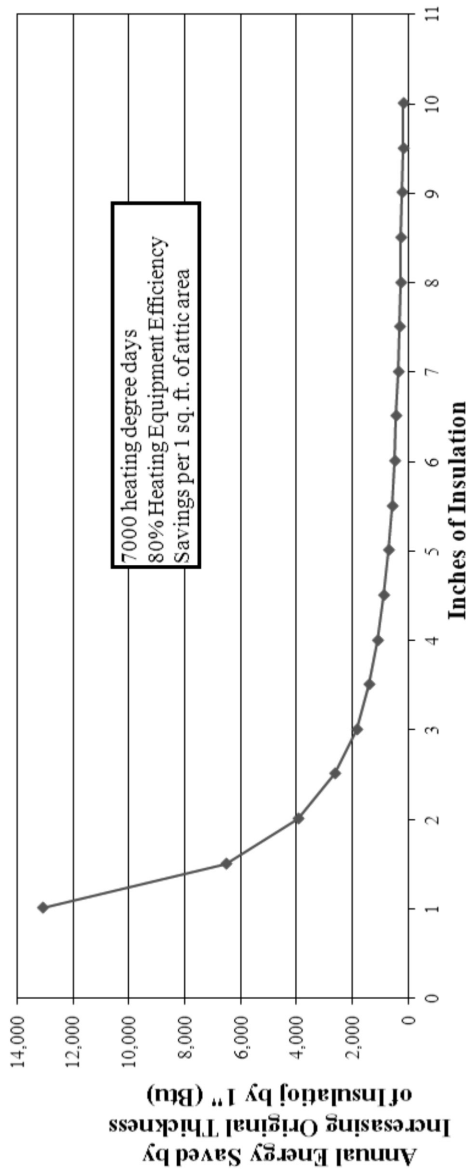

Figure 3. Law of Diminishing Annual Energy Saving Returns Through Added Insulation

were introduced into the market with long payback periods and low R-values. The promise with these low R-value devices is that the payback period can improve significantly through increased volume production, technological improvements or an increase in prevailing energy prices. Initial production of these products is usually limited so that unit manufacturing costs are high, which means a higher installed price. However, as production volumes increase, manufacturing costs decrease and prices can be reduced. In addition, the technological implementation of a device simply gets better with successive generations resulting in increases in power generation efficiency. The incentive exists to improve these products. For example, advancements in wind turbine technology (Figure 4) since the early 1980s have resulted in improved operating economics due to increased reliability (from 60% to 98% availability), lower operating and maintenance costs (from 3¢ per kilowatt hour to 1¢ per kilowatt hour), and reduced installed costs (from $4000 per installed kilowatt to $2100 per installed kilowatt) (Wiser and Bolinger, 2012).

Wind turbines have benefited from tremendous economies of product scale. As the size of individual turbines has progressively increased over the last decade, economies of scale have resulted in the cost-per-watt of generated power trending lower. Technological design and material advances were required to achieve the reliable design and operation of larger and more sophisticated components such as state of the art blades. Since the early 1980's, productivity of turbines, as measured by annual generation per unit area swept by the rotor blades, rose from approximately 500 kWh/year per square meter to 1000 kWh/year per square meter (Class IV Winds). These turbine development efforts increased the power production efficiency and reduced the manufacturing cost needed to generate electricity. Hence, as shown in Table 1, between the 1980's and 2011, the R-value increased from roughly 0.004 to 0.015 and wind turbines became more economically competitive with traditional natural gas power plants. Between 2001 and 2004, discounted payback periods for wind turbine installations were even lower (6 to 8 years) than today as a result of more favorable metal commodity prices and reduced turbine costs. While R&D efforts have resulted in dramatic improvements in the economic status of wind power generation over the last two decades, additional developmental efforts will be required for wind technology to be directly competitive with conventional power generation.

