Energy Efficient Technology Diffusion Factors: A Systematic Review

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Abstract— Due to the escalating population and the resulting increase in energy use, the world is faced with the challenge of energy crisis. To mitigate the rise in energy crisis, innovation, adoption, and diffusion of energy efficient technologies is imperative. Review of available literatures indicates that expected improvement in energy consumption has not been achieved in spite of the innovation and improvement in energy efficient technologies. This imbalance points towards the lack of proper adoption and diffusion of these technologies. This paper has looked into prior arts to determine the factors responsible for this diffusion process. Upon identifying the factors, it is evident that some factors can be improved to act as accelerators to the diffusion process. The other set of factors tend to remain as hindrances which can be reduced to an extent, but not removed completely. The paper further investigates the reasons behind these factors and categorizes them under three groups – financial, informational, and behavioral. Findings prove that most of the factors can be attached to a financial cause. Thus research and development alone is not the answer to the rising energy demand, but effective economic motivation is necessary to curb the demand. Future research will look into the present energy policies and group them based on their targeted sector. This will enable to locate the gaps in the policies already implemented and subsequently help in the creation of new policies.

Index Terms— Energy Efficiency, Energy Efficiency Gap, Technology Diffusion, Energy Market Barriers, Energy Market Failues, Technology Adoption, Technology Innovation.

1 Introduction

IN recent years the United States along with the whole world is faced with the most severe energy deficit. A fundamental imbalance between supply and demand defines the nation's energy crisis, which is a product of population and the energy use per capita. This escalating imbalance has increased the need for the innovation, adoption, and diffusion of new and advanced Energy Efficient (EE) technologies. Understanding the process of technological innovation is therefore of utmost importance.

Evidences show that there has been a considerable amount of EE technological improvements throughout the world since late 1970, yet they fail to resolve the current energy crisis. Lack of adoption of EE technologies can be cited as one of the major reasons behind not reaching the desired goal. The present situation provides impetus to investigate the factors that influence the diffusion of EE technologies in order to strategize the diffusion of new EE technologies. Formulation of new energy policies or modifications of the existing ones to focus on the factors that affect the diffusion of the new technologies is bound to improve the present energy deficit.

This research study identified the various factors that might theoretically impede the diffusion of new EE technologies. Subsequnetly, the study focused on exploring to what extent the identified factors identified could be overcome by the efficient implementation of the energy policies. The identified factors have beed classified based on their root causes into three categories: (1) Financial, (2) Informational, and (3) Behavioral. After the analysis of each of the factors, it was apparent that majority of the factors originated from Financial root causes. Proper Governmental interventions targeting the financial cause can ameliorate this problem substantially. Policies that increase the cost of energy, or provide higher economic incentives can benefit the rate of diffusion.

2 Problem Statement

Energy conservation and the use of renewable sources of energy have become important since the oil crisis of 1973. Consequently, sectors that are responsible for a significant share of energy consumption – like the building sector – are of special consideration. The world energy consumption has increased from 285 Quadrillion BTU in 1980 to 462 Quadrillion BTU in 2005 with an expected consumption of 695 Quadrillion BTU in 2030 [1]. Researchers in every field are working closely with the industry for the development of energy efficient technologies. There has been a considerable amount of EE technological improvement throughout the world since late 1970's which is evident from Fig 1. But contrary to this, the consumption of energy has not been reduced as desired. This is due to a slow adoption rate of the EE technologies due to various factors.

The goal of this research study ,was to identify and analyze the various factors, which influence the diffusion of EE technologies.

The specific objectives of the study to accomplish the research goal were as follows:

i. Identify the factors affecting the diffusion of EE technologies.
ii. Characterize the identified factors as market barriers and marlet failures.
iii. Explore the root causes of the identified factors and identify interventions through proper energy efficiency policies.

