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MARKET PENETRATION OF NEW ENERGY SYSTEMS ESTIMATED BY ECONOMETRIC AND STOCHASTIC METHODOLOGY

by

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ABSTRACT

A methodology has been developed to evaluate the market potential of new energy technologies and systems in today's fast changing U.S. economic and energy environment. An econometric and stochastic model approach is used to analyze the technical, economic, and market factors influencing the possible market penetration of new energy systems. The market model methodology includes four phases:

- Phase I - Segment the new technology/end-use market;
- Phase II - Estimate the technical market;
- Phase III - Estimate the economic market; and
- Phase IV - Estimate the market penetration.

The market penetration of new Integrated Community Energy Systems (ICES) has been estimated by this methodology. To illustrate the methodology, highlights of the ICES application are included in this paper.

MARKET PENETRATION OF NEW ENERGY SYSTEMS ESTIMATED BY ECONOMETRIC AND STOCHASTIC METHODOLOGY

INTRODUCTION

A methodology has been developed to evaluate the market potential of new energy technologies and systems in today's fast changing U.S. economic and energy environment. An econometric and stochastic model approach is used to analyze the technical, economic, and market factors influencing the possible market penetration of new energy systems. The model can be used for analyzing the impact of anticipated changes in the economy, energy, competing technologies, and end-use markets. Moreover, sensitivity analysis can be conducted inexpensively to examine the effects of alternative policies and assumptions. Because market potential can be estimated by specified technology and end-use market, the model can be used for developing strategies for technology research, design, and development and commercialization.

The methodology has been applied to measure the possible national impact resulting from the commercialization of new Integrated Community Energy Systems (ICES) over the next 25 years. Currently, the U.S. Department of Energy is developing these systems under its energy conservation program. To meet the energy needs at a community level, the ICES use the simultaneous output of electricity and heat in a power plant (cogeneration); whereas, conventional systems utilize (1) electricity from a central power plant; and (2) other fuels consisting of natural gas, petroleum, liquefied natural gas, and coal. Because ICES are more efficient than conventional systems in the use of primary fuels, they have potential to save energy.

The highlights of this methodology application are also included here.

METHODOLOGY

The four phases shown in Fig. 1 involved in estimating the market penetration of new energy systems are:

Phase I - Segment the New Technology and End-Use Market
Phase II - Estimate the Technical Market
Phase III - Estimate the Economic Market
Phase IV - Estimate the Market Penetration

Phase I - Segment the New Technology and End-Use Market

The new technologies/systems are analyzed to select the alternative options considered to be commercially viable. By matching the energy demand and supply characteristics, appropriate new and conventional systems are selected for each end-use market.

An attempt is made to group the similar technology options or end-use markets together to limit the number of categories. Several possible examples for market and system segmentation could include:

(1) Market Segmentation by Region

- Census Region
- State
- SMSA

(2) Market Segmentation by End-Use Sector

- Residential
- Commercial
- Industrial

(3) Market Segmentation by Application

- New
- Retrofit

(4) System Segmentation by Size

- Large
- Medium
- Small

(5) System Segmentation by Plant Characteristics

- Diesel Engine
- Gas Turbine
- Steam Turbine

The desired segmentation is heavily influenced by: (1) decision-makers' objectives, and (2) the time and resource constraints imposed on the analysis.

Phase II - Estimate the Technical Market

The technical market includes all feasible applications where a new technology/system can be applied on a commercial basis. The technical market is equivalent to the portion of conventional systems market where new systems could be used. To estimate the current technical market, data are collected for all the applications of conventional systems that can be substituted by new systems. To identify and measure the technical market, it is usually recommended to segment it by system-type and end-use markets (discussed under Phase I of the methodology). For new energy systems, the technical market could be expressed in terms of: (1) energy demand in Btus, (2) conventional systems sales in dollars, or (3) any other suitable unit.

Econometric models can be developed for forecasting conventional systems markets. The market of a conventional system will increase because of: (1) growth in end-use market, and (2) penetration of conventional systems in these markets. Alternatively, the conventional system forecast could be sourced from the national economy and energy (econometric) models if possible. From the estimates of the future conventional system markets, the new energy systems technical market can be estimated as discussed earlier.