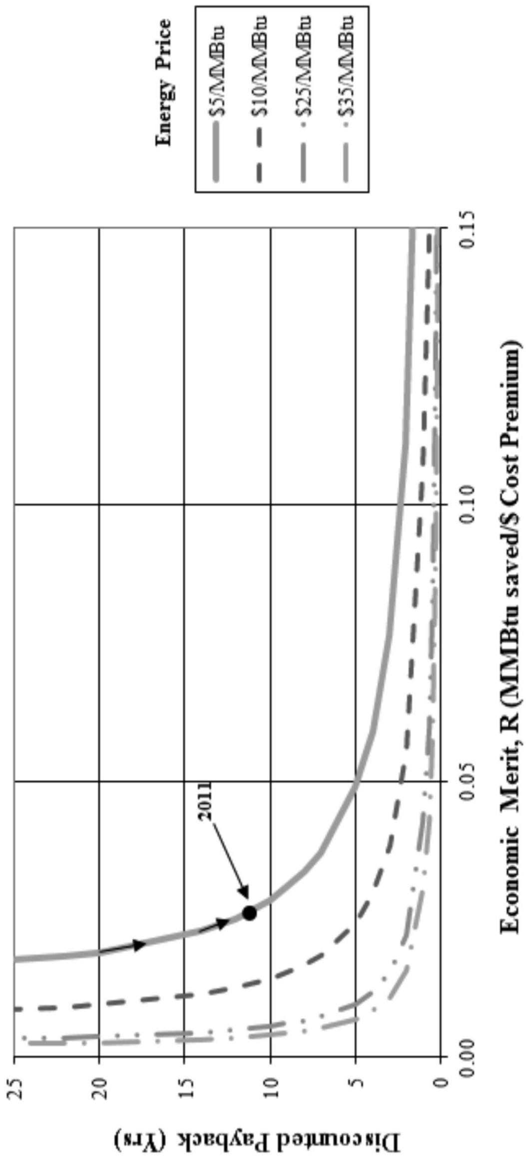

Figure 4. Wind Turbine Product Evolution

Table 1. Wind Turbine Payback Data (Wiser and Bolinger, 2012; "Electric Power Monthly October 2011," 2011)

	Wind Turbine (2011)	Wind Turbine (1980s)
Specific Yield, kWh/yr/m2	1000	500
Cost of Generator, $/MW	$2,100,000	$4,000,000
Power Generated, kW-hr/yr	3,284,000	1,642,000
Natural Gas energy equivalent, Mbtu	32,966	16,483
Natural Gas Savings, $/yr	$164,828	$82,414
Discounted Payback Period vs. Nat gas power plant, years	11.1	>100 years
R Value	0.023	0.005
Specific Yield, kWh/yr/m2	1000	500

Assumptions:
1) Class IV wind location,
2) Power plant efficiency, site to source = 34%
3) Fuel Price of $5/MMBtu
4) Generator Capacity is 1 MW
5) Natural Gas Power Plant Capital Cost = $665/MW

ANALYSIS OF RESULTS: ECONOMIC SENSITIVITY

Renewable energy products located on the steep part of the payback curve have the potential to show significantly improved economics with rising energy prices. Conversely, a decline in energy prices (Figure 5) can greatly diminish the attractiveness of an investment for a low R-value product. Economic volatility of products with long payback periods is high. The generally accepted minimum requirements for payback period range from three to five years and have been substantiated by market research. Customer acceptance drops to less than 10% for efficiency investments resulting in more than a five year payback period ("Cool Visions," January, 1999). Similar research has shown that the economic viability for CNG cars and refueling systems can be achieved if the payback period of the incremental cost is five years or less (Chu, 2012).

