ENERGY EFFICIENCY IMPROVEMENT AND CARBON DIOXIDE EMISSION REDUCTION IN PVC RESIN INDUSTRY IN THAILAND

MS. NARISARA WANICHWATANYU
ID: 55300700524

A THESIS SUBMITTED AS A PART OF THE REQUIREMENTS
FOR THE DEGREE OF MASTER OF ENGINEERING
IN ENERGY TECHNOLOGY AND MANAGEMENT

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Thesis Committee

....	
(Dr.Athikom Bangviwat)	Advisor
Jindarat Pimsamarn	
(Asst. Prof. Dr. Jindarat Pimsamarn)	Member
....	
(Dr. Boonrod Sajjakulnukit)	Member
Somchart Chantasiriwan	
(Prof. Dr.Somchart Chantasiriwan)	External Examiner

Thesis Title: Energy Efficiency Improvement and Carbon Dioxide Emission Reduction in PVC Resin Industry in Thailand

Student's name, organization and telephone/fax numbers/e-mail

Miss Narisara Wanichwatanyu
The Joint Graduate School of Energy and Environment (JGSEE)
King Mongkut's University of Technology Thonburi (KMUTT)
126 Pracha Uthit Rd., Bangmod, Tungkru, Bangkok 10140 Thailand
Telephone: 0-8754-32376
E-mail: narisara.wanich@gmail.com , siligagle_sine@hotmail.com

Supervisor's name, organization and telephone/fax numbers/e-mail

Dr.Athikom Bangviwat
The Joint Graduate School of Energy and Environment (JGSEE)
King Mongkut's University of Technology Thonburi (KMUTT)
126 Pracha Uthit Rd., Bangmod, Tungkru, Bangkok 10140 Thailand
Tel: 02-872-9014 ext. 4136
Fax: 02-427-9634
Email: athikom@jgsee.kmutt.ac.th

Topic: Energy efficiency improvement and carbon dioxide emission reduction in PVC resin industry in Thailand

Name of student: Ms. Narisara wanichwatanyu **Student ID:** 55300700524

Name of supervisor: Dr. Athikom Banviwat

ABSTRACT

The objective of this research is to determine the energy saving potential and carbon dioxide emission reduction of the polyvinyl chloride (PVC) resin industry in Thailand by using bottom-up energy conservation supply curves (CSC) for electricity and fuel. Measures of energy saving and their costs are obtained from annual energy reports and personal interviews. CSC was constructed by plotting costs of conserved energy against amounts of energy saved for all potential measures. The results show that the total technical potentials of electricity, steam, and natural gas for the Thai PVC resin industry in 2013 are equal to 25,335 MWh per year, 403,631 and 501,000 GJ per year, respectively. The economic potentials of electricity, steam, and natural gas, which have their costs of saving less than energy costs, are equal to 16,625 MWh per year, 369,664 GJ, and 491,857 GJ per year respectively. The Carbon dioxide emission reduction potential associated with total economic potential of electricity, steam, and natural gas are 6,986, 43,150, and 57,413 tCO2, respectively.

Furthermore, the value of energy saving potential in the Thai PVC resin industry is equal to 310 million baht per year as compared to the total cost of energy used at 2,358 million Baht per year or accounting for 13.15% of the total energy used. The cost of electricity and fuel used in Thai PVC resin industry in 2013 are equal to 1,046 and 1,312 million Baht respectively, while the values of saving potentials in electricity and fuel (thermal) equal to 66 and 254 million Baht respectively, accounting for 6.31% and 19.36% of the electricity and fuel costs respectively.

Keywords: PVC resin industry; energy efficiency; electricity saving potential; carbon dioxide emission

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CHAPTER 1
INTRODUCTION

1.1. Rational/Problem Statement

At present, the industrial sector is the most energy-consuming sector in Thailand, accounting for 36.7% of the total final energy consumption in 2012 [1]. The industrial sector has continued to grow rapidly which results in the higher demand of energy consumption for production processes. Generally, the chemical industry is one of the most energy intensive sectors in Thailand. Its energy consumption accounts for 15.4% [1]. The energy intensity of the chemical industry in 2011, moreover, was increased continuously by about 24.11% compared to the overall energy intensity in 2012 [1]. Specifically, Thailand Plastic Resin industry has energy consumption growing in 2012 by about 5.5% (Figure 1.1), which that constitutes more than 80% of overall demand of energy consumption. Plastic resins are commonly used and produced in Thailand are polyethylene (PE), polypropylene (PP), polystyrene (PS), and polyvinyl chloride (PVC).

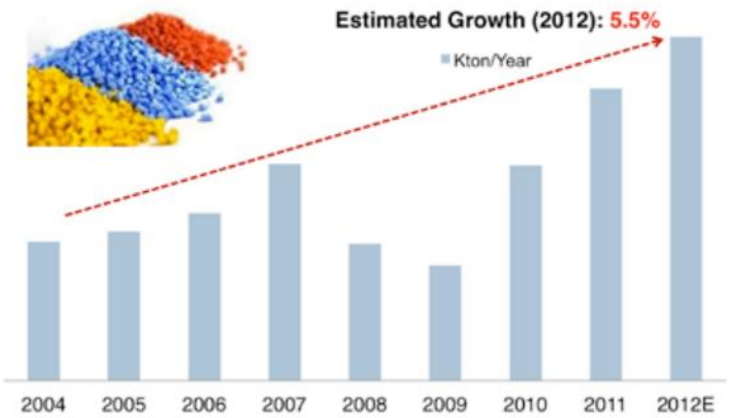


Figure 1.1 Thailand plastic resin consumption, 2002-2012 [2]

For these four types of plastic resins, the production capacity can sufficiently supply domestic demand and produce a high surplus for export. Engineering-grade plastic resins are generally imported, because of their complexity and high technological requirements of the production process. Due to the low production potential and technology and the lack of the high quality of raw materials, Thailand's production capacity of these kinds of plastics covers only 10% of domestic demand [3].

Particularly, the PVC resin business has been rapidly growing, about 20% in 2012, and it win increase more rapidly in the future than win the other plastic resin businesses. Furthermore, the PVC production capacity of Thailand is not only in the first South East Asia's rank but also in the seventh of Asia and twelfth of the world in 2012. It clearly indicates that Thailand is the one of leader of PVC producers. Therefore, the studying and understanding the energy efficiency improvement and evaluating carbon dioxide emission reduction of the PVC resin production processes in Thailand are necessary and important.

Consequently, in order to study the energy efficiency improvement and to evaluate carbon dioxide emission reduction of the PVC resin production processes in Thailand based on information of case study or Thai polyvinyl chloride (PVC) resin factory, the energy efficiency improvement was determined by developing a bottom-up approach. The energy conservation supply curves (ECSC) model was constructed so as to analyze the Thai economic potential as well.

1.2. Literature reviews

1.2.1. The use of conservation supply curve of energy efficiency and CO_2 emission in industry

Ali Hasanbeigi et al. [4] employed the bottom-up CSC model, the cumulative cost-effective and technical electricity and fuel savings, as well as the CO_2 emission reduction potentials in order to study the energy efficiency and CO_2 emissions of the Chinese cement industry in 2010–2030. The results firstly showed that the electricity of CSC model, the cumulative cost-effective electricity savings potential for Chinese cement industry for 2010–2030 was estimated to be 247 TWh, and the total technical electricity saving potential was 272 TWh. The CO_2 emission reduction connected to cost-effective electricity savings was 138 Mt CO_2 and the CO_2 emission reduction associated with technical electricity saving potential was 153 Mt CO_2. Finally, The fuel CSC model for the cement industry suggested cumulative cost-effective fuel savings potential of 4106 PJ, which was equivalent to the total technical potential with associated CO_2 emission reductions of 384 Mt CO_2.

Winyuchakrit et al. [5] analyzed the demand side of CO_2 mitigation. The results exhibited that in 2005, the per capita emission for Thailand was about 3.1 t-CO_2/year. In 2030, it would be increased to 8.2 t-CO_2/year and 5.9 t-CO_2/year without and with climate change mitigation measures, respectively.

Maarten Neelis et al. [6] performed bottom-up analyses of energy use and CO_2 emissions associated with the processes in the Netherlands. The total amount of CO_2 emissions associated with the processes was 20.4 Mt CO_2, which was more than 90% of the emissions in the chemical industry. The emissions was the sum of fuel used in the olefin production (5.1 Mt CO_2, 22%), the ammonia and methanol production (6.1 Mt CO_2, 30%), other fuel/electricity use (7.6 Mt CO_2, 37%) and carbon losses resulting from non-selectivity (1.6 Mt CO_2, 11%). Theses carbon losses from non-selectivity were estimated to be 35 Mt CO_2 worldwide.

Ernst Worrell et al. [7] applied a bottom-up energy supply curve to determine the cost-effective energy efficiency and the carbon dioxide emissions reduction opportunities in the US iron and steel industry. It was found that the total cost-effective reduction potential of 3.8 GJ/t, having a payback period of three years or less. This was equivalent to a potential energy efficiency improvement of 18% of 1994 US iron and steel energy use and it was roughly equivalent to 19% reduction of 1994 US iron and steel carbon dioxide emissions.

1.2.2. Energy efficiency improvement potentials by Best Practice Technology in chemical processes

Analyses by international energy agencies makes use of a *top-down* approach in order to estimate the energy saving potential by comparing the current performance of the sector to the Best Practice Technology (BPT) or determining the energy efficiency improvement potentials in the chemical and petrochemical sectors. To this end BPT energy use is compared with current energy use according to IEA energy statistics. In table 1 shows the results of the indicator analysis (*Top-down* approach), according to which the BPT energy use for the chemical and petrochemical sector is 27.0 EJ (excluding electricity). Actual energy use in 2006 according to energy statistics was 31.5 EJ, resulting in an energy saving potential of around 4.5 EJ/year (excluding electricity).The comparison of the country results of the indicator analysis leads to the following main findings:

- Energy efficiency improvement potentials through the use of BPTs are of the order of 5 -15% in Brazil, Canada, Japan, France, Italy, and Taiwan.

- In some other countries, such as Saudi Arabia and the United States, the potentials are found to be higher, i.e., in the order of 20% or more.
- India and China are exceptions with negative improvement potentials, indicating that the current practice is more efficient than BPT. As explained below, this is partly related to the decision to base BPTs on coal and oil as feed stocks, instead of natural gas.
- Negative improvement potentials are also found for South Korea, Germany and The Benelux countries which again imply that the existing processes are, on average, more efficient than BPT.