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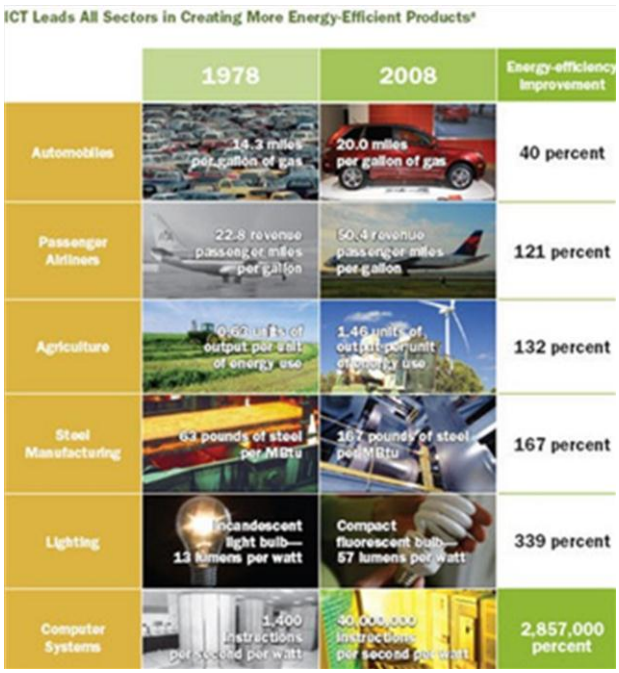

Fig. 1. Percent Energy Efficiency Improvements in different sectors
Source: Environmental Leader.

3 METHODOLOGY

3.1 Data Source

The strategy used for this systematic review was an extensive search of databases such as 'Academic Search Premier', 'Google Scholar', 'ERIC', 'Science Direct', and 'Psychology and Behavioral Sciences Collection'. The key words entered for the search procedure were 'energy', 'efficiency', 'EE technology', 'technology diffusion', and 'technology adoption'. In this process various social, environmental, and psychological journals (e.g., Journal of Applied Psychology, Journal of Environmental Psychology, The Journal of Consumer Affairs, Energy Policy, etc.) were consulted. Further, reference lists of all found articles were reviewed to identify additional published material. This process was repeated till saturation.

3.2 Inclusion and Exclusion Criteria

The entire search process resulted in more than 200 research studies. In order to be selected for the review, it was decided that individual studies that refer to diffusion of EE technologies with specific problems will not be included. Instead, studies that comment on broader perspectives would be included. Additionally, the selection pool was restricted to peer-reviewed articles only. The selection pool was further restricted pertaining to qualitative or quantitative research published since 1973, when the oil crisis drew the attention of researchers. Further exclusion criteria employed were: all articles that were published in languages other than English, articles that were redundant and duplication of published research, and articles that only contained discussion about a single, individual factor associated with residential energy consumption.

4 DIFFUSION OF ENERGY EFFICIENT TECHNOLOGIES

The natural rate of diffusion of new products depends on many factors. It follows its own S-curve where at the very beginning there are less people adopting it, and as time progresses more and more people start using it. Every new product follows the S-Curve shown in Fig 2 with its own slope. Energy efficiency is a relatively new concept, so it might take a while before more and more people gets accustomed to it. The characteristics of the diffusion curve depend on the characteristics of adopters and potential adopters. This may be guided by factors such as the nature of the adopters, the financial ability of the adopters, the advantages of the equipment presently used by the adopters, and their exposure to technologies. This heterogeneous character of the adopters leads to the difference in the expected returns. As a result, only those people to whom the investment seems profitable will be the early adopters. However, over time as the product becomes common and cheaper and the technology becomes widely available more and more people will start adopting it. Thus, a time will reach in the diffusion curve where the slope becomes zero.

In context of EE technologies, it is still in its early adoption phase. The curve exhibits moderate slope testifying the fact that people need to be more aware and educated about the technologies. However, researchers such as Lovins [2] pointed towards alternative sources of energy that were available in abundance, and were renewable and more environment friendly in comparison to the fossil fuels. A consensus regarding the concept of energy efficiency was found among several existing studies, which described energy efficiency as "maintaining or increasing the level of useful output or outcome delivered, while reducing energy consumption" [3].

