ENERGY, ECONOMIC, AND ENVIRONMENTAL IMPACTS OF ADVANCED TECHNOLOGY IN THE PROCESS INDUSTRIES

Joan L. Pellegrino and James E. Reed
Energetics, Incorporated

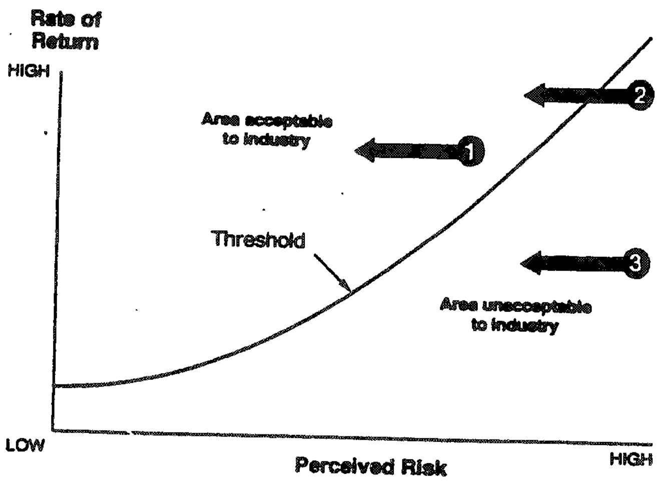
INTRODUCTION

Understanding the potential impacts of advanced technology is critical to both public and private sector decision-makers involved in industrial research and development. From the private sector perspective, predicting the impacts of technology development can directly influence profits, productivity, and market share on a global level. The literature is replete with cases where companies and reputations have been built (or ruined) by the impacts of the development (or lack of development) of new technology. In the public sector, government entities involved in research and development have similar goals in the sense that they are seeking a significant impact as the result of technology development. They are not motivated, however, by a desire to increase profit margins or market share, although indirectly these effects may occur. The motivations of government research programs are often grounded in a desire to improve the state of the nation in general, for example, through enhanced environmental quality, conservation of natural resources, advances in medicine or the physical sciences, and other worthwhile causes. Given the plethora of problems in the world needing solutions or improvements, and the growing scarcity of government funds for research and development, it is no wonder that choosing what research to fund has in itself become a difficult and carefully defined process. Determining the national benefits of research is by necessity an essential part of this process.

A national impacts assessment is one way to evaluate the benefits of individual research projects and enhance the management of multi-faceted government research programs. It provides ammunition for the research program director to defend the project from a mission standpoint, and to justify programs at the collective as well as individual project level. More importantly, it provides big-picture knowledge of the research so that research is not conducted in a vacuum. The big picture often reveals surprising elements that may influence the effectiveness or validity of the research. Such elements might include the existence of competing technology with lower costs; the existence of equivalent R&D projects in the industrial sector; a potential market that is rapidly diminishing; or projects with inherent weaknesses (high capital costs, marginal benefits).

The dilemma faced by most public sector decision-makers in the research arena is not if, but *how* to conduct a credible assessment of national benefits. For basic R&D, where much of research is far from being used in practical applications, research priorities are identified on the basis of theoretical and often very intangible benefits. In exploratory, bench scale, and pilot plant research, benefits may be determined on a much more tangible basis, particularly if the anticipated result is a technology or technical methodology that could potentially be commercialized by industry. In this case, the calculation of a standard financial indicator like the rate of return can be an effective way to evaluate advanced technology research and subsequently predict the impacts of the adoption of that technology on the nation. The additional value of using the rate of return as the basis for an impacts methodology is that industry recognizes this parameter and also uses it as a gauge for managing its research portfolio. As shown in Figure 1, there is an acceptable threshold for rate of return and perceived risk beyond which industry is willing pursue research and development of new technology. When the rate of return is very high, even if the risk is high, industry

Figure 1. Rate of Return Versus Risk: Industry's Threshold for R&D Investment



may pursue the research to capture the high returns (this is also true of gamblers). Alternately, when the risk is very low, industry may pursue the research even if the returns are modestly attractive. There is, however, a rate of return below which most industries will not pursue a research project, regardless of risk. This rate of return, often termed the hurdle rate, can vary widely among industrial sectors but typically ranges from 20 to 30 percent. Many highly valuable and important projects fall within the unacceptable region. In fact it is in this unacceptable region that government seeks to provide leveraged funding for research. By doing so, it is often possible to accelerate technology development to a point where industry will find continuation of the research an acceptable and profitable proposition. In Figure 1, the three arrows represent technology research projects that are being considered for government funding. Project one (1) is already in an area where industry would be willing to provide funding, and probably should not receive government funding (this might be considered corporate welfare). Project three (3) is in an area where industry would not fund the project and is a candidate for government funding. However, it is so high risk and the payoff is so low that even with government funding the project is still unlikely to be further developed and commercialized by industry. Project two (2) is close to the region where industry would provide funding; government funding would accelerate the technology to a point where industry would further develop and commercialize it. This might be considered the ideal situation for a government-funded project.