In short, the methodology includes the trends in the end-use markets which are affected by the state of the national or regional economy.

To focus only on the realistic (rather than theoretical) applications, certain threshold criteria can be developed to screen the extreme applications where new energy systems will not become competitive even under most favorable conditions. This will allow the maximum utilization of resources available for the analysis.

Phase III - Estimate the Economic Market

The economic market is the portion of the technical market where a new energy system is economically attractive over its competing systems. New and conventional systems are designed for the end-use market to estimate the system cost. Next, an economic comparison is made between the competing systems to allocate the portion of technical market to economic market. Because of changes in technologies, and in the economic and energy environment, the economic share of new energy systems will continuously change. The cost of alternative systems will escalate differently because of differences in the system characteristics.

A brief description of the methodology to estimate economic market follows:

A stochastic approach is used to estimate the economic market from the technical market. The average cost of delivered energy from an alternative system is derived by market segment. Because of the differences in capital cost, fuel prices, energy-use patterns, operations, maintenance, climate, etc., each system cost is expected to change with applications within a market segment. To recognize these variations, a probability distribution is determined for each system cost. For convenience, a triangular distribution can be assumed with the expected cost having the highest probability. Two extreme points of the triangular distribution coincide with the least and most favorable application within the market segment as shown in Fig. 2 which includes ICES as an example. Next, the probability of a particular new energy system being most economical is estimated. By multiplying this probability by the technical market, the new energy system economic market is determined. The analysis is carried out for an historic base period and subsequently extended to all years under consideration. By escalating the present costs with suitable forecasts, the cost of competing systems in future years can be estimated.

In short, the impact of anticipated changes in the economic and energy outlook is reflected in the estimates of new energy systems economic market.

Phase IV: Estimate the Market Penetration

New energy systems cannot be expected to capture the economic market immediately; rather, new products have been shown to follow a growth pattern somewhat similar to the S-shape (classical model). Market response is slow in the beginning because of: (1) unwillingness of investors to take risks with the new technology, and (2) lead times associated with the new technology. As technology viability is shown, many new investors enter the market place to remain competitive, and a period of rapid growth follows. Finally, the technology approaches maturity in the marketplace. The penetration of the economic market can be estimated with the help of Gompertz's curve or any other S-shape curve. To estimate the growth curve, Stanford Research Institute (SRI) has developed the following behavioral lag function: (1)

$$Y = \frac{1}{1 + \left(\frac{h}{K}\right)^{\alpha}} \qquad \text{(Eq. 1)}$$

where: Y = market penetration fraction,

h = years required for 50% of the market to respond to the entrance of new commodity,

K = years since new commodity introduction, and

α = response parameter.

This model has been used successfully by SRI to estimate the solar energy market penetration. (1)

To minimize subjective errors associated with the estimation of growth curve (Eq. 1), a two-step approach is suggested:

(1) Econometrically estimate the market response curve for similar technology in the past (if possible).

(2) Modify the growth curve to suit the new technology.

The response parameter, α, can be estimated by a regression analysis using form:

$$\log\left(\frac{1}{Y} - 1\right) = \alpha \log (h/K) \qquad \text{(Eq. 2)}$$

The penetration share captured by new technology is multiplied by the economic market to yield the market penetration. An annual analysis then is carried out starting with the commercialization period.

Implementation of these four phases leads to an estimation of new energy system market penetration under an assumed outlook of technology, energy, and economy. With this model structure, market penetration forecasts can be quickly updated to reflect the new state of energy, economy, and/or technology.

EXAMPLE OF METHODOLOGY IMPLEMENTATION: ICES APPLICATION

To aid the Department of Energy (DOE) in its RD&D and commercialization planning, the market penetration methodology was applied to ICES for estimating their market potential over the next 25 years. Figure 3 shows the model structure. The main objectives were to: (1) measure the ICES national impact, and (2) examine the effects of the alternative DOE policies. Some highlights of this application are included here.