Table 1.1 Energy efficiency potential of the chemical and petrochemical sectors by application of Best Practice Technology (Top-down approach) for selected countries, 2006 (including both process energy and feedstock use) [8]

Country	Final process energy and feedstock use (incl. electricity)				Final process energy and feedstock use (excl. electricity)			
	Reported Energy Use (PJ/yr)	BPT Energy Use (PJ/yr)	EEI	Improve-ment potentials	Reported Energy Use (PJ/yr)	BPT Energy Use (PJ/yr)	EEI	Improve-ment potential
USA	7321	5655	0.77	22.7%	6412	4928	0.77	23.1%
China	5323	5332	1.00	(-0.2)%	4301	4514	1.05	(-5.0)%
Japan	2252	1959	0.87	13.0%	2053	1800	0.88	12.3%
South Korea	1562	1594	1.02	(-2.1)%	1416	1477	1.04	(-4.3)%
Saudi Arabia	1369	1058	0.77	22.7%	1369	1058	0.77	22.7%
Germany	1241	1209	0.97	2.6%	1064	1068	1.00	(-0.3)%
India	1096	1133	1.03	(-3.3)%	1096	1133	1.03	(-3.3)%
Benelux Countries	1092	1147	1.05	(-5.1)%	1004	1077	1.07	(-7.3)%
Taiwan	859	738	0.85	14.1%	736	640	0.87	13.1%
Canada	843	766	0.91	9.2%	776	712	0.92	8.2%
France	714	631	0.88	11.5%	627	561	0.90	10.5%
Brazil	651	576	0.88	11.6%	572	513	0.90	10.4%
Italy	457	408	0.89	10.7%	389	354	0.91	9.1%
World	35217	29940	0.85	15.0%	31529	26990	0.86	14.4%

Maarten Neelis et al. [9] studied the energy efficiency trends in the Dutch manufacturing industry between 1995 and 2003, using indicators based on publicly available physical production and specific energy consumption data, and developed a reliable top-down monitoring framework for studying the energy efficiency trends of the manufacturing industry. They estimated that efficiency improvements at 3.2% per year on average between 1995 and 2003, excluding non-energy use (95% confidence range between 2.6% and 3.8%). This was equivalent to 103 PJ savings on primary energy use per year. Increased use of combined heat and power contributes 9 PJ to this total. Between 1995 and 2003, the reference energy use increased by 35% and the actual energy use by only 20%, resulting in an observed EEI of 0.89 in 2003, i.e. an energy efficiency improvement of 11% in this time period. If the non-covered products have grown in this period by only 20% rather than 35%, the actual energy efficiency improvement for the industry is only 7.5% instead of the 11.0% observed. If, on the other hand, the growth rate of the non-covered products has been 50%, actual savings would be 14.2% rather than the observed 11.0%.

D. Saygin et al. [10] analyzed the German basic chemical industry's energy use and energy efficiency improvements in the period between 1995 and 2008 by using a bottom-up model and compared the results to data from the German Energy Balances, and with data published by the International Energy Agency (IEA). The observed energy efficiency improvements range between 2.2 and 3.5% per year.

1.2.3. Energy conservation measures in the petrochemical industry

This can be divided into two levels:

1) Development and improvement of production technology

2) Energy efficiency improvement for processes and equipment

1.2.3.1. Development and improvement of production technology

There are two major types of energy that have been used in the production processes of petrochemical industries: thermal and mechanical energies. Mechanical energy is used to control the working conditions of equipment, i.e. control the system pressure, and mixing the chemicals. Mechanical energy is mostly generated from electrical energy. Thermal energy is used in many activities, such as preheat raw materials before entering reactors, heat for chemical reactions, and energy for chemicals separation. Energy conservation is achieved by changing and improving production process technologies to facilitate less energy consumption, i.e. reduce the production temperature or reduce the production pressure. The following section provides few developed technologies that have been applied to the petrochemical industries.

Table 1.2 Some Technologies Developed for the Petroleum and Petrochemical Industry

Technology	Sample
1) Process control	Natural networks, Knowledge-based system
2) Process optimization and Integration	Analytical tools, Site integration, Advance process control
3) Catalytic (catalyst and reactor)	Catalysts with higher selectivity, increase time life
4) Reactor design, Advance distillation column	Process intensification, Reactive distillation, Dividing-wall column
5) Bio-technology for treatment facilities	Bio-feedstock, Bio-Treatment
6) Combustion technology	Low NOx burner, High efficiency burner
7) Utilities	Reverse osmosis (RO), Low maintenance pump
8) Power Generation	Co-generation, Gasification, Power recovery
9) Others	Dehydrogenetion, Hydro-pyrolysis (non-catalytic), Byproduct upgrading technologies, Using heavy feedstock

1.2.3.2 Energy-efficiency technologies and measures for chemical industry sector [11-13]

This subsection provides descriptions of the industrial measures. The first measure, which cuts across industries is described, followed by descriptions of the industrial specific measures

Table 1.3 Cross-cutting Electricity Efficiency Measures

INDUSTRIAL MEASURES	
Cross-Cutting Electricity Efficiency Measures	
Measures	**Details**
Motors	
Replace motors	To replace existing motors with high-efficiency motors
Adjustable speed drives (ASDs)	To adjust motor speed drives match to load
Power factor correction	To reduce the magnitude of reactive power in the system by installing capacitors in the AC circuit and replacing motors with premium-efficient motors
Minimizing voltage unbalances	By regularly monitoring the voltages at the motor terminal and through regular thermo graphic inspections of motors
Motor practices	Proper motor maintenance

INDUSTRIAL MEASURES	
Cross-Cutting Electricity Efficiency Measures	
Measures	**Details**
Compressed air	
Operation and maintenance (O&M)	Better maintenance to decrease costs
Turn off unnecessary compressed air	To turn off unneeded compressors or delay bringing on additional compressor until needed
Reduce leaks in pipes and equipment	Leak repair and maintenance
Use air at lowest possible pressure	To perform at maximum energy efficiency such as minimizing pressure
Load management	To monitor whether in full operation or not, partial load operation should be avoided
Minimize pressure drop in design of distribution system	To minimize pressure drop to reduce energy loss
Sizing	The proper sizing compressors, regulators, and distribution pipes
Pumps	
Operation and maintenance (O&M)	Better maintenance to decrease costs
Controls	To shut of unneeded pumps or, alternatively, to reduce pump load until needed
System optimization	To perform at maximum energy efficiency such as installing multiple pumps for variable loads
Sizing	To reduce pump size, peak load also
Cooling circulation pump-variation speed drives (VSDs)	To consider the installation of VSDs on cooling circulation pumps
Replace v-belts	To replace v-belt drives with direct couplings
Building	
Replace T-12	To replace T-12 by T-8 and electronic ballasts
Replace fluorescent	To replace mercury or fluorescent lamps with metal halide lamp
Switch off/O&M	To train personnel to switch off light when not needed
Controls/sensors	To be shut off during non-working hours automatic controls such as occupancy sensors
Super T-8s	To use super T-8 fluorescent systems
HVAC management system	
Cooling system improvements	To improve the efficiency of chillers by lowering the temperature of condenser water
Duct/pipe insulation/leakage	To install duct insulation and perform regular duct inspection and maintenance
Window film	To use low-emittance windows for improving window insulation
Programmable thermostat	To control temperature settings of space heating and cooling and optimize settings based on occupancy and use of the building
Setback temperatures (weekend and off duty)	To set back building temperature during period of non-use such as weekends or non-production times
ENERGY STAR transformers	To replace existing transformers by ENERGY STAR transformers

Table 1.4 Efficiency Measures in Chemical industry

INDUSTRIAL MEASURES	
CHAMICAL	
Clean room – controls	To reduce recirculation air change rates
Clean room - new designs	To use new design room for improved air filtration and the use of cooling towers in lieu of water chillers
Process control (batch + site)	To implement computer-based process controls for monitoring and optimizing energy consumption
Power recovery	To use recovered power for equipment operated at elevated pressure
O&M - extruders/injection molding	To improve and maintenance procedures of extruders
Extruders/injection molding – multi pump	To use multiple pumps and an appropriate control system
Direct drive extruders	To use a direct drive instead of a gearbox r belt
Injection molding - impulse cooling	To use impulse cooling for regulating the cooling water to increase cooling rate and reduce productivity
Injection molding - direct drive	To use a direct drive instead of a gearbox r belt

1.2.4. Overview of Thai Plastic Resin Industry

Thailand has capabilities in manufacturing both polymer products or raw materials, and plastic products or final goods. Polymer products can be divided into three main types by grade. First type is conventional or commodity grade. Thailand is very capable in the production of conventional grade polymer products namely polyethylene (PE), polypropylene (PP), polystyrene (PS), and polyvinyl chloride (PVC). These products are relatively cheap to produce and can be used in a wide variety of commodities production. The second type is engineering grade. This type of polymer products is used in engineering works which need the strong plastic instead of metal. The price is relatively high compared to conventional grade. The last one is the specialty grade. This type of polymer plastic is used for specific purposes, such as when a heat resistant or acid resistant plastic is needed. Specialty grade is relatively expensive more than the entire kinds of plastic. Thailand is still unable to produce specialty grade plastics due to the necessary high production technology needed. Hence, in order to respond the domestic needs, Thailand has to import specialty grade plastics [14].

The plastics industry is an important market for absorbing the production supply of and stimulating growth in the petrochemical industry of a country, as the petrochemical industry consumes about 70% of Thailand's annual total output of polymers and resins. Petrochemical industries are important sources of many other industries that require plastic components as part of their final products. Therefore, the development of the plastics industry is an important mechanism to drive the development of other related industries leads to the industrial development of the country as a whole. [15]

Moreover, the demands for polymers in the manufacturing of plastic products, which are normally supplied into downstream industries, are summarized in Table 1.5. It reveals that almost half of total domestic consumption of polymers (46.5%) in 2007 went to the packaging industry, followed by the textile industry (18%), the construction industry (10%), the electrical and electronic industry (7%), the automotive industry (6%), and agriculture industry (2%), respectively.[25]

Table 1.5 Polymer Consumption in each Industry [25]

Industry Group	Proportion (%)		
	2005	2006	2007
Grand total	100	100	100
Agriculture	2	2	2
Automotive	5	5	6
Construction	11	10	10
Electrical & Electronics	7	7	7
Other	14	13	12
Packaging (Incl. bottles & containers)	45	44	47
Textile	16	19	18

Table 1.5 also illustrates the links between, and the supporting roles of the plastic industry to many other important Thai industries. While the plastic industry can create a great deal of value for other industries, the growth, and the potential of other industries have a direct effect on the production growth and market expansion of plastics industry as well.