A very effective modeling tool based on rate of return has been used by government research decision-makers at the U.S. Department of Energy (DOE) for a number of years to evaluate R&D projects. The remainder of this paper describes the history of this model, its underlying methodology, how it has been successfully applied, and the results for a research portfolio of advanced industrial technologies.

HISTORICAL PERSPECTIVE

Back in 1976 when the functions of the U.S. Department of Energy (DOE) were conducted under the Federal Non-Nuclear Energy Research and Development Act (P.L. 93-577), a company called Energy and Environmental Analysis (EEA) was asked by DOE to develop a system that would evaluate and track the benefits of energy technology research.[1] The work was supported through the former Office of Industrial Programs (now known as the Office of Industrial Technologies, and part of DOE's Energy Efficiency and Renewable Energy Office). The result of this effort was the Threshold Analysis Model (TAM), a unique computer model that calculates the rate of return for individual technologies based on cost inputs and uses the results to predict market penetration. The theory behind market penetration in this early version of the model was developed by E. Mansfield and A. W. Blackman, and was based on historical innovation data in four industries.[2,3,4]

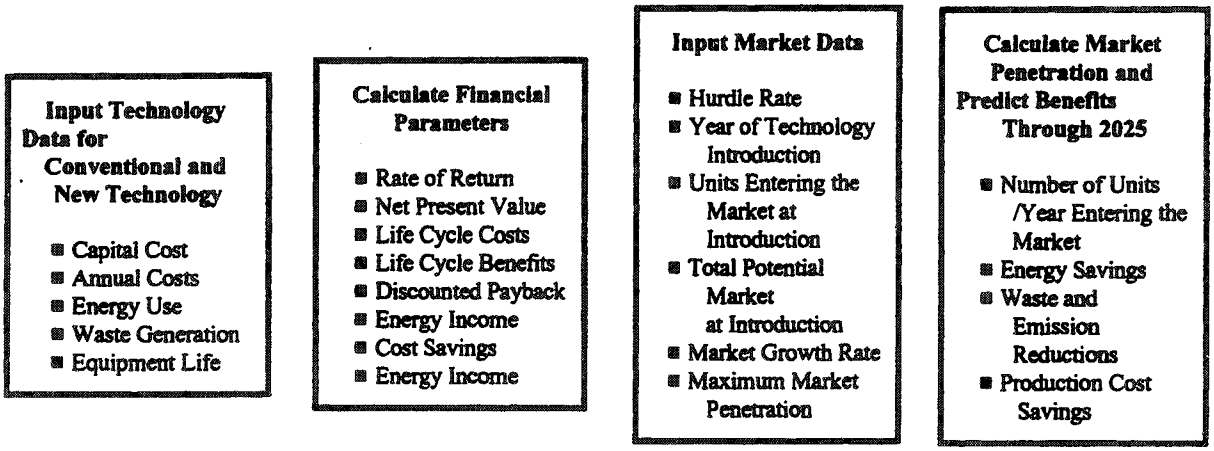
In the early 1980's Energetics, Incorporated received a contract from the Office of Industrial Programs to modify and update certain parts of the model. This work resulted in the revision of the original Mansfield-Blackman coefficient, the incorporation of a multiple market option, the update of other critical parameters, and the development of a theory and user's manual.[5,6,7,8] The theoretical modifications were subsequently refereed by Wade Blackman, and represent the final modification to the original theory contained in the model. The original TAM was programmed in Fortran and designed to run on a VAX system, and remained in this format until the mid-1980s when a PC-compatible version was produced. In 1995 Energetics developed a user-friendly spreadsheet version of the model (Microsoft Excel) called the OIT Project Benefits Worksheet (PBW). This newest version, which is still in use today, contains the core of the original theory but has been simplified to exclude some parameters which increase the complexity of the analysis and are not essential for a preliminary benefits assessment (e.g., taxes, depreciation, current dollar analysis).