On the very steep part of the payback curves, technological advancements and innovation drive improved economics. Small increases in R-value through innovation and manufacturing cost reductions result in large decreases in payback period. Federal/State policies can create market push and help to establish initial growth in the marketplace. As an example, both the Federal Production Tax Credit (about $2.2c/kW-hr) and State Renewable Portfolio Standards (RPSs) have been key drivers behind the 30% growth in wind turbine installations over the past few years (Wiser and Bolinger, 2012; Berquist, 1998). Likewise, feed-in tariffs have played a critical part in the fast growth of renewable energy technologies in Europe. These policies have supported the rapid growth of wind and solar installations in the U.S. and Europe by contributing to higher volume production, lower costs and improved economics to the end users. Financial incentives such as these can often be sufficient to spur sales volumes of early entry products to levels necessary to realize lower manufacturing costs and prices. Once the economics are improved to a certain level through incentives, increased product demand in the marketplace and the resulting increased volume production needed to meet that demand can result in sustainable growth.

Products with short payback periods lie on the shallow part of the payback curves and their economics are less impacted by volatility in costs and energy prices.

CONCLUSIONS: FORECASTING ALTERNATIVE ENERGY TECHNOLOGIES

Economic merit varies greatly between energy-related products, as shown in Figure 6. The graph is useful for judging the efficiency improvement potential of a product and its sensitivity to energy rates and incremental changes in product price. Several examples of how these payback curves and an understanding of economic merit can be utilized to forecast market opportunities for future technology development are illustrated below. The examples include photovoltaic power generation and energy efficient products such as windows, lighting and thermostat control tech-

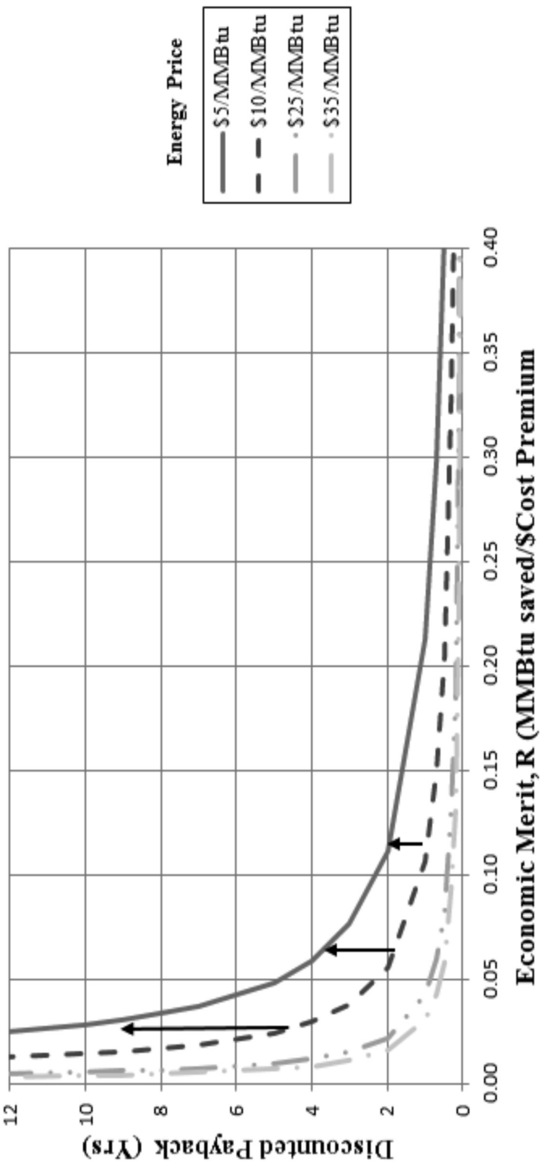

Figure 5. Decreasing Energy Prices

nologies. Finally, a brief assessment is provided with regards to the future U.S. prospects for high efficiency vehicle technologies.

Advanced Lighting Technology

Figure 6 clearly illustrates the current economic opportunity for advancing lighting technology beyond fluorescent bulbs. Since the payback period between incandescent and fluorescent lighting products is so short (Table 2), there is room to develop advanced technology at a higher cost than fluorescent lighting to pursue greater energy efficiency and savings, albeit at a longer payback period. LED lighting technology has the potential to fill this product gap.