Economic Value of the Thai Plastic Sector

The exports of Thailand's polymers and plastic products have important economic value to the Thai economy, bringing in approximately US$ 8.2 billion worth of foreign currency in 2008, making Thailand the 12th largest exporter in this sector. The value of the

2008 plastic industry export contributed 4.6% of Thailand's total exports, and 3.1% of Thailand's GDP.

Table 1.6 Economic Values of Plastic Industry

(US$ million)

Economic value	2006	2007	2008	% Δ 2007/2008
Total export value of Thailand	129.7	153.9	177.8	15.5
Export value of Plastic Sector	6490.4	7549.1	8162.4	8.1
Share in total Thai exports	5.0%	4.9%	4.5%	-6.4
Share in Thai GDP	3.2%	3.1%	3.1%	1.8

Thailand has a very strong potential in the petrochemical industry, and is able to both meet local demand and create a surplus for exporting, worth US$ 5.4 billion in 2008. These exports contributed significantly to the 2008 trade surplus, which was worth US$ 2.1 billion. However, the potential in the plastic products industry is not very strong, and has caused a deficit of US$ 108 million. This weakness is due to the industry's lack of high technology and high grade raw materials, which leads to a lacking capability in adding higher value to the final products. The result is that Thailand is able export comparatively cheap products, but has to import the more expensive goods [25].

1.2.5. Overview of Thai PVC industries

Polyvinyl chloride (or vinyl) has stable physical properties, and excellent transparency (Plastics Technology Center). It is often used as packaging, film and sheet, hose, pipe, and tubing, appliance housings, bottles, squeeze tubes, automotive trim pieces, business equipment components, construction and vinyl siding, etc. The vinyl products can be divided into rigid and flexible materials. Rigid applications, accounting for 60% of total vinyl production, are concentrated in construction markets, which include pipe and fittings, siding, carpet backing, and windows. Bottles and packaging sheet are also major rigid markets. Flexible vinyl is generally used in wire and cable insulation, film and sheet, floor coverings, synthetic leather products, coatings, blood bags, medical tubing and many other applications [16].

In Asia, the growth rate is as big as 4.5%. This high rate is based on rapid growth of PVC industries in China, India and other ASEAN counties. Fig. 1.2 presents the trends and predictions of PVC demand in Asia. It demonstrates that the annual growth rate of

Asian PVC demand from 1990 to 1997 was 6.6%. Growth rate after 1997 was predicted as 4.5% per year. Industrialized countries in Asia, such as Japan, Korea, and Taiwan, PVC industries are almost in matured stage. Big growth rates are predicted for China and India. Especially in China, growth rate will be increased continuously and it is predicted to be 10.7% per year. Development of Chinese PVC demand at the beginning of 21st century is noteworthy because of their very big capacity of demand.

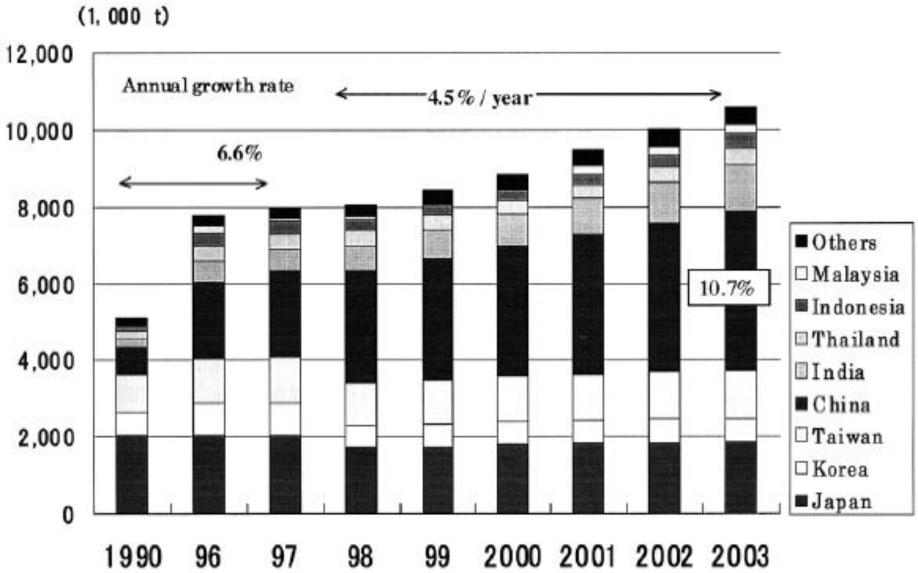


Figure 1.2 Trend of Asian PVC demands. Reprinted with permission from the Data of the advisory committee for the Basic Industries Bureau of Ministry of International Trade and Industry (MITI), Japan [5]

Introduction of polyvinyl chloride

PVC is a synthetic plastic that is used widely nowadays, because PVC is not corroded by chemicals, insoluble in polar solvents, non-flammable and has a high constant dielectric. The chemical structure of the subunits is:

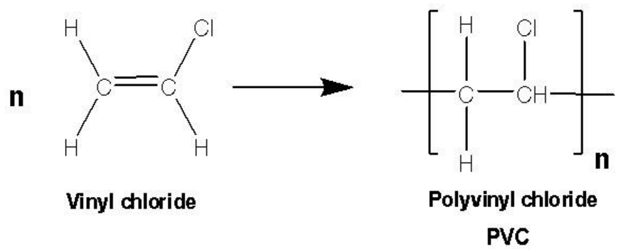


Figure 1.3 Sub molecule of Polyvinyl chloride

Fig. 1.3 shows that the large chlorine atoms attached to the carbon atoms in the structure of PVC. PVC is a synthetic plastic that is used widely nowadays because it is not corroded by chemicals, is insoluble in polar solvents, is non-flammable and has a high constant dielectric [9-10]. The melting temperature of PVC is approximately 212^{o}C. In addition, the chlorine atom molecules also cause polarity (dipole moment) between the chain molecules of PVC. PVC has a temperature of glass transition (T_g) of about 87^{o}C, which is quite high and hardness. Therefore, it is difficult to bring only PVC through the process. Thus, the addition of certain chemicals to assist in the process to produce PVC products is essential. The addition of lubricant will result in the PVC flowing more easily, Substances causing weakness (plasticizer) reduce the brittle of PVC to soft in order to reduce the degradation of PVC heat during the manufacturing process. The product is made of PVC such as synthetic leather, insulation of cables, bottle, shoes, medical equipment, and the electronic equipment etc.

1.2.6. Overview of PVC Production Process

The industrial production process for polymers consists of six steps (units).

- Law material step where law material is stored and adjusted
- Catalyst preparation step, where the catalysts are synthesized or prepared
- Polymerization step.
- Separation step, where the unreacted monomers are recovered and the products are separated from the water or the solvents.
- Recovery step, where the unreacted monomers and solvents are recovered.
- Finishing step, where the separated polymers are dried, packed and stored.

There are four kinds of production processes for addition polymerization, as shown below: [17-24]

- Bulk polymerization process
- Suspension polymerization process
- Solution polymerization process
- Emulsion polymerization process

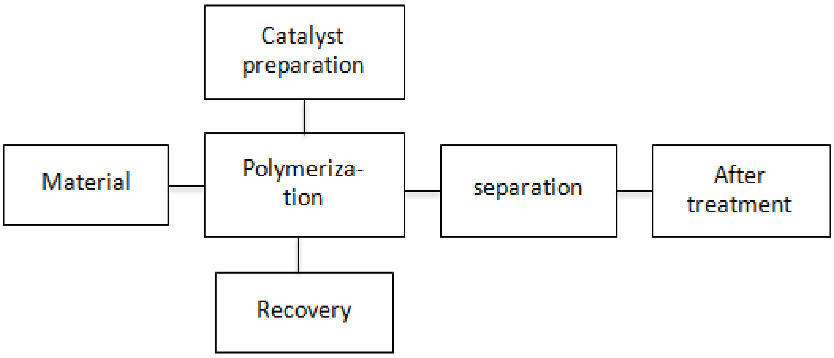


Figure 1.4 Block diagram of polymerization processes [14]

In the case of the bulk polymerization process, the polymerization step is the most important because of the difficulty of removing heat. However, in the bulk polymerization only VCM and catalyst are indispensable. Other steps, such as law material step, separation step, recovery step and finishing step are very simple. Overall, bulk polymerization process is the simplest process.

The solution polymerization process is different from the bulk process by using organic solvents due to the decreasing heat removal and the viscosity of solution in the reaction. All steps are more complicated than other three processes because of solvent treatment. Equipment cost and running cost are highest among four processes. However, this method has a disadvantage in terms of toxicity and flammability of the solvent.

In the case of the suspension polymerization process, in order to avoid the use of solvents as mentioned above. A method was developed to synthesize polymers. Water is applied as a medium for efficient heat removal and the reaction must be stirred solution or a mixture of monomers with water order to the disintegration of the monomer droplets. This result is more cooling of monomer surface area. Typically, the diameter of the monomer droplets is in the range of about 10 to 1000 microns (μm) regularly depending on the speed of stirring. However, water separation and wastewater treatment are needed. Recovery step is more important, dehydration and drying processes are needed, and then equipment cost and running cost are higher than bulk process. Therefore, the polymerization step of suspension process is much easier than bulk process.

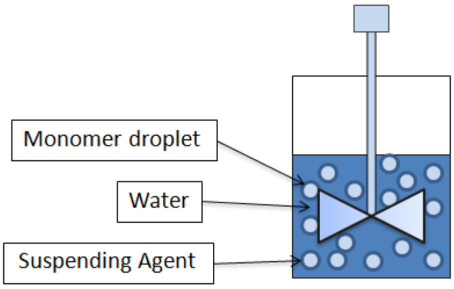


Figure 1.5 System simulation diagram of suspension polymerization process

In figure 1.5, it can be seen that this system employs a substance, that can dissolve in the monomer phase. Moreover, suspending agents such as polymer combination of polyvinyl acetate and polyvinyl alcohol will be added to prevent agglomeration of polymer (By co-polymer that is facing the side with the polar (hydroxyl group) into the water and turn out with less polar into polymer.) to prevent agglomeration of polymer.