Since its inception the TAM has been used in various ways to support the research decision-making process for DOE's industrial energy research programs. In the late 1970's, the Office of Industrial Programs (OIP) required projects to have a completed threshold analysis prior to receiving funding and used the TAM throughout project duration to assess benefits. In the early 1980's the TAM was robust in defending OIP's research from attack during the Sunset Review and subsequent budget defense exercises. Because of the credible documentation the TAM provided, the OIP earned a reputation as one of the best defended research programs in the government. The TAM afforded an effective defense for funding decisions, as well as an explanation of the theoretical underpinnings of the research. In the late 1980's the role of the TAM changed direction, and it became used more as a marketing assessment tool rather than for the evaluation of impacts. Over the last several years, with the development of a new, simplified version, the TAM has once again become the standard for the evaluation of benefits in the Office of Industrial Technologies (formerly OIP).

METHODOLOGY

This discussion will focus on the basic methodology behind the simplified spreadsheet version of the TAM (hereafter referred to as the PBW), as this version was used to obtain the results shown later in this paper. A diagram of the computational flow for the model is shown in Figure 2. The core methodology behind the model is the comparison of a new technology with its conventional counterpart in a typical operating environment. Data for both the new and conventional technology is input on a unit basis. For example, if comparing a new glass melting furnace with a conventional glass melting furnace, a unit size of some throughput of tons/hour or tons/year of glass product would be chosen. Anywhere data is required in the model the same unit basis would be applied, including market data. A duty cycle is also chosen (i.e., hours of operation per year) that coincides with typical operating conditions in practice. User inputs include data on capital costs, annual costs, energy consumption, and waste generation. The user must also input essential market data (e.g., total potential market, estimated upper limit on market penetration, year of technology introduction).

Figure 2. Computational Flow of the Spreadsheet-Based TAM



Once the user has input the required data, standard algorithms are used to compute total life-cycle costs and benefits, net present value, internal rate of return, discounted payback period, uniform capital recovery factor, levelized cost of energy, and annual cost benefits. These financial parameters are then used to perform a market analysis based on the Mansfield-Blackman market penetration model. The original Mansfield approach is based on historical data on innovations in four industries, which showed that the number of firms adopting each of the innovations followed an S-shaped curve as a function of time. Further, Mansfield showed that the rate which controlled the interval between market introduction and market saturation was itself a linear function of statistically significant variables characterizing either the innovation or the industry of interest. Blackman later contributed to Mansfield's work by reformulating the original derivation in terms of market share rather than the number of firms adopting the innovation. The final result is the core of the Mansfield-Blackman penetration model, and is described the following equation,

$$\ln[m/L-m] + \ln[(L/N) - 1] = R(T-t)$$

where m is the market share obtained at the end of the year T, L is the market share at saturation (i.e., the maximum potential market share), t is the year of market introduction, N is the market share obtained at the end of year t, and R is the rate constant. The rate constant R is defined as

$$R = (0.222)IB + (0.530)P - (0.027)S - 0.316$$

where IB is the innovation index, P is an index measuring the innovation's potential profitability (based on rate of return), and S is an index measuring the size of the innovation's required capital investment. The form of this penetration model that is used in the PBW is a modified version of the above where the size term (S) has been dropped.

The model uses the Mansfield-Blackman approach to project penetration of technology units into the marketplace over the next thirty years. Based on the projected penetration of units, the model calculates the associated benefits with the deployment of the technology in the marketplace (e.g., energy savings, energy cost savings, reductions in emissions, production cost savings). The format of the current version of the model is a series of linked worksheets that cover individual data input fields as well as tabulation of results. The worksheets are color-coded to simplify data entry – green signifies that input is required and red indicates a fixed data field.

Case Study

To illustrate how the model works, input sheets and results for a recently analyzed project are shown in Figures 3 through 9. The project selected is a new burner technology that dramatically reduces emissions of nitrogen oxides and carbon oxide from natural gas combustion. The technology uses combustion air/natural gas premixing, air staging with extensive heat removal between stages, and forced internal circulation of the partial products of combustion from the primary zone to reduce peak flame temperatures. The conventional counterpart is a register-style burner using either induced or forced external flue gas recirculation. The unit size and duty cycle chosen for the analysis are a refinery boiler generating 40 million Btu/hour for 330 days/year, 24 hours/day.