ICES and End-Use Market Segmentation

The ICES were divided into three generic sizes, based on distinct technical characteristics of their prime-movers, as shown below:

ICES Type	Electric Capacity (MW)	Prime Mover
Small	1-10	Diesel Engine
Medium	10-50	Diesel Engine, Gas/Steam Turbine
Large	50-150	Steam Turbine

To analyze the climatic and fuel cost geographical variations, the national market was broken down into four census regions: northeast, north central, south, and west as shown in Fig. 4. Moreover, each census region was divided into seven generic communities to reflect the variation in the energy demand density which is critical in determining the ICES competitiveness. Distribution cost, a major component of a typical ICES facility cost, increases rapidly with decline in the energy demand density.

An appropriate type of ICES was selected for serving the energy needs of each community within a region. The energy end-use included space heating, water heating, refrigeration, air conditioning, lighting, cooking, appliances, etc.

ICES Technical Market. The 1978 ICES technical market was estimated on the basis of particular historic energy demands selected from the residential/commercial sector as shown in Fig. 5. To select the realistic market, two threshold criteria were used: (1) rural demand cannot be economically supplied by ICES because of the low energy demand density; and (2) demand for single-family homes cannot be economically satisfied by ICES because of the low energy demand density.

The technical market was projected to the year 2003 using the forecasts of energy consumption growth rates in the end-use markets. These forecasts were obtained from the national energy model of Data Resources, Inc. (DRI). (2)

ICES Economic Market. The 1978 economic market was estimated for each community within a region.

The expected delivered energy cost by the conventional system was measured by: (1) weighing the region cost of gas, petroleum, coal, and electricity in residential/commercial sectors; and (2) adding the cost of end-use equipment. This cost was not expected to vary significantly within an urban area. Therefore, a range of costs was established by tabulating the weighted cost for sub-regions shown in Fig. 4.

Estimates of the ICES delivered energy cost involved a detailed engineering analysis. Using energy patterns in the commercial and residential sectors, as estimated by A.D. Little in its *Project Independence Report* (3), the various size of generic ICES facilities were designed for each census region. By dividing the total annual cost by useful cogeneration output, the delivered energy cost was obtained. For each market segment, an appropriate ICES size was selected to determine the expected cost. Next, the range of costs was established on the basis of least and most favorable cases within the market segment.

For each year between 1978 and 2003, the ICES/conventional system cost and their respective ranges were estimated using the fuel and other cost forecasts from the DRI economy and energy models. (4) Finally, the probability of ICES being more economical than conventional systems was derived by each market segment for all years between 1978 and 2003. The ICES economic market was estimated by using the market penetration methodology.

ICES Market Penetration. An effort has been made to use past experience in the marketplace to estimate the S-shape growth curve. Market research has identified that somewhat similar gas turbine systems penetrated the electric utility peak capacity market between 1960 and 1977. From this, it was concluded that the market acceptance of the gas turbine could provide the guidelines for the penetration of medium-size ICES which use gas turbines as one of the prime-mover options.

The installed capacity of gas turbine electric plants (1968 to 1977), and total electric plants (1960 to 1977) were sourced from the Federal Power Commission Newsrelease (5) (Maintained by Data Resources, Inc. in its energy data bank). The gas turbine electric plant capacity between 1960 and 1977 was sourced from an internal report of Argonne National Laboratory. (6) Fig. 6 shows the gas turbine share of total U.S. electric utility capacity. The penetration followed an S-shape growth pattern. The gas turbine technical market was defined to include all peak load capacity requirements of total electric utility capacity. According to the EEI report, (7) the peak load capacity was 12.% of the total electric utility capacity in the winter of 1977/78. In view of time constraints, the economic market was assumed to be 10% of the total electric utility capacity as shown below:

	% of Total Electric Utility Capacity in 1977/78 Winter
Diesel Engine	.4
Combined Cycle	1.2
Gas Turbine	8.5
Assumed Gas Turbine Economic Market	10.1%
Pumped Hydro Storage	2.0
Assumed Gas Turbine Technical Market	12.1%

An econometric model (Fig. 6) was fitted to estimate the market penetration curve. The half-life period was estimated to be 11.3 as shown in this figure. The model fit, which explained 95% of the variation in the gas turbine penetration between 1960 and 1977, is:

$$\log\left(\frac{1}{Y} - 1\right) = 3.2 \log\left(\frac{11.3}{K}\right) \qquad \text{(Eq. 3)}$$

where: Y = market penetration fraction,

K = years since introduction of gas turbine.