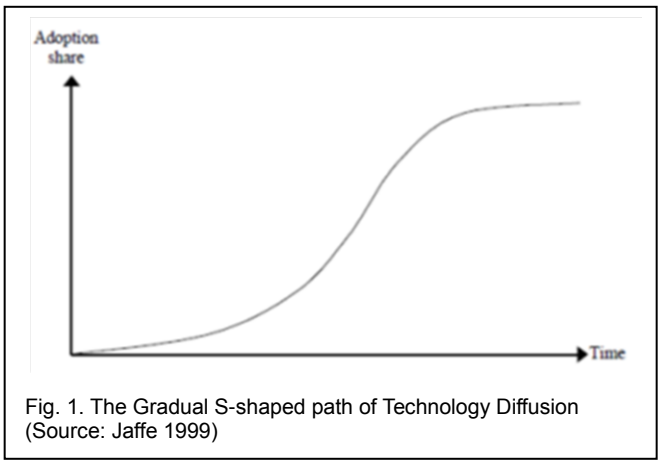

Fig. 1. The Gradual S-shaped path of Technology Diffusion (Source: Jaffe 1999)

The gap (or difference) between the most EE processes and technologies available and those actually in use is referred to as the 'energy efficiency gap'. Jaffe [4] sees energy efficiency from the perspective of use of energy efficient technologies. According to him energy efficiency gap is the gap between the most energy efficient technologies available at some point in

time and those that are actually in use [4]. Based on the available thoughts, this paper defines energy efficiency gap as the targeted energy savings by EE technologies and the actual savings through the use of the technologies.

The views about the aforementioned model of energy efficiency vary within a wide range. Some researchers believe that there cannot be any cost effective solution associated with energy efficiency. On the other hand certain other researchers think that there are certain market barriers which affect the proper implementation of energy efficient technological solutions [5]. The question remains of how much energy efficiency can be achieved after overcoming the market barriers.

5 Factor Affecting Diffusion of Energy Efficient Technologies

In order to explain the concept of energy efficiency gap it is very important to learn about the various impediments, which are either slowing or preventing the process of diffusion of EE technologies. The impediments could be mainly characterized as market barriers and market failures. Both market barriers and market failures could be defined as factors that are detrimental to the diffusion of EE technoogies. The market barriers can be completely transformed into accelerators by proper iplementaion of EE policies. Unlike market barriers, market failures cannot act as accelerators to the diffusion process.

5.1 Market Barriers

Based on comprehensive literature review, this section presents the factors that impedes the diffusion process of EE technologies. However, these barriers can be transformed into accelerators for diffusion process with proper implementation of policies.

a. Failures in Energy Market: Failures in energy markets, so that consumers do not get any information for the future pricing for energy. This creates a confusion regarding the financial benefit and leads to lack of incentive for investing in energy efficiency [3].
b. Organizational Failure: Organizational failures due to the absence of absolute authority of a single decision maker. This is also guided by the presence of decision makers both inside a particular organization as well as in a market. As more people are involved in the decision making, confusion is created and the end result is the failure of organizations to implement energy efficiency [3].
c. Lack of Incentive for Research and Development: Market failure is also caused due to the lack of incentives in private sector for research and development as also due to shortage of information for consumers regarding financial benefit of adopting technologies. Another controversial market failure is due to the limitation of small scale investment in energy efficiency due to financial constraints. This is more of a barrier in the market than a failure.
d. Lack of Financial Incentive by Government: Organizations are not adequately awarded by the Government when they take a step forward and invest in energy efficiency. On the other hand the capital market does not punish for the inefficiencies in energy utilization. Due to the lack of incentives, the organizations tend to continue their traditional practices [4].
e. Estimated Life Efficiency: Upon the launch of any EE product, when its expected efficiency is calculated, certain factors are not considered accurately, which in the long run affect the energy efficiency investment decision.
    1. Uncertainties in the price of technology and energy that can impact the net energy savings for the customers can be one such barrier. This causes reluctance among the customers to invest in EE products in the future as they cannot rely on the expected savings data provided with the product. This effect is amplified when these uncertainties in the energy and technology prices increases. Due to the decrease in technology price people are refraining from investing now with the thought that price may further go down in future.
    2. Other major factors which are not considered during the calculation is the importance of certain variables such as the purchasers discount rate, the investment lifetime, the present cost of the product, etc. The time of return on investment required by the customer might be lesser than the time line considered during the analysis of the product, which create inertia in the customer for investing in such product. Heterogeneity in the nature of the consumers may lead to the differences in the expected return value of the investment.
    3. Studies by Sebold and Fox, Hirst, (PROPER CITATION) and others have found that the actual savings from these investments are around 50% to 80% of the estimated savings by the analysts. This over estimation by the analysts is mostly because projections are often based on theoretical studies which do not necessarily apply to the actual savings in certain situations [4].
f. Mispricing of Energy: The mispricing of energy such as electricity and natural gas, which are set by certain administrative regulatory bodies act as a hindrance in the process of adoption of energy efficient technologies. The cost of energy is based on either average cost or regulated price, and the marginal cost or minimum market price. When the price is below the marginal cost it is seen that it creates an incentive for the consumer to consume more energy as compared to conservation or efficiency [6].