Figures 3 and 4 show capital and annual costs for both the new and conventional technology. The new technology costs slightly more to purchase and operate than the conventional. Figure 5 shows that the new technology uses less energy

Figure 3. Capital Cost Worksheet

Capital Cost Component	Conventional Unit	New Unit	Incremental Capital Costs	Incremental Savings	Net Cost Increment
First Cost of Equipment	$ 60,000	$ 70,000	$ 10,000	$ -	$ 10,000
Site Preparation and Engineering	$ -	$ -	$ -	$ -	$ -
Installation	$ 60,000	$ 70,000	$ 10,000	$ -	$ 10,000
Contingency Allowance	$ -	$ -	$ -	$ -	$ -
Field Indirects	$ -	$ -	$ -	$ -	$ -
Interest During Construction	$ -	$ -	$ -	$ -	$ -
Start-up Expenses	$ -	$ -	$ -	$ -	$ -
Working Capital	$ -	$ -	$ -	$ -	$ -
Misc Expenses @ 18% of Capital	$ 10,800	$ 12,600	$ 1,800	$ -	$ 1,800
TOTAL: Initial Capital Investmen	**$ 130,800**	**$ 152,600**	**$ 21,800**	**$ -**	**$ 21,800**

Costs should be entered in 1995 dollars.

Figure 4. Annual Cost Worksheet

Annual Cost Component	Conventional Unit	New Unit	Incremental Annual Costs	Incremental Savings	Net Cost Increment
Payroll plus Labor Indirects	$ -	$ -	$ -	$ -	$ -
Non-Fuel O&M @ 3% of Capital	$ 1,800	$ 2,100	$ 300	$ -	$ 300
By-Product Credit	$ -	$ -	$ -	$ -	$ -
Value of Increased Production	$ -	$ -	$ -	$ -	$ -
Pollution Control and Waste Disposal		$ -	$ -	$ -	$ -
Other Costs/Credits	$ -	$ -	$ -	$ -	$ -
TOTAL: Annual (non-energy) Costs	**$ 1,800**	**$ 2,100**	**$ 300**	**$ -**	**$ 300**

Costs should be entered in 1995 dollars.
There may be NOx credits associated with installation, but these have not been estimated.

than the conventional, due to improvements in efficiency and the elimination of a flue gas recirculation fan. Each boiler with the new burner installed will save 9,900 million Btu/year. Combustion-related emissions are calculated automatically by the model based on fuel savings and published conversion factors for criteria pollutants (and carbon dioxide), as shown in Figure 6. The net reduction is emissions is 600 tons per year for each boiler with the new burner.

Figure 5. Energy Worksheet

	Annual Unit Energy Use Conventional Technology	Annual Unit Energy Use New Technology	Energy Savings By Others	Net Energy Saved
	(million Btu/year)			
Distillate Oil	-	-	-	-
Residual Oil	-	-	-	-
Natural Gas	316,800	307,296	-	9,504
Propane	-	-	-	-
Gasoline	-	-	-	-
Coking Coal	-	-	-	-
Steam Coal	-		-	-
Electricity	1,188	792	-	396
Pet Feedstock	-	-	-	-
Other	-	-	-	-
TOTAL	**317,988**	**308,088**	-	**9,900**

	1995 Fuel Prices ($ per million Btu)		Default 1995 Fuel Prices* ($ per million Btu)	
#	Distillate Oil	4.02	Distillate Oil	4.02
#	Residual Oil	2.48	Residual Oil	2.48
#	Natural Gas	2.58	Natural Gas	2.58
#	Propane	5.39	Propane	5.39
#	Gasoline	6.12	Gasoline	6.12
#	Coking Coal	1.77	Coking Coal	1.77
#	Steam Coal	1.38	Steam Coal	1.38
#	Electricity	4.47	Electricity	4.47
#	Pet Feedstock	2.97	Pet Feedstock	2.97
#	Other	2.00	Other	2.00

Express end-use electricity use as primary equivalent (10,500 Btu/kWh)

Savings in natural gas are due to a 3% estimated improvement in efficiency. Savings in electricity reflect the fact that an FGR fan is needed for the conventional technology.

Fuel Prices: All except coal taken from the EIA Monthly Energy Review, March 1996; coal prices are taken from the EIA Annual Energy Outlook 1996.

Price of petroluem feedstock based on refiner acquisition price of crude oil (average value).