Lighting technologies have made great gains with the advent of compact fluorescent light bulbs and recent innovations utilizing LED technology. As recently as early in 2012, the high retail price for LED lights made them largely uneconomical for everyday home and business applications though they had already entered niche flashlight, bike light, automobile, and high definition television markets. However, in the past year alone, LED bulb retail prices declined by approximately 50%; a 60 W equivalent bulb dropped in price from roughly $40 to $20. As volumes continue to grow and costs decline, retail prices are anticipated to decline to less than $10 for a 60 W equivalent bulb by 2015 (Brodrick, 2011).

The cost reductions for these solid state products will primarily come from reduced depreciation costs on capital equipment, lower labor and material costs and optimized manufacturing processes. Increased volume production resulting from Federal minimum lighting efficiency standards will also contribute toward reduced manufacturing costs. Assuming that retail prices decline significantly, the payback curves forecast that LEDs could fill a niche in the lighting market for a high efficiency product beyond that currently offered by CFLs. One environmental factor which could affect the purchasing of LEDs in lieu of CFLs in the future is the disposal of toxic Mercury contained in each bulb. The DOE is investing in research and development that will support LED manufacturing at reasonable costs. This investment will further push LEDs into the mainstream lighting market in the coming years.

Photovoltaics

Improvements in both efficiency and cost reductions have been significant for Photovoltaic (PV) solar panels over the past three decades. Crystalline silicone panels have increased from roughly 8% sunlight to

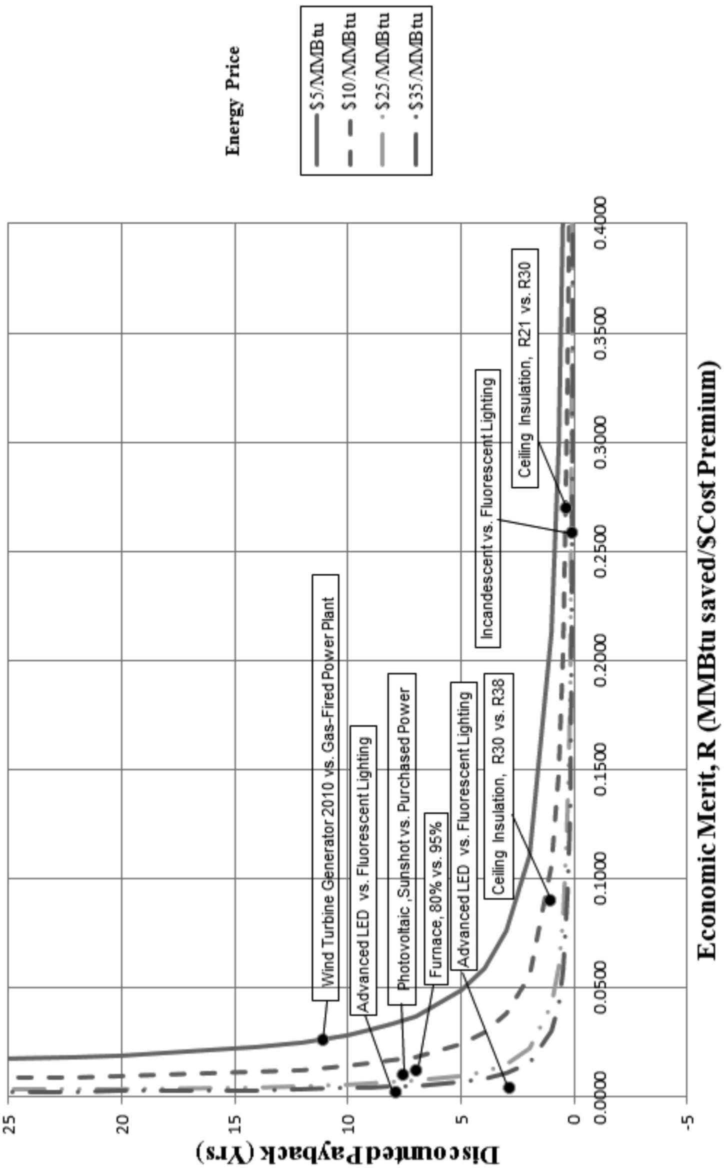

Figure 6. Examples of Product Evolution

Table 2. LED Payback Data ("Electric Power Monthly October 2011," 2011; Brodrick, 2011)