For the emulsion polymerization process, as in the suspension polymerization process, water and an emulsifier are applied the control of the polymerization reaction is much easier than the bulk process and equivalent to the suspension process. The separation step is fairly important because separation of polymer from latex stabilized by emulsifier is needed. Drying process is also needed. So equipment costs and running costs are higher than for the bulk process.

Table 1.7 Techniques used in the synthesis of PVC.

Type of polymerization	Proportion of production	Application
Suspension polymerization	80%	Pipes, door frames, windows and work relating to construction
Emulsion polymerization	10-15%	Synthetic leather, gloves, rubber tiles
Bulk polymerization	10%	Applies to products that have contact with food because PVC has high purity

General information PVC process in case study

Due to confidentiality issues, which were the most important concern of all PVC companies participating in this study, the name of any companies in this study including the PVC resin industry are not mentioned.

In this research, the PVC production capacity of this study was around 1,129,330 ton per annual (TPA) in 2013 and 1,409,330 ton per annual for the overall PVC industries

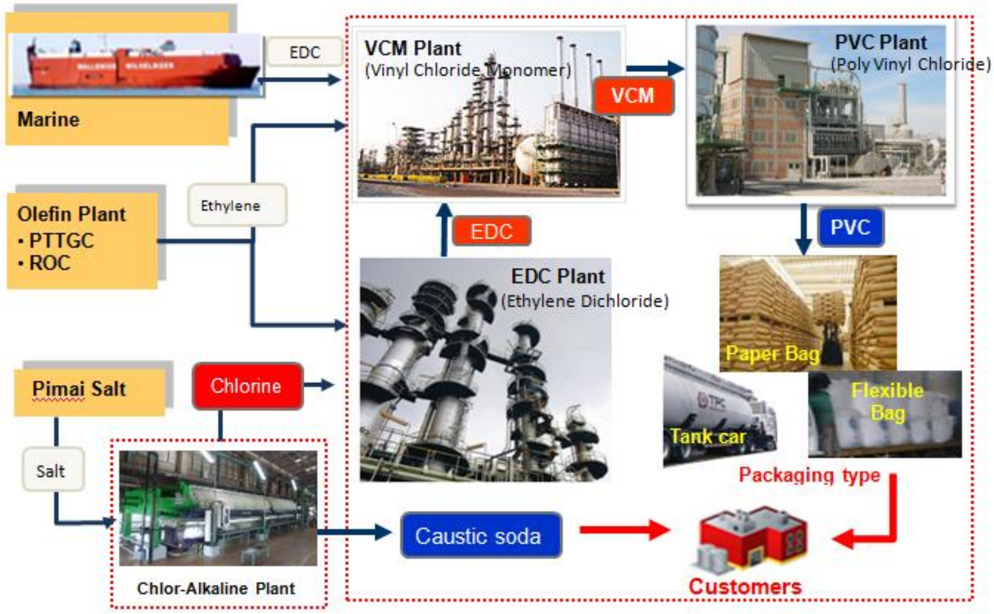


Figure 1.6 Overview of PVC production process

The production process in this factory can be divided into three main parts (Fig.1.6). The first part is the Chlor-Alkaline plant. The factory receives salt from Phimai through the process to extract Chlorine by using electrolysis. The main product of Chlor-Alkaline plant is Chlorine which is then forwarded to VCM plant and by-product is caustic soda. The second part is VCM plant. Start from chloride of Chlor-Alkaline plant and Ethylene was purchased from outside the plant through the production process convert to Ethylene Dichloride (EDC). Ethylene Dichloride (EDC) and Ethylene are fed to VCM plant in order to produce VCM, which is the main raw material to be used in production process of Polyvinyl Chloride (PVC) resin in PVC plant. Last part is PVC plant. The process diagram of a PVC plant is illustrated in Fig. 1.7.

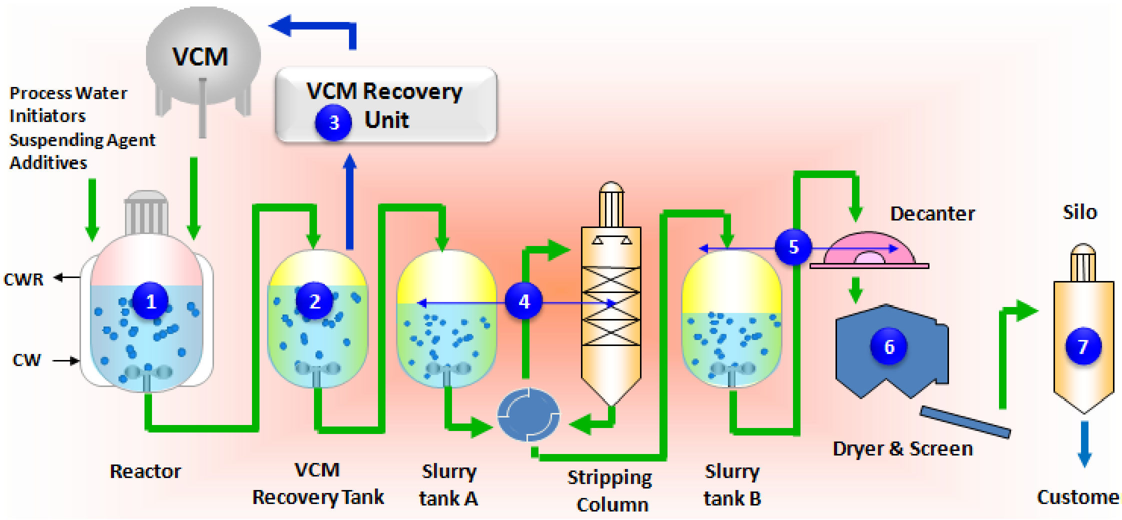


Figure 1.7 Shows the Process Flow Diagrams of the PVC Resin Process

1. VCM from the VCM plant is stored in the spherical tanks, then fed into the reactor with other raw materials, such as process water, initiators, suspending agent and additives. After the polymerization the reaction occurs in reactor under appropriate condition, we obtain PVC slurry (PVC powder suspended in water).
2. The PVC slurry is transferred from a reactor to a VCM Recovery tank in order to separate the VCM from the slurry and recover the VCM by a VCM Recovery unit.
3. The VCM Recovery unit has distillation which purities VCM, which is sent back to be stored in spherical tanks before being fed into reactor in order to produce PVC in the next PVC process.
4. PVC slurry from the VCM Recovery tank is transferred into slurry tank A, and then fed into a stripping column to extract the residual VCM in the PVC particle pores out.
5. PVC slurry is transferred to slurry tank B, and fed into the Decanter centrifugal due to separate water from the PVC. Then we get low moisture of PVC, called PVC cake.
6. After that, PVC cake is fed into Dryer for drying PVC resin with a humidity of less than 0.3%
7. PVC resin, which passes the screen will be transported with air (pneumatic conveying system) to be stored in the Silo before supply to customers.

1.3. Research objectives

The main objectives of this research are:

- To construct the bottom-up Energy Conservation Supply Curve model for the chemical industry in order to capture the cost-effective (economic potential) and technical potentials for energy saving in this sector
- To analyze the potential for reducing energy use and carbon dioxide emissions for the PVC resin industry sector in Thailand
- To employ the bottom-up, CSC model and economic analysis, and then determine the energy efficiency potential of the PVC resin industry in Thailand

1.4.Scope and approach

In order to study energy efficiency improvement and carbon dioxide emission reduction in polyvinylchloride (PVC) resin industry in Thailand, this study used information from case study. In the assessment of energy efficiency, first to estimate technical potential by integrate data on efficient measures and scale up the energy saving before construct energy conservation supply curve model in order to analyze Thai economic potential for the PVC resin industrial sector in base year 2013. Then estimate carbon dioxide emission reduction on this sector.

CHAPTER 2
THEORIES

2.1. Bottom up model

Bottom-up models are typically considered as the technological options or the project-specific mitigation policies. This model mainly concentrates on the engineering energy saving evident at the microeconomic level, and a detailed analysis of the technical and economic dimensions of specific policy options. Bottom-up model can be used to determine the cost of energy saving by comparing the financial costs and energy saving of different technologies using discount rate. The cost-effective opportunities for energy saving is the so-called energy efficiency gap which is usually found by developing this model.

2.2. Conservation Supply Curve (CSC)

The Conservation Supply Curve (CSC) is analytical tools, which is normally used to capture both the engineering and the economic perspectives of energy conservation, and are expressed by graphing incremental cost of an energy conservation or energy efficiency program as a function of the incremental amounts of energy saved. A supply curve of conserved energy is one method of expressing such a potential. It is based on the assumption that conserving energy requires investments. These investments can be amortized over the period of energy savings to yield a "cost of conserved energy." A supply curve is basically constructed from a series of conservation measures and looks like a series of gradually rising steps. Each step on the curve represents one measure; its width indicates the energy saved and its height the cost of conserved energy. Measures are cost-effective if their cost of conserved energy is lower than the price of the energy the measure saves.

The steps in the construction of a CSC is the calculation of the marginal cost of conserved energy (*CCE*), which is computed by dividing the total cost of conservation (*TCC*) by the total energy savings (*E*). The difficulty with the concept of the cost of conserved energy is in knowing to what it applies. Clearly, to compute *E*, two production technologies must be regarded namely one before and one after the conservation measure.

However, the conservation measures are usually defined in ways that one does not know either the starting or ending technology, but only the change in technology.

The Conservation Supply Curve (CCE) can be calculated from Equation 2.1.

$$\text{Cost Conserved Energy} = \frac{\textit{Annualized capital cost} + \textit{Annual change in O\&M costs}}{\textit{Annual energy savings}} \qquad (2.1)$$

The costs could be in Thai baht, U.S. dollar, or any other currency. The energy savings could be in Gigajoules (GJ) or any other energy unit. The annualized capital cost can be calculated from the following equation.

$$\textit{Annualized capital cost} = \textit{Capital cost} \times \frac{d}{1-(1+d)^{-n}} \qquad (2.2)$$

d: discount rate, n: lifetime of the energy efficiency measure.