Figure 6. Waste and Emissions Worksheet

	Annual Unit Waste Production (Tons/Year) Conventional Technology	New Technology	Waste Reduction By Others	Net Waste Reduction
Non-combustion Related				
Non-hazardous (RCRA)	-	-	-	-
Toxic (TRI)	-	-	-	-
Hazardous (non-TRI)	-	-	-	-
CFCs	-	-	-	-
VOCs	-	-	-	-
NOx Reduction	-	(7)	-	7
Other 2	-	-	-	-
Other 3	-	-	-	-
Other 4	-	-	-	-
Combustion Related				
Particulates	1	1	-	0
VOCs	1	1	-	0
Sulfur Dioxides	1	1	-	0
Nitrogen Oxides	23	22	-	1
Carbon Dioxide	18,902	18,311	-	591
TOTAL	**18,927**	**18,328**	-	**600**

This burner significantly reduces NOx emissions over and above those attributed to the decrease in natural gas use. The reduction in NOx emissions has been estimated at about 33% over the conventional system (a reduction from 30 ppm to 20 ppm NOx).

Figure 7 shows the financial results of the model based on the cost and energy inputs. The technology provides an internal rate of return of about 119 percent, with payback in a little less than one year. The value of NOx credits (which was not calculated for this analysis) could push this return up even higher. With its current economics, the technology is an attractive retrofit option for boilers and process heaters, particularly in non-attainment regions of the country.

Figure 7. Financial Worksheet

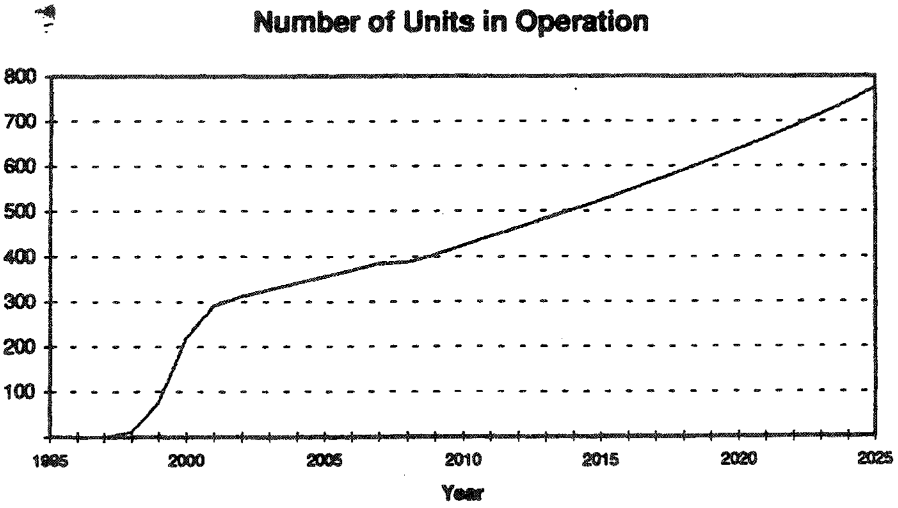
Unit Technology Inputs	
Discount rate:	10%
Equipment lifetime (yrs.):	15
Initial capital investment:	$21,800
Annual costs:	$300

User's Unit Summary Financial Results	
Annual energy income:	$26,290
Annual net income:	$25,990
Total Life Cycle Cost:	$24,082
Total Life Cycle Benefit:	$199,967
Net Present Value:	$175,885
Benefit-Cost Ratio:	8.30
Internal Rate of Return:	119.22%
Rate of Return:	119.22%
Uniform Capital Recovery Factor:	0.1315
Levelized Cost of Energy (per mil. Btu):	$0.32
Annual Production Cost Savings:	$23,124
Discounted Payback Period:	0.93

Figure 8 shows the additional data utilized for the market penetration portion of the model, and the results. With the relatively high rate of return this technology penetrates the current market rather quickly and begins to enter the growth market shortly after 2000. Figure 9 provides a tabular representation of market penetration and the associated primary benefits.