As greater institutional problems are envisioned with medium-size ICES, as compared to those of gas turbine systems, the above model was modified to result in slower penetration rate. This was done arbitrarily by extending the half-life period of 11.3 yr to 15 yr.

Furthermore, compared to the institutional barriers encountered by medium-size ICES, fewer barriers are expected with the introduction of small-size ICES. For this case, the half-life period was shortened arbitrarily to 10 yr. Conversely, the half-life period was increased to 20 yr to reduce the penetration rate for large-size ICES that are expected to have more institutional and environmental problems than medium-size ICES.

Highlights of ICES Market Potential

The ICES market model was used to estimate the market penetration under long-term economic and energy outlook of Data Resources, Inc. released in April 1979. The energy outlook for the next 25 years is summarized below:

- difficult period lies ahead because of serious questions raised by OPEC energy supply disruptions and higher prices;
- natural gas and domestic oil to be deregulated by 1985;
- real GNP to grow 2.9% annually for the period, declining gradually from 3.5% (1976 - 1980) to 2.6% (1990 - 2003);
- continued inflationary pressures, driven strongly by fuel prices, and resulting in a 6% compounded rate of growth in GNP deflator; and
- fuel and electricity prices to grow at 4.4% in real terms.

Estimated ICES Market Penetration

The results are summarized below:

- ICES are estimated to capture 2.2 Quads of residential/commercial real demand in 2003 as shown in Fig. 7.
- ICES can result in: (1) 1.05 Quad/yr of total fuel savings, and (2) 0.85 Quad/yr of scarce fuel savings by 2003.
- The northeast region could account for 40% of the total U.S. market penetration in 2003 as shown in Fig. 8.
- Medium-size ICES (10-50 MW) could account for more than 50% of the total penetration in 2003 as shown in Fig. 9.
- Long-run R&D strategy emerges from this model. Development of advanced ICES can significantly increase the estimated economic market (Fig. 7) and results in much higher market penetration.
- Short-run commercialization strategy also emerges from this model. The medium-size ICES should be commercialized first in the northeastern market.

Sensitivity Test of ICES Market Penetration

A sensitivity analysis was conducted to test the impact of the assumption that only small-size ICES (up to 10 MW) could be commercialized. Greater environmental and other institutional barriers are associated with medium/large-size ICES. The analysis shows that the ICES market penetration drops from 2.2 Quad/yr to 1.4 Quad/yr in 2003.

CONCLUSIONS

Short and long-run strategies for technology development and commercialization could be formulated as illustrated by application of the methodology to ICES. Other benefits include: (1) improved understanding of the end-use markets for new energy systems, and (2) development of technical and market data bases for new energy systems.

In conclusion, the methodology structure:

(1) integrates trends of economy, energy, technology, and end-use markets;

(2) identifies new energy system potential by end-use market and region;

(3) measures market penetration sensitivity;

(4) updates forecasts inexpensively in today's rapidly changing environment; and

(5) tests alternative policy assumptions.

REFERENCE CITED

(1) Stanford Research Institute, *Applicability of SRI Market Penetration Methodology to Energy Technology Commercialization Studies*, prepared for Department of Energy.

(2) Data Resources, Inc., *Long-Term Energy Review*, limited circulation to its clients, Volume 3, No. 1 (Spring 1979).

(3) Arthur D. Little, Inc., *Federal Energy Administration Project Independence Blue Print Final Task Force Report -- Residential and Commercial Energy Use Patterns 1970-1990*, prepared for Interagency Task Force on Energy Conservation, Volume I (November 1974).

(4) Data Resources, Inc., *U.S. Economy Long-Term Review*, limited circulation to its clients (Winter 1979).

(5) Federal Power Commission News Release, *Power Production, Capacity, Fuel Consumption*, Maintained by Data Resources, Inc. in its energy data bank.

(6) Hub, Ken, Argonne National Laboratory (December 1977), unpublished information.

(7) Edison Electric Institute, *1978 Annual Electric Power Survey*, Publication No. 78-4 (1978)

BIBLIOGRAPHY

MITRE Corporation, *A System for Projecting the Utilization of Renewable Resources -- SPURR Methodology*, Prepared for U.S. Energy Research and Development Administration, September 1977.