	60W Incandescent	13 Watt Fluorescent vs. Incandescent	3.6 Watt LED vs. Fluorescent (equiv 60 W output)	3.6 Watt LED vs. Fluorescent (equiv 60 W output) -- Future Estimate
Life of Bulb, hours	1000	8000	25000	25000
Unit Cost of Bulb, $	$0.32	$2.00	$20.00	$10.00
Kw-h used	65.7	14.24	3.94	3.94
Power Cost, $	7.22	1.57	0.43	0.43
Discounted Payback, years		0.15	7.9	2.9
R-Value, MMBtu/$		0.105	0.002	0.0044

Note: Table 2 values assume eleven cents per Kwh and 1095 operational hours for analysis.

electric conversion efficiency to more than 20%. Installed panel costs have dropped from an average of $12.00/Watt in 1998 to less than $4.00/Watt in 2012 for many commercial applications (Barbose, 2010). However, the current discounted payback period, when comparing PV panels versus purchased power, still remains high exceeding 20 years in most locations. See Table 3 regarding the payback analysis for the Denver area. Additional efficiency and cost reduction gains are needed to make PV competitive with purchased power. However, the long payback period for PV systems falls on the steep part of the curve, therefore portending to significant future opportunities for R&D investments. Modest re-

Table 3. PV Payback Data (" NREL PV Watts Calculator," 2011; Barbose, 2010)

Best Case Installed First Cost for Commercial PV, $/DC kW, 2012	2,500.00
Commercial Electric Rate, 2012, $/kW-hr	0.1056
Annual Power Generation per DC kW, kW-hr of AC power	1,453
Discounted Payback period between 2012 PV and purchased power, yrs	29.1
Discounted Payback Period between Sunshot Initiative and purchased power, yrs	7.6

Table 3 Assumptions: Crystalline PV Panels; Sanyo HIT-N235SE10 modules; Colorado location, 18.6% module efficiency; AC to DC Conversion Efficiency of 77%; Commercial installed price for greater than 100 kW installations.

ductions in manufacturing costs or increases in competing retail electric rates can have a significant impact on the technology's economic viability. In line with this opportunity, the Department of Energy's SunShot Initiative has set an ambitious goal to reduce the total installed cost of photovoltaic systems by about 75 percent and achieve an installed panel cost of $1/Watt so that PV is cost competitive with conventional forms of electricity, without subsidies, before the end of the decade ("U.S. Department of Energy: SunShot Initiative," 2011). The SunShot Initiative is projected to reduce the cost to generate power from PV to roughly 6 cents per kilowatt hour without subsidies ("SunShot Vision Study," 2012). This accomplishment would greatly support the increased adoption of solar electricity across the United States.

Advanced Thermostat Controls

As illustrated in Figure 7, the use of conventional programmable thermostat controls can result in very short paybacks of approximately 1-2 years depending on the type of thermostat selected. Given that market research has shown that consumers are willing to accept payback periods up to approximately five years, there is a distinct economic opportunity for advanced thermostats that offer the homeowner an optimized balance between comfort and efficient energy use. There is one company, NEST, which recognized this opportunity and recently introduced an innovative thermostat based on self-learning control software ("NEST, the Learning Thermostat," 2011). This premium priced (approximately $250 retail price) thermostat offers an aesthetically pleasing architecture combined with artificial intelligence which automatically programs the heating and cooling schedule based on user trends and occupancy. The elegance of this product is that it doesn't rely on the consumer to program a preferred temperature schedule. Many homeowners end up using the programmable thermostat as a mechanical switch without taking advantage of the programming function, thus negating potential savings.