Figure 8. Market Penetration Worksheet

Inputs	
Hurdle rate IRR (%):	25%
Year of introduction:	1998
Number of units at introduction:	12
Total potential market at introduction (# units):	300
Growth rate of total potential market (annual):	4%
Maximum market penetration (fraction):	0.90
ventory of Conventional Units at Replacement Tech. Introduction:	0



Credibility and Implications of Results

The credibility of the model's results depends entirely upon the accuracy of the inputs. Gathering the inputs is often the most difficult part of the modeling process. The research investigator must not only be able to provide information about the potential technical capabilities of the new technology, but must be able to estimate practical details such as capital and operating costs, energy requirements, environmental aspects, and so on. When research is being conducted at the exploratory or bench scale, this is often very difficult to do. Further, this data must be provided for the conventional counterpart for

Figure 9. Market Penetration Results

Year	Units in Operation	Energy Savings *billion Btu/year*	Waste Reduction *1000 tons/year*	Production Cost Savings *(million $/year)*
1995	-	-	-	-
1996	-	-	-	-
1997	-	-	-	-
1998	12	119	7	0
1999	77	762	46	2
2000	219	2,168	131	5
2001	291	2,881	174	7
2002	313	3,099	188	7
2003	327	3,237	196	8
2004	341	3,376	204	8
2005	355	3,515	213	8
2006	369	3,653	221	9
2007	383	3,792	230	9
2008	387	3,831	232	9
2009	404	4,000	242	9
2010	424	4,198	254	10
2011	444	4,396	266	10
2012	464	4,594	278	11
2013	484	4,792	290	11
2014	504	4,990	302	12
2015	524	5,188	314	12
2016	545	5,396	327	13
2017	567	5,613	340	13
2018	590	5,841	354	14
2019	613	6,069	368	14
2020	637	6,306	382	15
2021	662	6,554	397	15
2022	689	6,821	413	16
2023	716	7,088	429	17
2024	745	7,376	447	17
2025	775	7,673	465	18

comparison. In some cases, the research may not have reached a stage where such analysis is feasible. In other cases, the information is proprietary and may compromise the property rights of an industrial research partner. For many cases, however, preliminary estimates can be made for most of the parameters using standard rules of thumb for cost engineering, historical equipment costs, and other published data. This data, when supplemented with the developer's intuition and intimate knowledge of the technology, can often provide a quite reasonable (yet highly preliminary) estimation of project benefits.

It should be emphasized that because of the preliminary nature of the inputs, the results cannot be viewed at the same level of accuracy as similar analyses that would be used by a corporate entity to make research decisions. In the corporate world, where fractional increases in profit margin can make a tremendous impact on competitiveness, the costs and benefits of the anticipated new technology are carefully estimated and considered beginning on the day the idea is put forth. By comparison, the results of the PBW are at best a useful tool for broadly examining potential impacts, within a wide margin of error.

What the spreadsheet analysis does provide is a back-of-the-envelope profile of the performance of an individual technology in terms of energy savings, waste reduction, and production cost savings over the next thirty years. This information is highly valuable to the government research program manager in terms of technical and administrative decision-making. It can be used to

- increase the program manager's general knowledge of the technology area,
- enhance the program manager's ability to make informed decisions about the research,
- provide reasoning for continuation of funding for projects,
- identify projects where continued R&D is questionable, and
- clarify project weaknesses (e.g., low rate of return, high capital costs, marginal energy savings) and strengths.

Just as important, the information provides a valuable method of evaluating the potential impacts of specific research. The performance profile provides a means to

- quantify energy, economic, and environmental benefits at the national level,
- measure project success in a way that is easily understood and justifiable,
- force industry partners to evaluate R&D in terms of real impacts, and
- evaluate the return on the federal investment.

Another interesting aspect of the model is that it allows the user to incorporate unique attributes that may contribute to reductions in production costs or increased national energy and environmental benefits. Often these attributes include improvements in productivity, increased production through-put, reductions in the use of raw materials, recovery of valuable by-products, and reductions in the cost of pollution abatement, control, and disposal. There is also an option to include benefits that may accrue indirectly, that is, to other than the direct user of the technology (these of course are not included in the financial analysis). The ability to incorporate these elements allows the user to more accurately reflect all the potential benefits of the technology. Flexibility in entering and selecting parameters also permits the user to perform sensitivity analysis where these and other parameters are varied. The model does not permit the analysis of incremental improvements to technology over time within a single model run. However, such analysis can be conducted by making several model runs.

RESULTS

Over the last two years the PBW has been used to evaluate nearly 150 new technologies that have received research funding from DOE's Office of Industrial Technologies. These technologies cover a broad spectrum of the industrial sector as well as a number of cross-cutting technical areas. To provide a perspective on the range of the analysis, Table 1 provides a sampling of technologies analyzed, categorized by corresponding industry areas.