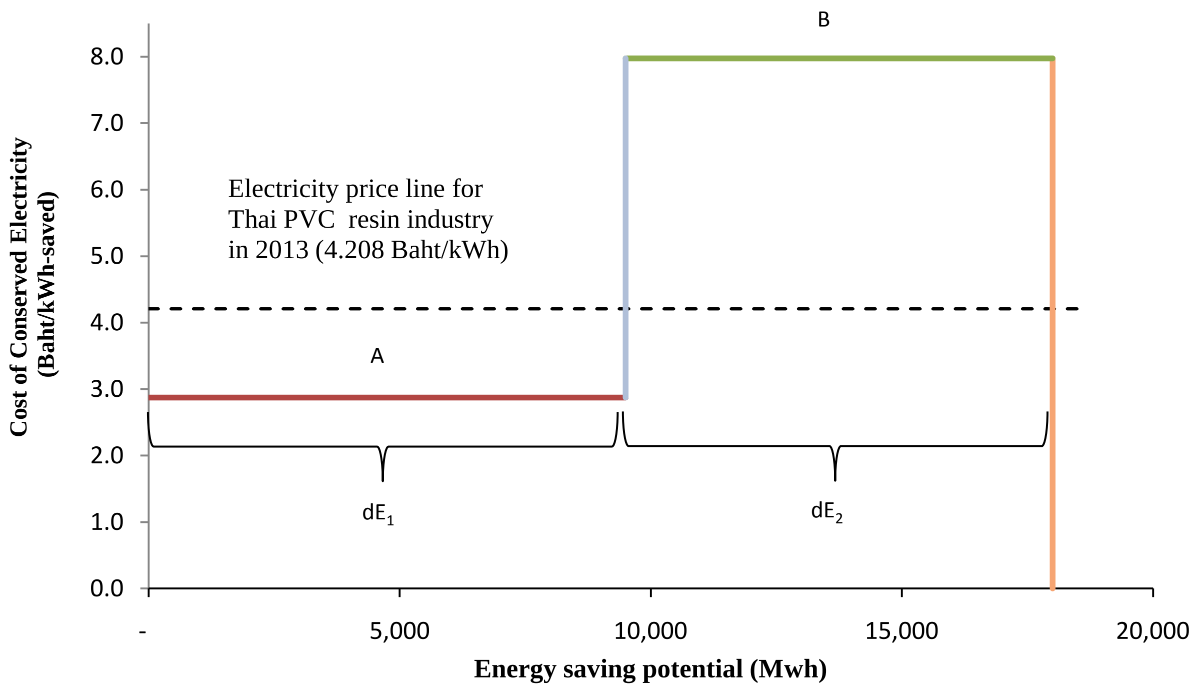


Figure 2.1 Schematic view of a Conservation Supply Curve

Figure 2.1 demonstrates a schematic of a CSC that enhances the visualization of the above discussion. For measure A, which is cost effective, the annual net cost saving is positive; whereas for measure B, which is non-cost effective, the annual net cost saving is negative. For measure B, the area between energy price line and CSC should be targeted by any fiscal policy. McKinsey& Company (2008) has also developed greenhouse gas abatement cost curve for different countries using the concept of conservation supply curve. Stoft (1995) investigated the characteristics of CSC and presented how a CSC is derived from a production function. In CSCs, the energy price line must be determined as well. All measures that fall below the energy price line are cost-effective. Furthermore, the conservation supply curve can show the total technical potential for electricity or fuel saving in Thai Chemical Industry. On the curve, the width of each measure (plotted on the x-axis) represents the annual energy saved by that measure. The height (plotted on the y-axis) shows each measure cost of conserved energy.

The advantage of using a conservation supply curve is that it provides a clear, easy-to-understand framework for summarizing complex information about energy efficiency technologies, their costs, and the potential for energy savings. The curve can avoid double counting of energy savings by accounting for interactions between measures, is independent of prices, and also provides a framework to compare the costs of efficiency with the costs of energy supply technologies as well as providing guides for predicting the impact of changes in assumptions.

2.1.1 Discount rate

The discount rate is the interest rate used in a discounted cash flow analysis to determine the present value of future cash flows. The discount rate takes into account the time value of money (the idea that money available now is worth more than the same amount of money available in the future because it could be earning interest) and the risk or uncertainty of the anticipated future cash flows (which might be less than expected). In this study, the real discount rate equal to 30% is assumed for the base case scenario to reflect the barriers to energy efficiency investment in Thai Plastic resin industry such as perceived risk, lack of information, management concerns about production and other issues, capital constraints, and preference for short payback periods and high internal rates of return.

2.3. Economic analysis

The Conservation Supply Curve (CSC) also gives very useful information, namely the cost of conserved energy (CCE), annualized cost of energy efficiency measures, annualized energy cost savings and annualized net cost savings by each individual technology or group of technologies. The calculation of CCE is explained above. If dE is the energy saving by technology, then the annualized cost of energy efficiency measure, annualized energy cost saving, and the annualized net cost saving of that technology can be calculated from:

$$\mathrm{AC} = \mathrm{dE} \times \mathrm{CCE} \qquad (2.3)$$

$$\mathrm{AECS} = \mathrm{dE} \times \mathrm{P} \qquad (2.4)$$

$$\mathrm{ANC} = \mathrm{AECS} - \mathrm{AC} = \mathrm{dE} \times (\mathrm{P} - \mathrm{CCE}) \qquad (2.5)$$

AC: Annualized cost of energy efficiency measures (Baht), AECS: Annualized energy cost savings (Baht), ANC: Annualized net cost savings (Baht), P: energy prices, and dE: energy savings in CSC

It should be noted that the above calculations are done based on the assumed lifetime for each energy efficiency measured in the CSC. For the cost-effective energy-efficiency measures in the CSC, the annual net cost saving is positive. For the measures whose CCE/CCF is above the energy cost line, the annualized net cost saving is negative. Next, the cost-effective measures can be finished by implementing those measures from the energy cost saving based on the annual revenue whereas the non-cost effective measures is calculated from the amount of energy cost saving by implementing those measures, it implies that the annualized cost of the measures is typically higher than the annualized cost saving. Thus, the annual net cost saving for non-cost effective measures is negative. However, it should be emphasized that in the case of non-cost effective measures, the significant cost saving occurs from energy saving which is equal to dE×P as mentioned above. Therefore, from an energy policy point of view, any fiscal policy for non-cost effective energy efficiency measures should target the annualized net cost saving of the measure, which is the area between the CSC and the energy price line.

2.4. Determining CO_2 emission reduction

The CO_2 emission reduction can be determined by using conservation supply curves (CSC) as the analytical tool. In this determination, the CSCs are also regarded in the views of cost effectiveness in order to show the amount of energy savings. Then the CO_2 emission factor (0.4202 kg-CO_2/kWh or 116.727 kg-CO_2/GJ). Noticed that, CO_2 emission reduction potential is based on the efficiency of cogeneration, which the emission factor that calculated from the relation from IPCC Guidelines for National Greenhouse Gas Inventories 2006 [26], have to be multiplied with total energy saving (kWh). Finally, the CO_2 emission reduction (kg-CO_2) will be obtained.

$$\mathrm{CO_2\ emission\ reduction\ (CO_2)} = \mathrm{CO_2 emission\ factor} \times \mathrm{Total\ energy\ saving\ (kWh\ or\ GJ)} \qquad (2.6)$$

CHAPTER 3
METHODOLOGY

In order to reach the goal of this study, the steps of work can be divided into 3 main steps which are energy-efficiency potential, estimating DSM potential and process of implementation. The details of each step are described below:

3.1. Energy-efficiency potential

To perform the energy-efficiency potential completely, the 4 steps of energy-efficiency potential are comprised of technical potential, economic potential, achievable program potential, and naturally occurring, have to be performed as described below [27]:

- **Technical potential** refers to the amount of energy savings or peak demand reduction that would occur with the complete penetration of all measures analyzed in applications where they were deemed technically feasible from an engineering perspective, or the theoretical maximum amount of energy use that could be displaced by the technology being evaluated disregarding all non-engineering constraints.
- **Economic potential** is typically used to refer to the technical potential of those energy conservation measures that are cost effective when compared to either supply-side alternatives or the price of energy. Economic potential takes into account the fact that many energy efficiency measures cost more to purchase initially than do their standard-efficiency counterparts. The incremental costs of each efficiency measure are compared to the savings delivered by the measure to produce estimates of energy savings per unit of additional cost. These estimates of energy efficiency resource costs can then be compared to estimates of other resources, such as building or operating new power plants. Moreover, economically cost-effective is subset of technical potential (e.g., as compared to conventional supply-side energy resources), estimated economic potential does not address market barriers to implementation.
- **Achievable program potential** generally represents the amount of savings that would occur in response to specific program funding, marketing, and measured incentive levels.
- **Naturally occurring** is the amount of reduction estimated to occur as a result of normal market forces that is in the absence of any utility programs.

In this study, however, the economic potential is the only step of energy-efficiency potential that can be considered due to insufficient data, combined with the limited timeframe of this research.

3.2. Estimating DSM Potential

In order to comprehend the estimation of DSM potential easily, Figure 3.1 is provided below. Estimating DSM potential can be separated into 3 parts which are developing initial input data, estimate technical potential and develop supply curves and estimate economic potential, respectively.

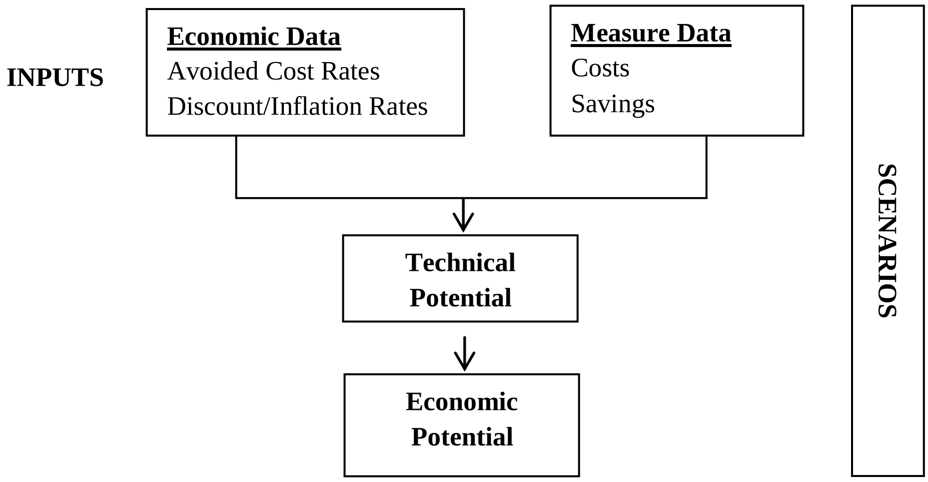


Figure 3.1 Estimating DSM Potential

Step 1: Develop Initial Input Data

To develop the initial input data correctly, a list of energy efficiency has to be first measured and included into the scope. Secondly, data is collected and then developed as technical data (costs and savings) on efficient measure opportunities. Finally, electricity consumption and intensity by end use, end-use consumption load patterns by time of day and year and market shares of energy efficiency technologies and practices are analyzed and developed thoroughly.