Schiffel, D.; Costello, D.; Posner, D.; and Wiltidder, R., *The Market Penetration of Solar Energy: A Model Review Workshop Summary -- Solar Energy Research Institute*, January 1978.

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FIGURE I.

NEW ENERGY SYSTEMS MARKET MODEL METHODOLOGY INCLUDES FOUR PHASES

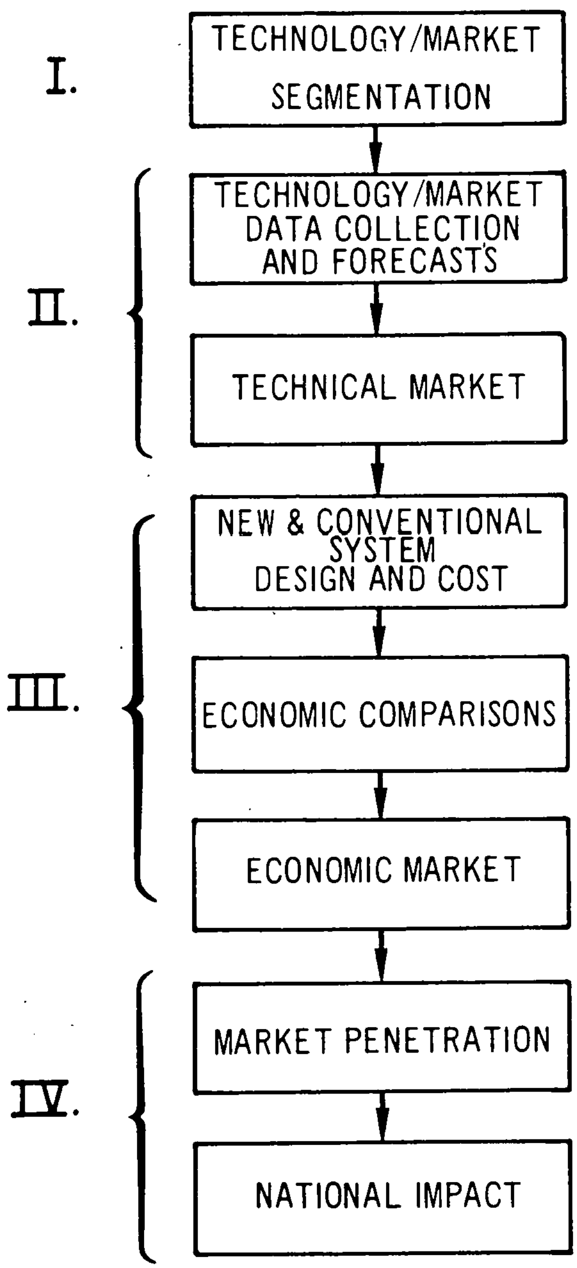
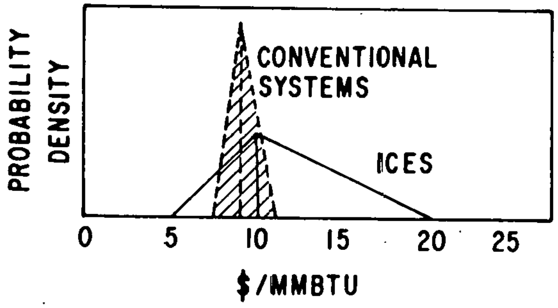


FIGURE 2.

ICES ECONOMIC MARKET ALLOCATION IS BASED ON STOCHASTIC METHODOLOGY



$$\left(\begin{array}{c}\text{ECONOMIC}\\ \text{MARKET}\end{array}\right)_{I,J,K} = \left(\begin{array}{c}\text{PROBABILITY}\\ \text{OF BEING}\\ \text{LEAST COST}\\ \text{SYSTEM}\end{array}\right)_{I,J,K} \times \left(\begin{array}{c}\text{TECHNICAL}\\ \text{MARKET}\end{array}\right)_{I,J,K}$$

WHERE: I = COMMUNITY (7)
J = REGION (4)
K = YEAR (25)

FIGURE 3.