The primary focus of these research projects is to improve the energy efficiency of industrial processes, which is in keeping with the mission of the funding source (DOE/OIT). It is interesting to note, however, that for most of these technologies there are benefits above and beyond the obvious reductions in energy use and combustion air emissions. The PBW is designed to capture these benefits in terms of monetary value to the user, and also successfully demonstrates the external value to society in general through quantification of factors such as reduction in emissions and waste. Table 2 illustrates some of the advantages of these technologies that fall outside the realm of typical benefits, and that have been captured in analysis of various projects.

Using the Model for Decision-Making

To demonstrate the utility of the model for the decision-making process, model results for 11 of the technologies analyzed for the petroleum refining sector have been aggregated . Data is presented in Figures 10 and 11 for energy savings and waste reduction (solid, liquid and gaseous wastes, as well as quantities of criteria air pollutants and carbon dioxide). Results are not provided for individual projects to protect the confidentiality of the developer(s).

As can be seen in Figure10, energy savings associated with these eleven technologies rise steadily toward the year 2015 and then begin to decline. The same trend is observed for waste reduction. This decline occurs because the model assumes that at some point in the future, other new technologies will take the place of these technologies, and they will

Table 1. Sampling of Technologies Analyzed

Industry-Specific Technology	
Aluminum	Calciners with improved energy efficiency Electrolysis technology to recover aluminum, salt and oxides fractions from aluminum salt cake Spray forming of primary aluminum Production of neoydmium-iron alloys using electrolysis
Chemicals	Diacid production from renewable feedstocks Low temperature catalytic gasification for industrial waste water Plastics/solvents derived from biosynthetically-derived organic acids Production of intermediates from methyl chlorosilane direct process residue
Forest Products	Chip/pulp refiner gap and wear measurement Removal of sticky and light contaminants from waste paper On-machine ultrasonic sensors for measurement of elastic stiffness Electrolytic recovery of spent Kraft black liquor pulping chemicals
Glass	Glass temperature sensor Glass furnace side port oxygen enrichment Cullet preheat system for glass furnaces Thermal swing absorption for low-cost on-site oxygen production
Metalcasting	Improved microstructural performance of aluminum castings Clean aluminum castings Expandable pattern casting Determination of distortion and interfacial heat transfer in sand molds
Petroleum Refining	Advanced fluid catalytic cracking Development of superior asphalt recycling agents Two-stage forced recirculation burner for refining process heaters Advanced membrane separation system
Steel	Electrochemical de-zincing of steel scrap Steel plant waste oxide recycling Direct ironmaking process Advanced process control for steelmaking
Cross-Cutting Technical Areas	
Advanced Materials	Chemical vapor deposition of fiber coatings Direct metal oxidation for producing CFCC composites for steam reforming equipment Microwave joining of silicon carbide tubes Steel mill rolls made from nickel aluminides
Cogeneration	Advanced turbine system Ceramic stationary gas turbine High performance steam system Lox NOx gas turbine retrofit
Combustion	Advanced radiant combustion system Waste driven heat pumps
Solar Industrial	Air pollution control/solar detoxification of air Water pollution control/solar detoxification of water Solar process heating systems
Municipal Solid Waste	MSW Combustion/Oxy-enriched coincineration Combustion of refuse-derived fuel pellets

Table 2. Examples of Additional Benefits of New Technologies

Technology	Additional Benefits
Production of intermediates from methyl chlorosilane direct process residue	- Reduction in use of raw material (metallurgical grade silicon) - Reduction in amount of chlorine released to rivers - Reduction in solid waste sent to landfills
Electrolytic recovery of spent Kraft black liquor pulping chemicals	- Reduces fouling of the recovery system - Recovers sodium as sodium hydroxide solution - Lowers the pH of the black liquor, which increases the efficiency of the recovery boiler - Increases production capacity for the same size equipment
Electrolysis technology to recover aluminum, salt and oxides fractions from aluminum salt cake	- Recovers aluminum and salt for recycling back to the secondary aluminum industry - Produces other value-added products - Eliminates landfilling of the aluminum salt cake
Steel mill rolls made from nickel aluminides	- Improves operation of steel reheat furnace - decreases material rejection rate (scrap)
Thermal swing absorption for low-cost on-site oxygen production	- Utilizes wasted heat from industrial furnaces - Promotes use of oxy-fuel firing, which reduces NOx emissions

eventually be replaced by even more advanced, more efficient technologies. There are many ways to incorporate this assumption into the model. The method chosen in this case was to assume the period when the technology would begin to be replaced was a function of the magnitude of capital cost. That is, a technology with a large first investment would take longer to be replaced by another more advanced technology than one with a low first capital cost. The substitution of the up and coming new technology in the outyears was then accomplished by assuming an average rate of return for the new technology (about 50%), and comparing that rate of return with the OIT-supported technology.