Step 2: Estimate Technical Potential and Develop Supply Curves

In order to precisely perform an estimation of technical potential and energy supply curves, the data on efficient measures must be matched to the data on the existing buildings and integrated.

Step 3: Estimate Economic Potential

In this step, there are many economic input data that need to be gathered, such as current and forecasted retail electric prices, and current and forecasted costs of electricity generation, along with estimates of other potential benefits of reducing supply, such as the value of reducing environmental impacts associated with electricity production. There are matched and measures are integrated with economic assumptions, after that the total economic potential using a supply curve approach is estimated.

3.3. The process of implementation

In this research, to analyze the potential for the efficiency of the Polyvinyl Chloride resin production processes and carbon dioxide reduction emissions in Thailand, data from case studies and bottom-up approaches have to be collected and performed, respectively. The analysis consists of three steps. First, a 2013 baseline for energy and material use is established by using data of 2013 for which detailed energy statistics of Thai PVC resin industry. Furthermore, so as to improve energy efficiency and scale up the saving energy from each measure, the analysis and characterization of energy-efficient technologies have to be demonstrated as well. Finally, to assess the cost-effectiveness (economic potential), energy efficiency improvement in Thai PVC resin industry is completed by employing energy conservation supply curves (CSCs).

3.3.1. Establishing a baseline for energy used in the Thai plastic chemical industry

The baseline for the energy used in the Thai plastic chemical industry is basically constructed by means of collecting information from the case studies which is totally retrieved by plant visits and energy reports, that are directly submitted to the Department of Alternative Energy Development and Efficiency, Ministry of Energy is used to establish the 2013 energy consumption for the PVC resin industry.

3.3.2. Characterization of energy efficient technologies

In order to characterize energy efficient technologies, the potential for reducing energy use and carbon dioxide emissions from PVC production process in the baht need to be analyzed together with compiling information on the costs, energy savings, and carbon dioxide emissions reductions of a number of technologies and measures. This results in improving energy efficiency in the Thai PVC Resin industry.

For each technology or measure, the costs and energy savings per ton of PVC produced in 2013 are firstly estimated. Then, the calculation of carbon dioxide emissions reductions based on the fuels used at the process step to which the technology or measure is applied. Finally, carbon dioxide emissions reductions for each measure are calculated based on weighted average carbon dioxide emissions coefficient is 0.4202 tCO_2/MWh or 0.11672 tCO_2/GJ [25], which are obtained from IPCC Guidelines for National Greenhouse Gas Inventories 2006. Additionally, to account for the interactive effects of competing measures, or to reduce the effectiveness of measures due to the previous implementation of a measure, the penetration rate of competing measures have to be limited and the order of implementation of the measures, which reduce the potential savings of subsequent measures after implementation of measure affecting other measures, have to be assumed.

After the implementation of the measures, the energy savings of each measure are scaled up and carbon dioxide reduction emissions are ended by comparing the PVC production of case study with the total PVC production in Thailand (production ratio equal to 1.248) before constructing the energy conservation supply curves.

3.3.3. Establishing Conservation supply curves and economic analysis

In order to capture the accumulated cost-effectiveness and total technical potential for electricity and fuel efficiency improvements in Thai PVC resin factory at case study, Electricity Conservation Supply Curve (ECSC), Steam Conservation Supply Curve (SCSC), and Natural gas Conservation Supply Curve (GCSC) are constructed separately. After calculating the cost of conserved energy (CCE) for all energy-efficiency measures, rank the measures in ascending order of CCE to construct the CSCs, three separated curves for electricity, steam, and natural gas should be constructed because the cost-effectiveness of energy-efficiency measures are highly dependent on the price of energy. Furthermore, the average price of electricity, steam and natural gas prices are relatively different and many technologies save either electricity or fuel, so it is more appropriate to separate electricity, steam, and natural gas saving measures. Hence, the ECSC with discounted average unit price of electricity is only plotted in the views of the technologies that can save electrical energy while the FCSC with discounted average unit price of fuel only plots technologies that save fuel (steam or natural gas).

After establishing the conservation supply curves (CSCs), ECSC, SCSC, and GCSC are analyzed as the economic potential by considering the curves. Namely, the conservation measure will be cost-effective or economic potential and the annual net cost saving will be positive, when the measures whose cost of conserved energy (CCE) is above the energy cost line or its cost of conserved energy is less than the price of the energy that the measure displaces. Example the price of electricity was 4.208 baht/kWh, and then measures having costs of conserved energy below that price would be cost-effective. On the other hand, the conservation measure will be non-cost effective and the annual net cost saving will be negative, when the measures whose cost of conserved energy (CCE) is over the energy cost line or its cost of conserved energy is more than the price of the energy. Therefore, economic analyzing considers only measures that make the conversation are cost-effective (economic potential). Then, the amount of CO_2 emission in each measure is lastly calculated.

CHAPTER 4
RESULTS AND DISCUSSION

To comprehend the results and discussion of this study easily, the Conservation Supply Curve and the official information in 2013 of Thai PVC resin industry an explained simultaneously depending on the procedures as presented in Chapter 3.

Moreover, in order to capture the accumulated cost-effectiveness and total technical potential for electricity and fuel efficiency improvements in Thai PVC resin industry, the Electricity Conservation Supply Curve (ECSC) and the Fuel Conservation Supply Curve (FCSC) were expressed independently. There are twenty-eight (28) energy efficiency measures, namely, nine (9) of which are electricity saving measures and nineteen (19) of which are fuel saving measures, which consist of two parts: Steam efficiency improvement (SCSC) and Natural gas efficiency improvement (NCSC), respectively.

However, the energy savings of each measure and carbon dioxide emission reduction derived from the case study were scaled up to the Thai PVC resin industry by using the production ratio (1.248) before constructing the conservation supply curves.

4.1. The Production Ratio of case study

According to the confidentiality issue, which was the most important concern of all PVC companies that participated in this study, the name of any companies in this study are not mentioned. In the research, assuming the name of case study is factory A. The production ratio of case study equal to 1.248 when compare with the total Thai PVC resin production as show in Table 4.1.

Table 4.1 shows PVC production ratio of the case study

PVC resin production factory	PVC production in 2013 (ton/year)	The PVC production ratio
Factory A (case study)	1,129,330	1.248
Factory B	280,000	5.033
Total	1,409,330	-

4.2. Measure or technology to improve energy efficiency in Thai PVC resin industry

The measures or technology to improve energy efficiency can be explained in three (3) sections. There are the measures to improved electricity efficiency, steam utilization, and natural gas utilization.

4.2.1 Measure or technology to improve electricity efficiency

As mentioned, there are nine (9) electricity saving measures which are:

E1: Monitoring leakage and improvement in compressed air system [28-30]

An air leakage is only not useless, but may also adversely affect the system. For example, in a system that has a large amount of air leakage, the air compressors are unable to produce the desired capacity of air, resulting in a pressure drop. After surveying, it was found that the leak of compressed air is about 18-40%, which highly affect to the loss of power. Thus, to improve electricity efficiency, the air leakage should be considered as well.

Furthermore, reducing leakage in a compressed air system not only saves energy loss, but also reduces a pressure drop in a system, decreases the use of compressed air, as well as reducing the cost of energy in compressed air. As mentioned, air compressor is fabricated with a high power consumption compared to generation. Therefore, finding the leaks and repairing the compressed air system can reduce the energy consumption in the plants.

The process monitoring of air leakages is comprised of three main steps. Firstly, survey the leaking point during a normal plant operation by using Ultra Sonic Leak Detector and spray foam (for the leak to be found easily) and then mark it as a sign that the leak. The label can be used to identify leaking equipment, position of leakage, inspection date, and priority of the leakage (3 levels), thereby suggesting that point should be resolved immediately, which are easy to update and modify it. Secondly, prepare a report and the calculation of the energy loss on the measurement of each case. Finally, conclude of the leak detection and find how to modify it. The energy and cost savings and investment of this technology were provided as follows:

Figure 4.1 Monitoring air leaks by using Ultra Sonic Leak Detectors

E2: Adjust set point pressure for load/unload condition in Air Compressor systems [28, 29]

The first electricity saving procedure is regulating the set point pressure in an air compressor system. An air compressor is typically equipped with a high power consumption compared to generation and it is one of the most important determining parts of overall system energy efficiency. Hence, to reduce energy consumption, this part should be regarded by searching for the leaks and adjusting the set point pressure as well.

During the load operation, the pressure in a system is increased, and then compressed air flows through the dryer and filter. And the friction in system generally causes the pressure loss across the dryer and filter. During unload operation, where is no air production in system, the pressure in the system decreases. It points that there is no pressure drop due to friction across the dryer and filter because no air is flowing. Furthermore, both of effective pressure bands and the volume of compressed air storage influence the rate of cycling between loads and unload operation. Thus, it is important to use the effective pressure band at the compressor outlet position when sizing compressed air storage to avoid short cycling problem. Definitely, the compressor air system consumes more power at higher pressures. Compressors should not be operated above optimum operating pressures because this not only wastes energy but also leads to excessive wear contributing to further energy wastes. The volumetric efficiency of a compressor is also less at higher delivery pressures.