ICES MODEL PRODUCES A CONSISTENT MARKET ESTIMATE
(INTEGRATES TRENDS IN TECHNOLOGY, ECONOMY, ENERGY, AND END USE MARKETS)

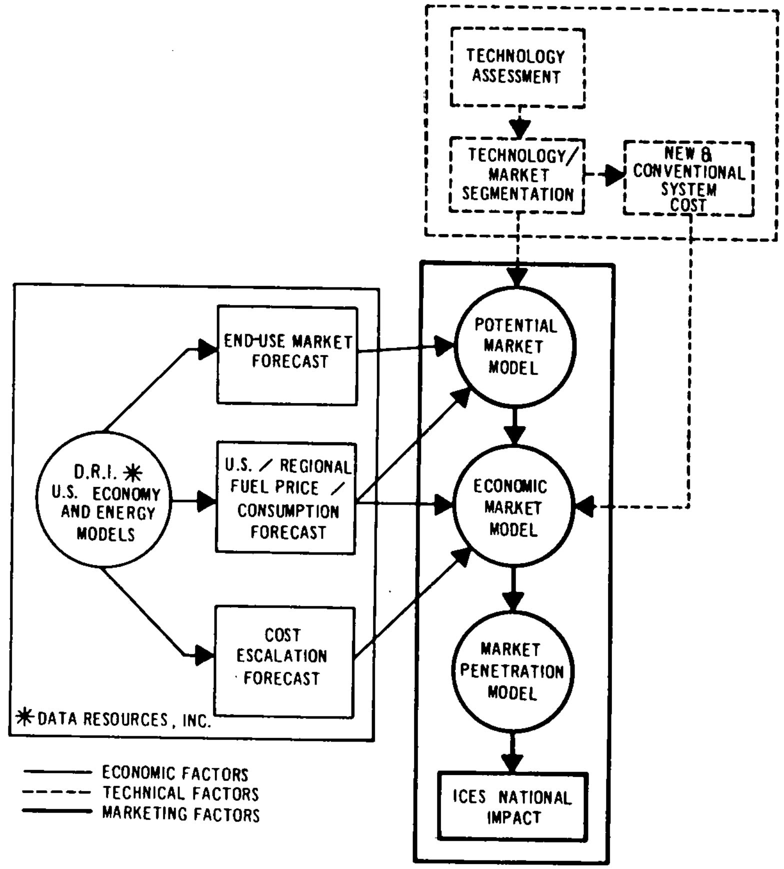


FIGURE 4.

MODEL IDENTIFIES ICES MARKET PENETRATION BY 4 CENSUS REGIONS

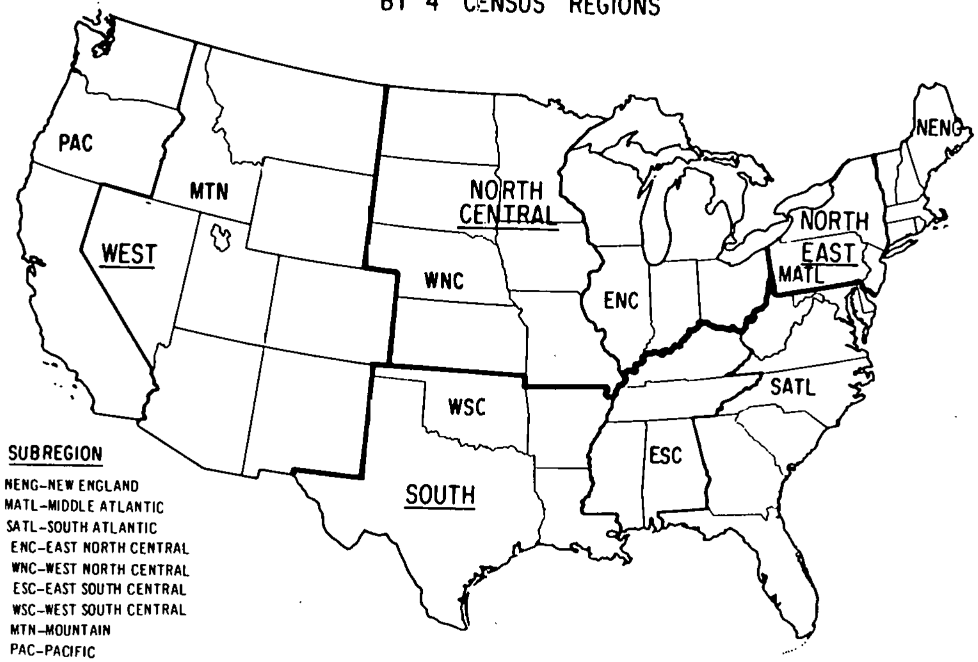


FIGURE 5.