Windows

Today, the norm for both new and replacement windows are double-glazed designs. Efficiency upgrades include double-glazed with argon gas and a low emittance ("e") coating and triple glazed with low "e." Double-glazed, clear windows offer an insulation value or R-value between 1.6 and 2.2; double glazed, low "e" windows offer an R-value between 2.4 and 3.1 and triple paned windows with low "e" can range

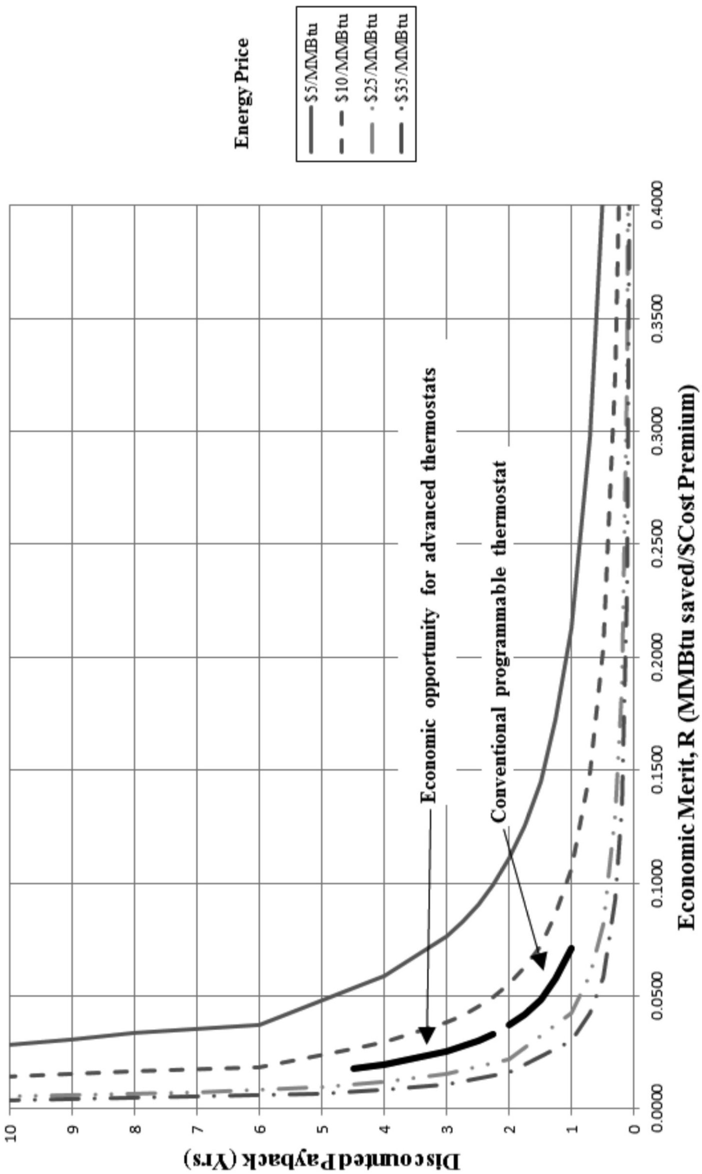

Figure 7. Economic Opportunity for Advanced Thermostat

from 3.7 to 5.0. As shown in Figure 8, these window insulation values compare to typical wall insulation which commonly ranges between R11 and R20.

Despite the lower insulation value for windows, on average, they only represent approximately 15% of a home's square footage and the economics for either new or replacement windows favor double-pane designs as the most effective option today and for the foreseeable future given current and projected heating fuel prices. While advanced triple pane, argon-filled windows have already been developed and are commercially available, from a strictly economic perspective, these products have "overshot" the mark for economic merit and have discounted payback periods exceeding 20 years in the majority of U.S. locations. Insulating window shades (blanket and honeycomb cellular types) can serve as effective window treatments by improving room comfort and providing energy saving economic benefits due to their relatively high complementary R-Value (3 to 5).