5.2 Market Failures

Unlike the market barriers that could be transformed into accelerators of the diffusion process, this section presents the factors, which cannot be completely eliminated with the implementation of policies. The market failures can be reduced,

but not complete eliminated.

a. Uncertainty of the future energy price: The uncertainty about future energy prices make it difficult to judge the future energy saving with the use of EE products. This makes the people less willing to invest in options where the future savings is uncertain as compared to any other beneficial financial investment where the savings is confirmed.
b. Hidden Cost: There are certain hidden costs associated with the investment in EE products. This refers to cost like the cost of adoption, change, etc. The hidden costs are often not realized by the customer unless he had already invested in the product.
c. Heterogeneous nature of customer: Golove [6] observed that in spite of some technologies being cost effective to a certain class of people,, there might be few who can afford more efficient products while for others the new technology might not be cost effective due to different behavioral trait or usage pattern. This situation is also referred to as aggregation bias. Fig 3 depicts how a technology that may be cost effective across a society may be uneconomical to a subset of that same population.

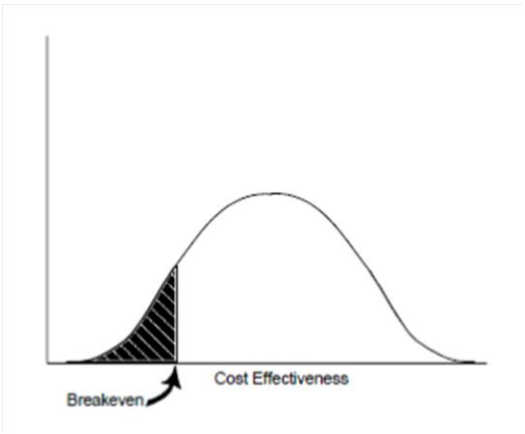

Fig3: Heterogeneity of Customers
(Source: Golove 1996).