ICES TECHNICAL MARKET BASED ON ENERGY DEMANDS FROM RESIDENTIAL/COMMERCIAL SECTOR

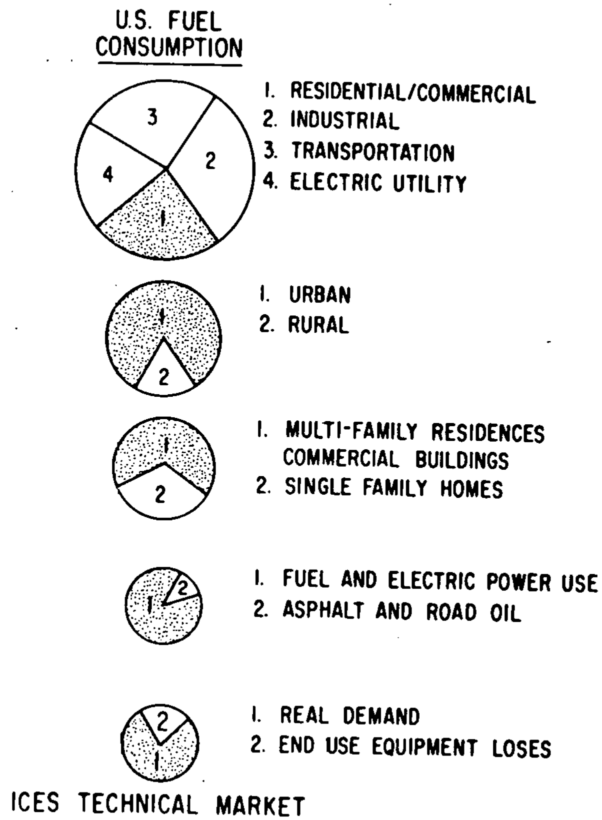


FIGURE 6.
MODEL OF GAS TURBINE PENETRATION IN
ELECTRIC UTILITY PEAK LOAD MARKET

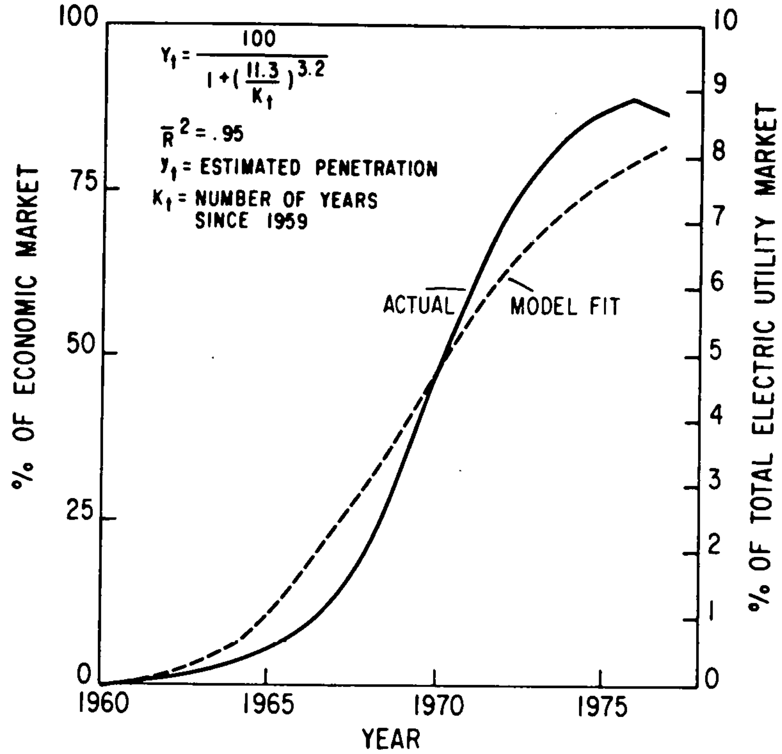


FIGURE 7.