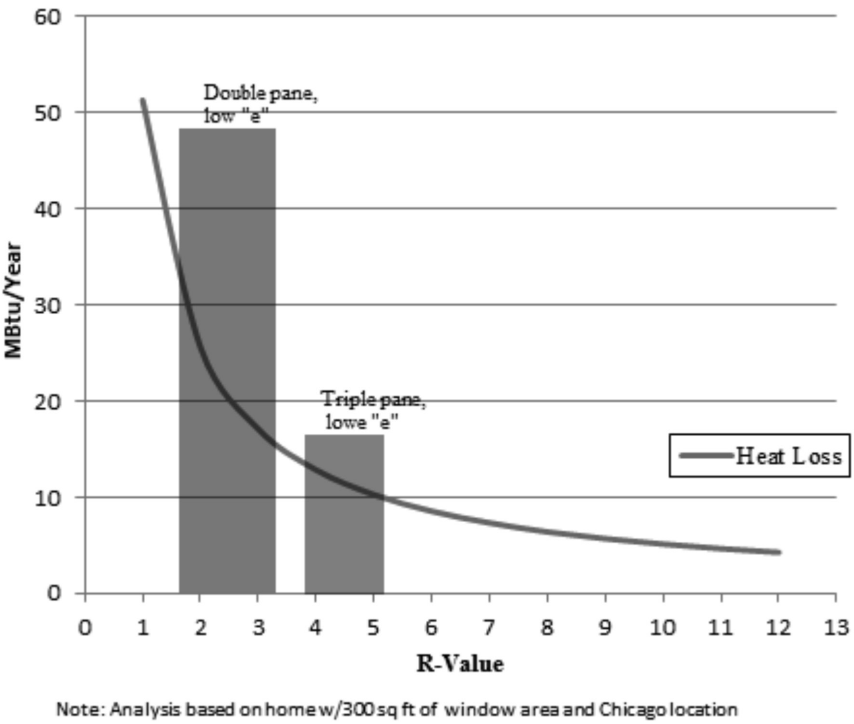

Figure 8. Window Heat Loss

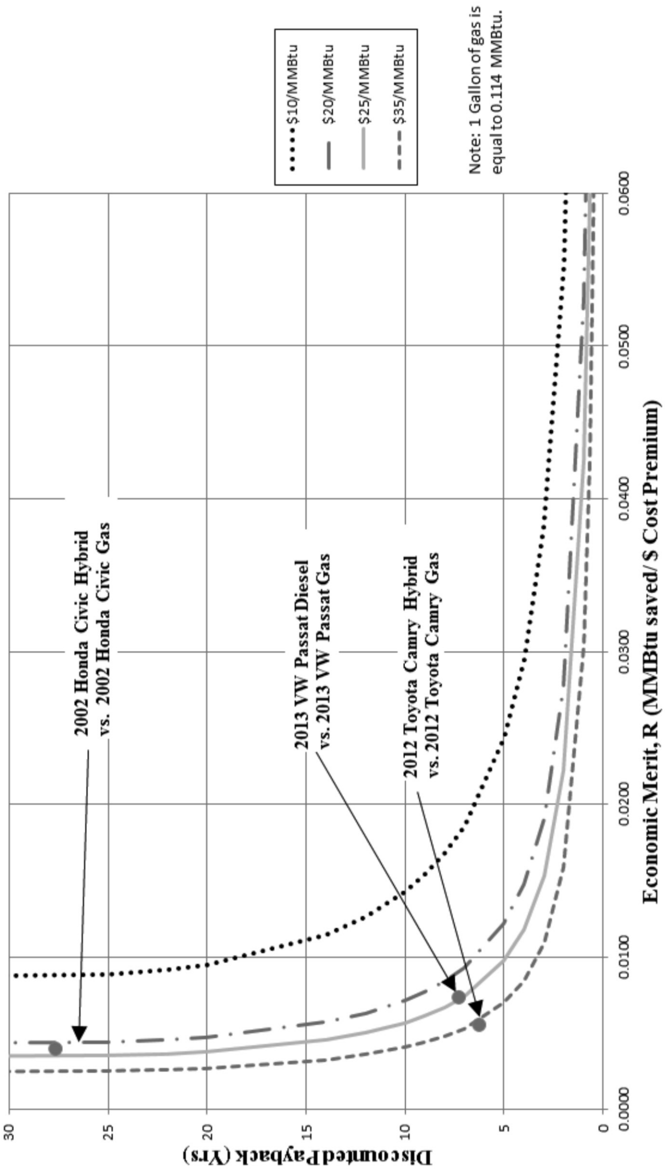

Figure 9. Example Payback for Hybrid and Diesel Automobiles

Energy Efficient Vehicles

Hybrid and diesel technologies are examples of evolving energy efficiency vehicle technologies. As shown in Figure 9, hybrid technology development has progressed from a discounted payback of approximately 28 years in 2002 ($1.31 per gallon gasoline), to where these vehicles now offer reasonable discounted payback periods when compared to conventional gasoline automobiles. The hybrid Toyota Camry LE 2012, for example, when compared to a 2012 gas Toyota Camry LE, has a discounted payback of 6.1 years, assuming a current gas price of $3.61 per gallon and annual mileage driven of 15,000 miles ("Can a Hybrid Save Me Money," 2013). This is a substantial improvement over the 28 year discounted payback for the 2002 Honda Civic Hybrid. The majority of the decrease in discounted payback period for the hybrid technology is the result of an increased price in gasoline between 2002 and 2012. The average U.S. price for a gallon of gasoline was $1.31 in 2002 and $3.61 in February of 2013 ("Gas and Diesel Fuel Update," 2013).

Diesel technologies have slightly lower first cost difference than the hybrid automobiles when compared to conventional gas engines, and also get substantial fuel savings over conventional gasoline engines. Per fueleconomy.gov, the 2013 Volkswagen Passat TDI SE clean diesel, for example, gets an average combined city/highway mpg of 38 mpg with only a $2,280 first cost difference over the conventional gas powered Passat ("Edmunds.com 2013 Volkswagen Passat," 2013 and "German Carmakers Start Clean Diesel Initiative in the USA," 2013). The gasoline-powered 2013 Passat SE gets a combined 28 mpg. This fuel efficiency savings results in a 7.3 year discounted