d. Selection bias: Sometimes the actual rate of return on certain projects is overestimated since they are preferred than the others. The selection bias can affect the decision of energy efficient investment to a considerable level.
e. Inertia to change: This factor refers to the shortcomings rising from the unwillingness of the consumers to invest in EE technologies, in spite of having higher returns on investment in comparison to that from other avenues of investment [3].
f. Financing: It is often noticed that some of the potential borrowers such as individuals with low-income and the small business owners, cannot afford to invest in EE technologies due to shortage of funds. Research showed when a customer borrows money to invest in EE products its efficiency reduces the risk of the lender, but that on the other hand does not reduce the interest rate [6]. Home mortgages are a typical example of this where the mortgage qualifications are judged based on the borrower's ability to repay the loan within the loan payback period, but does not consider the operating cost of the home being purchased inspite the fact that such cost have a considerable effect on the total cash flow of the home owner.
g. Misplaced Incentives: This refers to situation when the economic benefit does not accrue to the person who invests in the technology. Typical example are landlords who would invest in the new improved EE technologies, but the economic benefits of that investment will be enjoyed by the tenants who are responsible for the payment of the energy bills [6].
h. Market Structure: Due to the way the market is structures, occassionaly the popular and financially stronger firms obstruct the introduction of new improved energy efficient products into the market by their competitor(s) [6].
i. Imperfect Information: Consumers often are not aware of their energy consumption pattern. Neither are they aware of how to reduce the energy consumption. The monthly utility bill gives a whole figure about the total consumption at the end of every month, but it does not give the breakdown of the consumption by the individual equipment. Thus the consumers have minimal idea about the consumption pattern of individual equipment. Kempton and Layne [7] in their research suggested that the utility companies to provide more information in the utility bills if they expect the consumers to use the energy rationally. Koomey et al. [8] in his research interviewed owners and managers of 40 small business organizations and concluded that they are equally ignorant about their monthly energy consumptions as the residential customers.
j. Lack of Information: Like every other market, the energy service market also suffers from lack of future information which includes future energy prices. This uncertainty is one of the principle market barriers for implementation of energy efficiency. The fact that the risks associated with the future uncertainty of energy service market cannot be diversified is unique, and at the same time detrimental to this market.
k. Cost of Information: Limitation of information as well as the high expenses related with the potentially available information, often forces the participants to act without the full array of information. Thus limited access to potentially available information is a prominent failure in energy service market.
l. Accuracy of Information: Due to manipulation of information by the sellers for their own benefit, customers are cynical on the data provided by the sellers. This wary nature of the customers and the costs involved for acquiring additional information act as es-

sential barriers.

m. Ability to utilize Information: Considering the quantity and complexity of information related to EE investment decisions the firms and individuals do not always have the ability to store, retrieve and analyze the information. Added to this is the inexperience and lack of sophistication of the residential consumers to calculate energy savings from investment in efficiency, which prevents the energy service market to move forward.

n. False Notion: This refers to the common thinking among people that EE products are always coupled with other costly feature and cannot be bought separately. With this false impression in mind they are often reluctant to learn more about new products and its costs. One typical example of this can be a refrigerator which can be with or without an ice cream maker [6].

o. Inseparability of Features: Contrast to the above, there are products having certain costly feature not separable depending on the technological limitation or manufacturers' discretion. In certain cases due to technological limitation, in order to make a product more efficient certain features are removed. It is sometimes found that there is a direct tradeoff between energy efficiency of a vehicle and its safety. Thus to make the automobile more efficient its own weight is reduced which might affect its safety [6].

p. Cost of Products: The new EE products are typically much costly than the old affordable ones. With time, the production cost of the technology decreases thus increasing afordability. Fig 4 shows the movement of the energy efficiency and the product cost curve over time. The downward slope of the curve shows the negative tradeoff between the cost and the energy efficiency of a product. Innovation causes the curve to shift inside overtime.

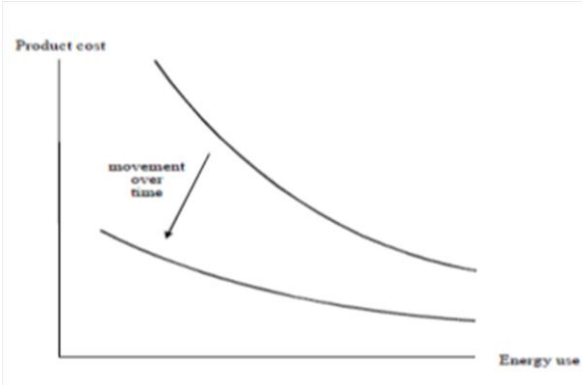

Fig4: Innovation in Product Characteristics
Source: Jaffe 1999.