E3: Membrane washing and Bus bar cleaning at CA plant [31, 32]

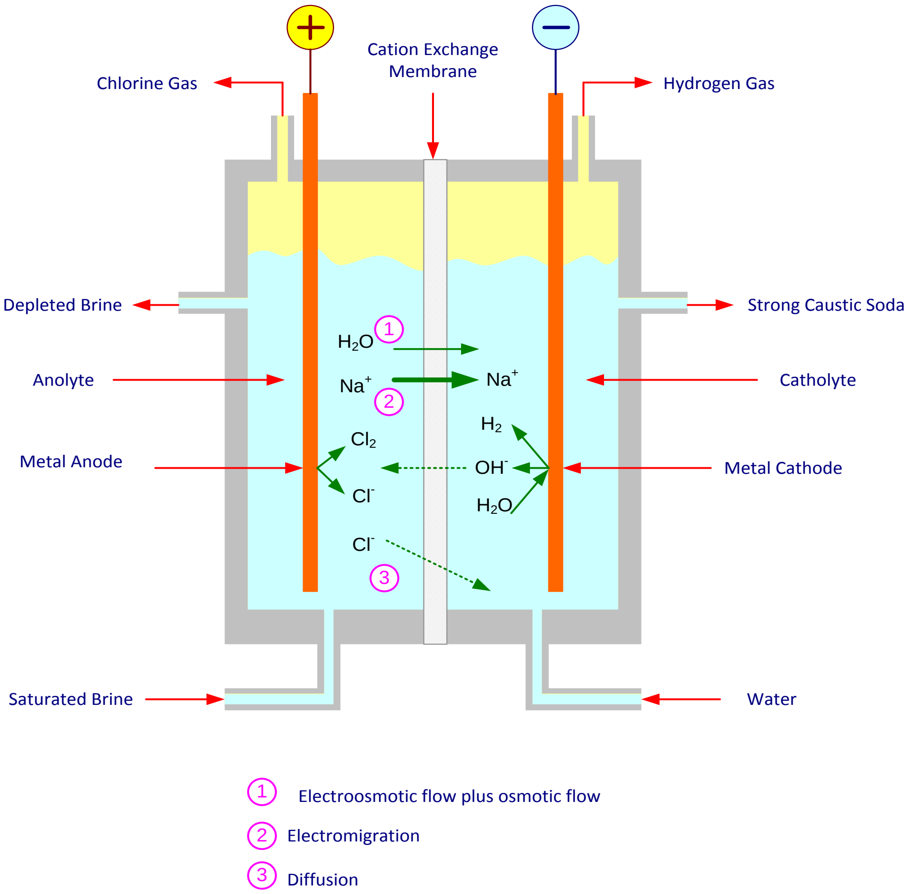


Figure 4.2 Electrolyzer in Chlor-alkali process

In order to better understand of this measure, the membrane system in the Chlor-Alkali (CA) plant first explained. In Chlor-Alkali plant, membrane cell is normally used in the electrolysis of brine as exhibited in Figure 4.2. At the anode, chloride (Cl−) is oxidized to chlorine. The ion-selective membrane allows the counter ion Na+ to freely flow across, but prevents anions such as hydroxide (OH−) and chloride from diffusing across. At the cathode, water is reduced to hydroxide and hydrogen gas. The net process is the electrolysis of an aqueous solution of NaCl into industrially useful products sodium hydroxide (NaOH) and chlorine gas.

In the membrane cell, the anode and cathode are separated by an ion-permeable membrane. Saturated brine is fed to the compartment with the anode. A direct current (DC) is passed through the cell and the NaCl splits into its constituent components. The membrane passes Na+ ions to the cathode compartment, where it forms sodium hydroxide in a solution. The membrane allows only positive ions to pass through to prevent the chlorine from mixing with the sodium hydroxide. The chloride ions are oxidized to chlorine gas at the anode, which is collected, purified, and stored. At the same time, hydrogen gas and hydroxide ions are formed at the cathode.

As mentioned above, the membrane cell is the main material in the Chlor-Alkali plant. Thus, so as to keep the membrane efficiency stable, to avoid contaminants in brine that is usually precipitated in the membrane during operation, membrane cleaning or washing becomes necessary. Membrane cleaning not only maintains the capability of membrane but also reduces the energy consumption in the electrolysis process. However, demineralized water is widely used to wash the membrane since it can provide the resistance of the membrane decreased. As a result, the power consumption can be reduced and it was found that the average was around 0.04 voltages per cell.

Figure 4.3 Flushing membrane

For this measurement, the electrolyzer is a monopolar ion exchange membrane electrolyzer type, which has a number of elements of 116unit/cell x 30 cells. Therefore, washing membrane technology can reduce electricity about 0.04× 30 cell which is equivalent to 1.2 voltages.

E4: Membrane replacement at CA plant [31, 32]

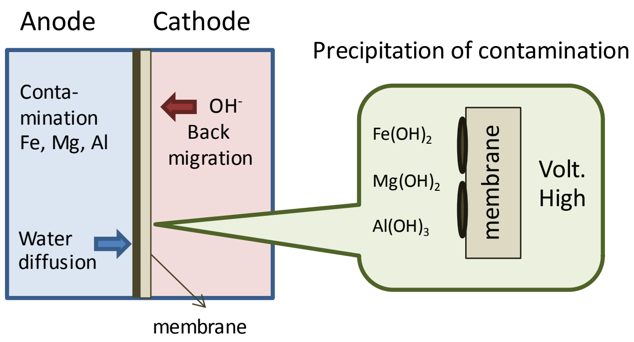


Figure 4.4 Contaminants in membrane

Nonetheless, the cleaning of a membrane is not the only way to improve the energy efficiency in a CA plant. Other choices, such as the membrane replacement, is an interesting procedure as well. A membrane is defined as a perm selective barrier separating two phases [29]. Under the influence of a driving force certain components can permeate the membrane while others are retained. Thus, a membrane is capable of selectively transporting components from one phase to the others. As mentioned in measure E9, since implement membrane for certain period, it found the contaminants in brine to precipitate in the membrane during operate, to make the resistance of the membrane increases and energy used also increase therefore, not only membrane cleaning is necessary but also replacement membrane when it expired are undeniable because membrane efficiency depends on time of used. This implies that if membrane is used for a long time, its performance will be decreased with duration of use which means that it may not be worth to operate anymore.

As aforementioned, the electrolyzer is a monopolar ion exchange membrane electrolyzer type and from the mention in measure E9 shown that, the monopolar type has number of elements of 116 unit/cell x 30 cells. For replacing membrane can reduce 0.1 voltages per cell. Therefore, replacing membrane can reduce electricity about 0.1× 30 cell or 3 voltages.

E5: Install VSD at cooling fan to reduce electricity consumption [33]

A variable speed drive (VSD), also known as a frequency converter, adjustable speed drive, or inverter, is an electronic device that controls the characteristics of a motor's electrical supply. Therefore, it can control the speed and torque of a motor in order to achieve a better match with the process requirements of the machine. It reveals that in applications where variable control is desirable, slowing down a motor with a VSD can reduce energy use substantially.

The solution links the speed of the fan with the temperature of the water in the cooling tower basin. Hence, the installation of a temperature sensor in the water linked to a VSD controlling the fan speed is necessary. For a temperature set point, it is used for the VSD to control the speed of the cooling tower fan according to the temperature of the water in the basin. Basically, fan speed is increased as the water temperature rises or exceeds the set point, and conversely slows down as the temperature cools or goes below the set point. A further benefit from this solution is the reduction in fan noise. In cases where a plant is adjacent to a residential area, controlling the fan speed with a VSD can provide for improved noise pollution. Compared to constant on or on/off control of a fan running at maximum speed, a VSD controlled system will be much quieter. At night, when the potential for noise disruption is highest, the VSD controlled fans are quieter because air temperature is generally lower.

Many industrial sectors have discovered the benefits of using VSD control in a wide variety of applications. Businesses in the commercial and public sectors can also utilize the benefits of VSDs, largely in applications involving pumps and fans, such as ventilation and air conditioning systems, combustion air for boiler systems, chillers and water–pumping systems. Especially, VSDs have the potential to make energy savings and increase profitability in industry.

Cooling towers, which are very common pieces of equipment in the industry, consume a significant amount of energy. Consequently, the implement of efficiency improvement and reduction of losses to save energy is important. The variable speed drive (VSD) can be installed between fan and water in cooling tower to save its energy by employing variable speed drive as demonstrated in Figure 4.5.

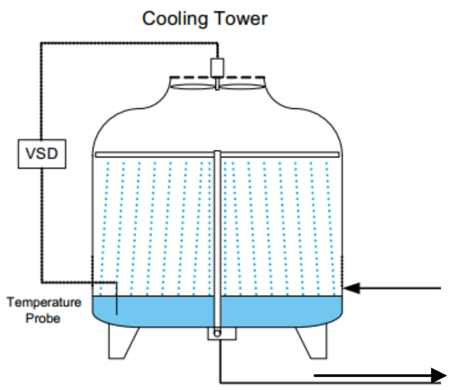


Figure 4.5 Install VSD at cooling tower

E6: Reduce power consumption by replacing new cooling fan blade at VCM production plant [34, 35]

In a cooling tower, water directly contacts with the surrounding air, which is able to transfer heat from a process or a cooling cycle in an efficient way. Furthermore, a small part of the cooling water, i.e. 1-2%, evaporates. This evaporation causes an increase in temperature and humidity of the air and a decrease of the temperature of the water. Evaporation can be possible to cool below the normal air temperature which means that the minimal realizable temperature is the wet bulb temperature.

Cooling fans inside the cooling tower can bring about a continuous air draught. When the fan is blowing, the apparatus is thus on overpressure, which is called forced draught. On the other hand, when the fan is sucking, the under pressure is then occurred, which is called induced draught. According to these two kinds of a forced draught, there are two types of fan such as axial (plate with blades) or radial fans (snail-shell) which can be possible to use.

However, the disadvantage of a radial fan is that it typically produces more sound and it earns lower profits. The figure below shows the possible configurations of a counter flow cooling tower. For Thai PVC resin industry, most cooling tower is an induced draft (axial fan).

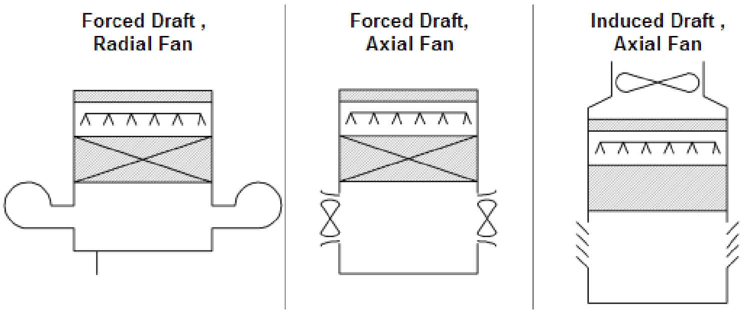


Figure 4.6 Possible configurations of counter-flow cooling tower

A cooling fan is a main component in a cooling tower, which is used to make a certain amount of air moving through the system, and must overcome the resistance of the system. Efficiency of cooling fan also depends on type that presented in Table 4.2.