payback period for the diesel Passat. Today, diesel automobiles only represent 2.6% of the U.S. market, as opposed to 55% in Western Europe ("Gas and Diesel Fuel Update," 2013). Given that new clean diesel technologies now can meet the strictest U.S. air pollution laws through low sulfur fuel and better particulate filtration, it is conceivable that this technology will grow significantly in market share in the U.S. despite the fact that diesel prices are about $0.40 to $0.50 higher than gasoline.

If fuel prices increase for gasoline, the value proposition for both hybrids and diesels will continue to increase in the U.S. Gasoline prices in many countries such as Italy, Spain, France, Germany, Japan and the United Kingdom are currently more than double that in the U.S. due to high fuel taxes. The taxes are a source of general revenue for maintaining and building new roads and can also represent a carbon tax and ecotax to promote environmental sustainability. Such high gasoline prices act as market drivers for the development of advanced, high efficiency vehicles, especially given that most automobile manufacturers are International companies selling cars, SUV, vans and trucks in countries throughout the world. Therefore, in many respects, the U.S. is a recipient of vehicle technology advancements that can often be driven by global gasoline and diesel market conditions.

As the many technology examples outlined above highlight, the use of payback curves can provide a powerful visual tool to forecast and identify future opportunities for research, development and commercialization of products that have economic merit. This analysis tool can be used by stakeholders in the energy industry to objectively assess, predict, and communicate where future investment in energy technologies has the greatest potential.

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