6 Analysis of Factors affecting the Diffusion of Energy Efficient Technologies

The factors discussed in the previous sections were categorized based on their root causes namely behavioral, financial and lack of information. Some of the factors fall under one of the category, while there are factors that can be included in more than one category. The factors categorized based on the root causes have been listed in Table 1 distinguishing them as market barriers or market failures.

Financial: This category includes the factors pertaining to monetary receipts, expenditures and return over investment. The factors categorized as financial factors are: (1) Failures in Energy Market, (2) Lack of Incentive for Research a Development, (3) Lack of Financial Incentive by Government, (4) Estimated Life Efficiency, (5) Mispricing of Energy, (6) Uncertainty of the future energy price, (7) Hidden cost, (8) Selection biasness, (9) Financing, (10) Misplaced incentive, (11) Market Structure, (12) The cost of Information, and (13) Cost of Product.

Behavioral: The factors, which were generated due to customer nature, behavior and biases were included in this category.. The factors categorized as behavioral factors are:

1. Organizational Failure
2. Estimated Life Efficiency
3. Heterogeneous nature of customer
4. Selection Biasness
5. Inertia to change
6. Misplaced incentive
7. False Notion
8. Inseparability feature

Informational: Some of the factors discussed the previous sections were generated as a result of lack of information among the customers and the manufacturers. The factors, which were categorized as behavioral factors are:

1. Estimated Life Efficiency
2. Uncertainty of the future energy price
3. Hidden Cost
4. Market Structure
5. Imperfect Information
6. Lack of Information
7. The cost of Information
8. The accuracy of information
9. Ability to act upon information

No.	FACTORS	Type	Financial	Behavioral	Informational
1.	Failures in Energy Market	B	√		
2.	Organizational Failure	B		√	
3.	Lack of Incentive for Research a Development	B	√		

4.	Lack of Financial Incentive by Government	B	√		
5.	Estimated Life Efficiency	B	√	√	√
6.	Mispricing of Energy	B	√		
7.	Uncertainty of the future energy price	F	√		√
8.	Hidden Cost	F	√		√
9.	Heterogeneous nature of customer	F		√	
10.	Selection biasness	F	√	√	
11.	Inertia to change	F		√	
12.	Financing	F	√		
13.	Misplaced Incentives	F	√	√	
14.	Market Structure	F	√		√
15.	Imperfect Information	F			√
16.	Lack of Information	F			√
17.	The cost of information	F	√		√
18.	The accuracy of information	F			√
19.	The ability to use or act upon information	F			√
20.	False Notion	F		√	
21.	Inseparability of Features	F		√	
22.	Cost of Products	F	√		

Fig 5 shows that most of the factors previously discussed can be categorized under the financial category. As a coraollary, energy policies targeting the financial sector can effect substantial modifications to the diffusion process of EE technologies.

Policies that raise the cost of energy, or provide more economic incentives can benefit the rate of diffusion. An alternative method of providing financial incentives can be in the form of subsidies for the development and introduction of new technologies, institutional reforms such as changes in building codes, and utility regulations. Application of technology mandates such as fuel economy standards for automobiles or use of renewable energy sources can also be considered to be viable strategies to promote energy efficiency. It is beyond doubt that the previously discussed suggestions will increase energy efficiency and help in reducing green house gas emision. But the cost viability of these programs for both individuals as well as organizations may pose a hint if concern. Though it is argued that upfront costs are negligible compared to the overall cost savings with the efficient use of energy, Government has to take leadership roles to overcome the roadblocks due to poorly designed instituions and lack of awareness among majority of consumers.