ICES PENETRATION TO CAPTURE 30% OF ITS TECHNICAL MARKET
BY YEAR 2003

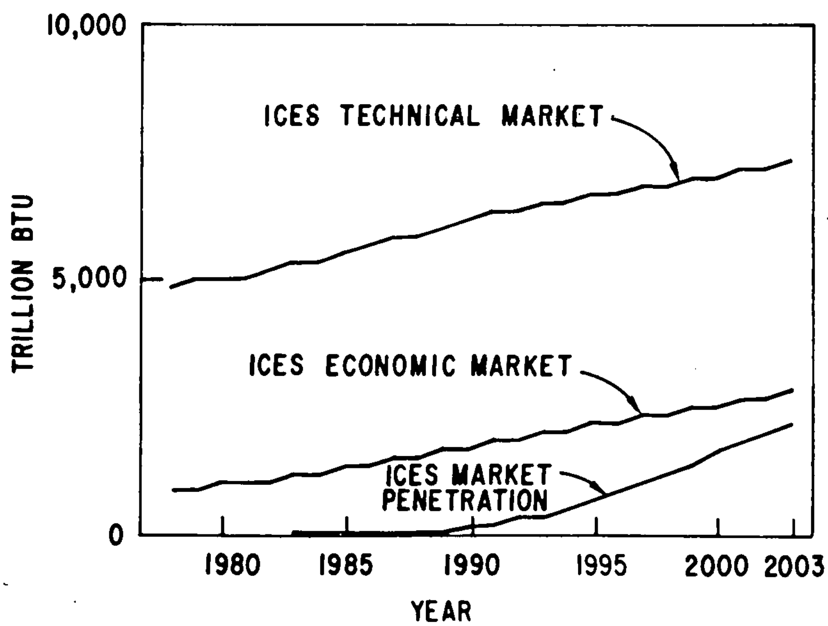


FIGURE 8.

NORTHEAST REGION IS ESTIMATED TO ACCOUNT 40% OF TOTAL ICES PENETRATION BY YEAR 2003

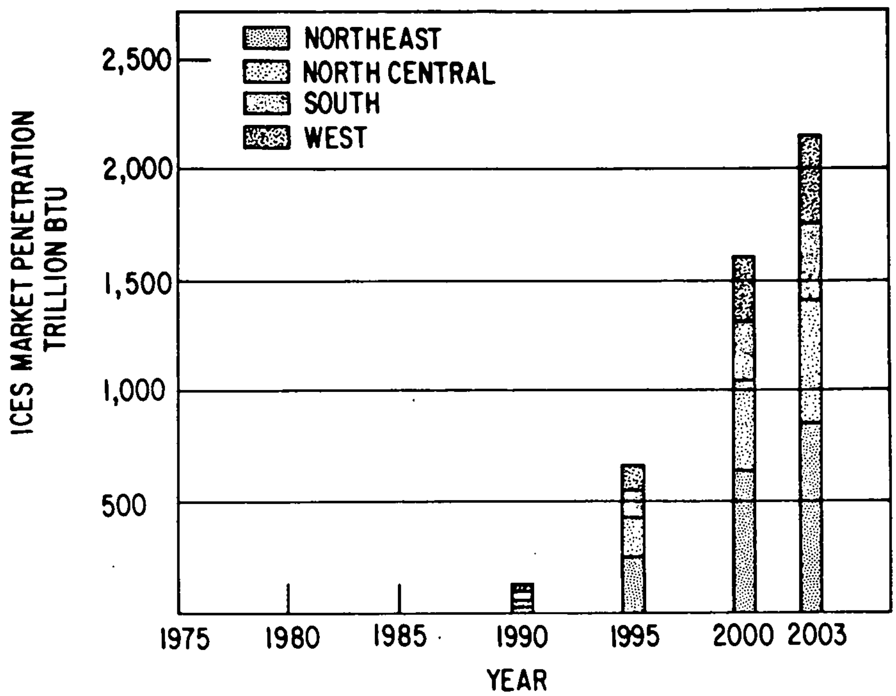


FIGURE 9.

MEDIUM SIZE ICES TO ACCOUNT 50% OF TOTAL PENETRATION IN YEAR 2003