Figure 10. Predicted Energy Savings for Petroleum Refining Projects

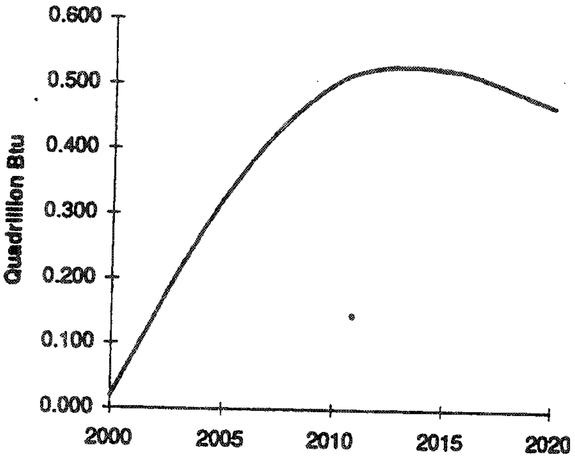
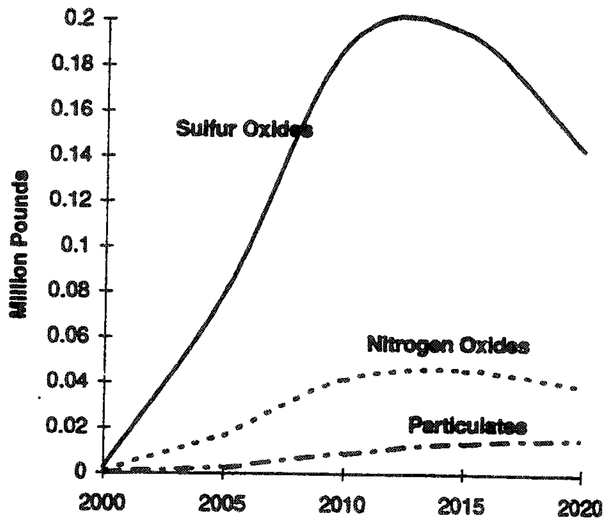


Figure 11. Predicted Waste Reduction for Petroleum Refining Projects



CONCLUSION

The spreadsheet-based economic model shown here has been successfully used to analyze the impacts of technology used in a variety of industrial areas. It generates projections on energy, waste, and production cost savings that can be used to gauge the potential benefits that may result from technology adoption. The model is highly flexible, and can be used to incorporate unique benefits that fall outside the realm of energy savings.

Although only aggregated results are shown here to protect developer confidentiality, it is obvious that when the same information is viewed on the project level it can be invaluable to the research program manager. With the data provided by the model the value of a project can be assessed in terms of the federal investment as well as national impacts. This is a distinct advantage for government research managers who must allocate very scarce federal research funds among a multitude of potentially important research projects.

Note

The authors gratefully acknowledge the support of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Office of Industrial Technologies (and its predecessors) for their support in the development of the Threshold Analysis Model and its subsequent use in a variety of activities.

REFERENCES

1. *Project Evaluation and Methodology: Background Material*, Energy and Environmental Analysis, Inc., Arlington, VA. March 1978.

2. E. Mansfield, "Technical Change and the Rate of Imitation", *Econometrica* 29(4):741-766 (1961).

3. A.W. Blackman, Jr., "The Rate of Innovation in the Commercial Aircraft Jet Engine Market", *Technological Forecasting and Social Change* 2:269-276 (1971).

4. A.W. Blackman, Jr., E.J. Seligman, and G.C. Sogliero, "An Innovation Index Based on Factor Analysis", *Technological Forecasting and Social Change* 4:301-316 (1973).

5. D.R. Holliday and H.E. Lowitt, "An Integer-Based Blackman Innovation Index: Hypothesis, Evidence, and Implications", *Technological Forecasting and Social Change* 26:59-79 (1984)

6. "Adjustment of Market Penetration Rate Constant Parameters in the Threshold Analysis Model", Energetics, Inc., Columbia, Maryland. December 1985.

7. *Office of Industrial Programs Threshold Model Theory Manual*, Energetics, Incorporated, Columbia, Maryland April 1989.

8. *Office of Industrial Programs Threshold Analysis Model Users Manual*, Energetics, Incorporated, Columbia, Maryland. April 1989.