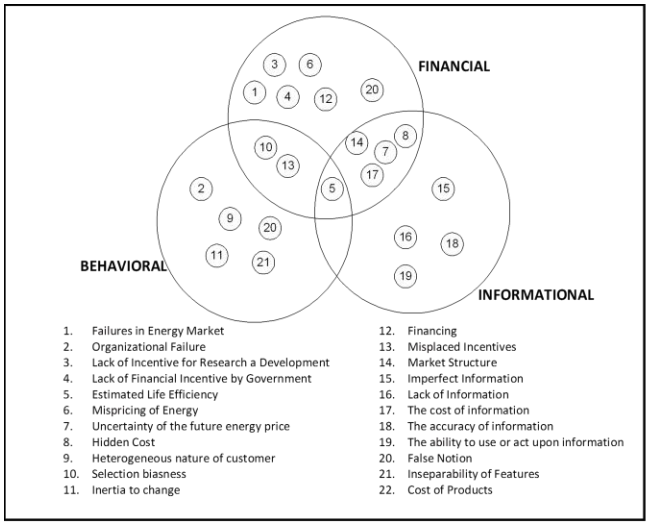

Fig5: Categorization of Factors

This study is a part of a larger study that included among other things analyses of the present energy policies. The findings of this research study provided the baseline information as well as the point of departure to perform the analyses of the energy policies and categorize them based on their target sectors, such as financial, informational or behavioral. This initiative will demonstrate the gaps in the current energy policies and provide a blueprint to rectify the shortcomings.

7 Conclusion

Following the energy crisis in 1970s, people became aware of energy efficiency. Consequently, there have been a considerable amount of EE technologies being developed to curb the soaring energy consumption in the building sector. However, there is a clear disparity between the expected energy savings from the utilization of the EE technologies and the actual realized savings. Lack of adoption of EE technologies can be cited as one of the major reasons for not reacing the targeted energy savings. The current situation motivated the present research study to investigate the various factors, which influence the diffusion process of the EE technologies. Following an exhaustive literature review, a comprehensive list of factors was identified. The factors were then characterized as market barriers and market failures. While both the market barriers and the market failures are detrimental to the diffusion of EE technologies, unlike market failures, market barriers can be transformed into accelerators with the aid of proper policy implementation. Further, the factors were catego-

rized into three categories namely financial, informational, and bevioral based on the root causes of the respective factors.

After analyzing all the factors and looking into the causal relationship of those factors with the diffusion of EE technologies, it was evident that financial cause guides most of the factors. As a result only continuous motivation for research and development to find answer for the diffusion of EE technologies will not serve the purpose. To make it effective, economic motivations in the form of escalating price of energy and diminishing price of technological alternatives due to innovation should be introduced in the market. Along with the economic incentives, policies and Government mandates also play critical role in the diffusion of energy efficient technologies. However, due to the diverse nature of market failure it will not be wise to depend only on one policy instrument to achieve the cost effective diffusion of energy efficient technologies. A precise package of policy instruments will be more effective to overcome the market failures and facilitate the successful diffusion of EE technologies.

REFERENCES

[1] International Energy Outlook 2007 (May 2007). <http://www.eia.doe.gov/oiaf/ieo/world.html>. Accessed May 19th 2008.

[2] A. B. Lovins, "Energy Strategy: The Road Not Taken," pp.

[3] ACG, "The Energy Efficiency Gap: Market failures and POlicy Options," pp.

[4] A. B. Jaffe, R. G. Newell, & R. N. Stavins, "Energy-Efficient Technologies and Climate Change Policies: Issues and Evidence " *Climate Issues Working Paper No. 19; KSG Working Paper,* vol. pp.

[5] M. D. Levine, E. Hirst, J. G. Koomey, J. E. McMahon, & A. H. Sanstad, "Energy Efficiency, Market Failures, and Governmental Policy," *LBNL-35376,* vol. pp.

[6] Market Barriers to Energy Efficiency: A Critical Reappraisal of the Rationale for Public Policies to Promote Energy Efficiency (1996). http://eetd.lbl.gov/ea/EMS/reports/38059.pdf.

[7] W. Kempton, & L. L. Layne, "The consumer's energy analysis environment," *Energy Policy,* vol.22, No.10, pp. 857-866,

[8] J. G. Koomey, M. A. Atkinson, J. E. McMahon, S. Boghosian, B. Atkinson, I. Turiel, et al., "The Potential For Electricity Efficiency Improvements in the U.S. Residential Sector," *LBL,* vol.*30377*, pp. July