Table 4.2 Technical data of ENCON fan and Aluminium/Metallic fan

Technical Data	ENCON Fans	Aluminium/Metallic
Efficiency	81% - 90%	56% - 65%
Design	Aerodynamic High profile design	Old convectional design
Material	High Grade Epoxy	Aluminium Casting
Blade	Hollow Blade (Less Weight)	Solid blade (more weight)
Axial	Low Axial thrust on Gear box	High Axial thrust on Gear box
Energy Saving Guarantee	20% up for Energy saving Guarantee	Energy Saving is nil
Endurance	Life > 10 years	Aging effect after 2-3 years

In this measure, ENCON blades designed by aerodynamics principles are replaced with Aluminium/Metallic blades due to old blades becoming deconstructed and damaged, as displayed in Figure 4.7. Besides, ENCON blades can reduce electricity costs by 20% - 30% immediately after the replacement of the old aluminum blade. Therefore, replacement blade is necessary to use due since the new blade has the higher efficiency, high-grade, light weights, low axial thrust on gearbox, long life as well as it also can save a large amount of energy.

a) Old blade b) ENCON blade (Aerodynamic blade)

Figure 4.7 Cooling fan at cooling tower

E7: Reduce power consumption by replacing new cooling fan blade at air compressor system [34, 35]

In order to improve the energy efficiency of the cooling tower, a new cooling fan blade can be applied to the cooling tower in an air compressor system, which the same as for the VCM production plant, as explained above in measure E6.

E8: Reduce power consumption by replacing new cooling fan blade at PVC production plant [34, 35]

In order to improve the energy efficiency of the cooling tower, a new cooling fan blade can be applied to the cooling tower of a PVC production process, which the same as for VCM production plant, as explained above in measure E6.

E9: CA (Chlor-Alkali) Energy saving by Bi-polar electrolyzer replacement [32, 36, 43]

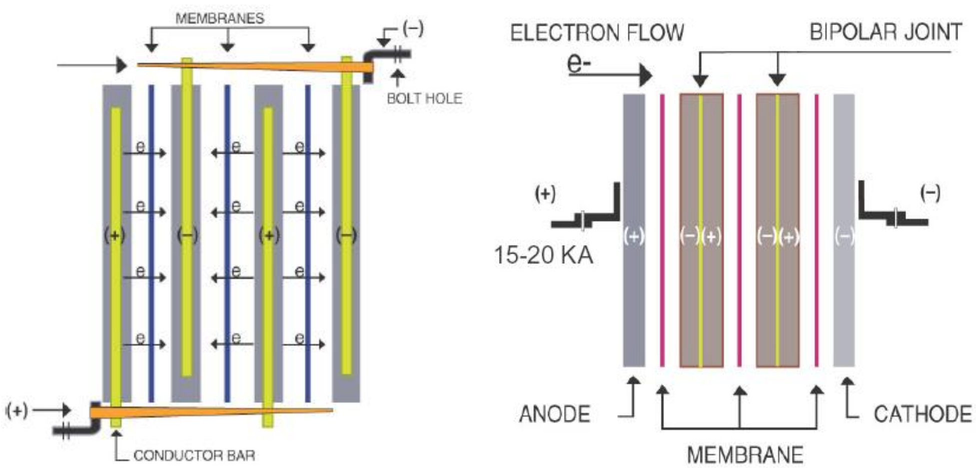
An electrolyzer is used to separate the solution by means of ion exchange membranes in a Chlor-Alkali process. There are two types of membranes which are monopolar and bipolar. Generally, the bipolar type is more effective than the traditional monopolar type. The benefits of bipolar membrane are presented along with the details of these two types of membranes in Table 4.3

Table 4.3 Monopolar and Bipolar membranes

Monopolar type	Bipolar type	Benefit of Bipolar
- Electrode Gap 3 mm.	- Zero Gap of Electrode	Lower Power Consumption
- Low Current Density (3-4 kA/m^2)	- High Current Density (5-6 kA/m^2)	Small Plant Size, Lower Investment Cost
- No. of element 116unit/cell x 30 cells	- No. of element 168 unit/cell x 1 cell	Lower Maintenance Cost

In an electrolyzer, the electrical current flows from the cathode to anode through the diaphragm inside on element. For the bipolar type ion exchange membrane electrolyzer, where contains an anion exchange layer and on the other side a cation exchange layer (Fig.4.8). Bipolar membranes are relatively interested because of their water dissociation capability which is an energy efficient process to produce acids and bases. The theoretical potential difference across a 100% perm selective bipolar membrane for the generation of a one molar acid and base solution at 25 °C can be calculated to be 0.83 Volt [18]. The actual potential drop across the bipolar membrane would be higher than this theoretical value because of irreversible effects due to the electrical resistance of the cation and anion exchange layers and the interphase region of the membrane.

Bipolar membranes have several advantages when compared to monopolar membranes as shown in Table 4.3. For instance, the electric current route is shortened or zero gap of electrode according to the short distance between the anode chamber and diaphragm. Additionally, chlorine gas stayed in the anode chamber contributes to the gas resistance, which results in decrease in electrolysis pressure, consequently, the power consumption is also decreased when compared with monopolar type about 10%.



(A) Mono-polar (B) Bi-polar

Figure 4.8 Monopolar and Bipolar ion exchange membrane electrolyzer

Furthermore, the original operation current density (kA/m^2) of 3-4 kA/m^2 in the industry turned out to be obsolete and high electric density operation with a rated operation electric current density of 5-6 kA/m^2. Due to the production per reaction area can be increased by applying the more electric current to the same electrolyte reaction area. As a result, it can significantly reduce the initial investment to build a smaller electrolysis plant.

Finally, a bipolar ion exchange membrane electrolyzer uses fewer number cells of elements lower than does monopolar type, so it can reduce maintenance costs as well.

4.2.2 Measure or technology to improve steam efficiency

There are fifteen (15) electricity saving measures as follows:

S1: Increase NaOH concentration inlet from 31.7% to 35.0% and adjust condition at Chlor-alkali (CA) plant

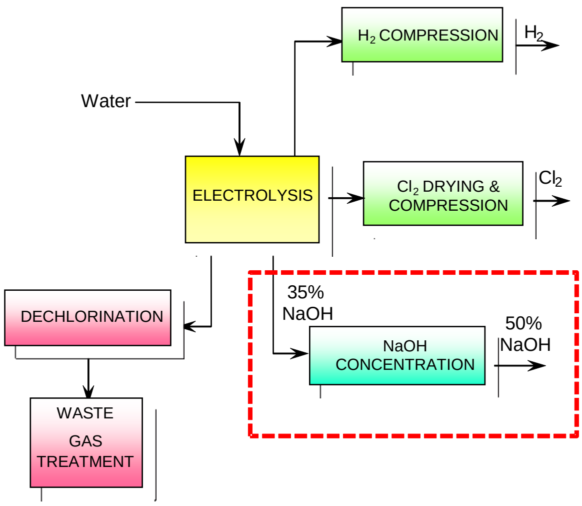


Figure 4.9 Electrolysis process

As previously mentioned in measure E9, it the replacement of a Mono-polar with Bi-polar ion exchange membrane electrolyzer can reduce electricity consumption due to the bipolar one having zero gaps of electrode and high current density. Moreover, it consumes electric power lower than monopolar about 10%. Therefore, replacement monopolar with bipolar can be operated with high concentration of sodium hydroxide from 31.7% to 35.0% at the inlet position.

S2: Set prevention maintenance (PM) by installing flushing at heat exchanger for preventing plugging at VCM plant [37]

The heat exchanger is a silent machine with no moving parts and is often regarded as a “no maintenance needed” piece of equipment, but this not the case. Although the maintenance can be relatively lower than for chillers and pumps, it is still needed and it should be performed at regular periods. For VCM plant, the spiral heat exchanger type is generally used to pre-heat VCM by steam before feeding to stripping section. In general, the main problem in heat exchanger is fouling and plugging which can be prevented by installing flushing system.

For installing flushing systems in this case, it may be mindful of the chlorination volume. A good cleaning system will soften the water and prevent hard scaling and fouling from coating the plates, but too much chlorine will affect the stainless-steel plate and can possibly cause corrosion. It implies that the more fouling in heat exchanger, the more steam have to be supplied to pre-heat VCM. So the flushing system should be installed to against this problem.

S3: Reduce steam consumption by adjusting condition of stripping column at PVC plant [38]

In a PVC plant, the absorption column is also employed as gas mixtures separation, impurities removal, and valuable chemicals recovery units in the process. The operation of removing the absorbed solute from the solvent is called as stripping. Furthermore, to permit regeneration (or recovery) and recycling of the absorbent, the absorbers are normally used together with strippers since the stand alone stripping is not adequate.

Typically, stripping operations are carried out in countercurrent flow processes, in which the gas flow is introduced in the bottom of the column and the liquid solvent is allowed to the top of the column. The mathematical analysis for both the packed and plated columns is very similar. For Thai PVC resin industry, packed column is widely used.

Thus, to enhance the steam efficiency in the process, the adjustment appropriate conditions at the stripping column should be performed. Since it can increase the extraction efficiency of VCM from PVC porous and can also reduce the amount of steam used in process as exhibited below.

S4: Reduce steam consumption at dryer by optimizing dryer temperature control

In the Thai PVC plastic resin industry, the continuous fluidized bed dryer is used to remove the moisture of PVC cake from the decanter. Regularly, drying operation is placed in the last process before packaging in order to prevent damage of the product due to excessive moisture. Namely, the immoderate moisture content is the cause of mold and agglomeration of production which affects to the next production process. Definitely, to remove the moist content in their product, the large amount of energy or steam has to be consumed in drying process. Hence, the optimization of temperature control in drying system is important to improve the steam utilization.

S5: Reduce MP steam consumption by increasing steam main pressure from PTT Chem (15.6 to 16.0 Kg/cm^{2}G)

Steam generation systems are found in industry and in the commercial and institutional sectors. Some of these plants employ large water tube boilers to produce saturated steam at lower pressure. They distribute steam for use in process applications, building heating, humidification, domestic hot water, sterilization autoclaves and air makeup coils.

Generally, increasing the main pressure steam from an external company causes the transport steam to be faster than the low pressure steam, moreover the energy is also increased at the manufacturer when compared to the low pressure steam. In this case, the MP steam consumption can be reduced by increasing main pressure steam from 15.6 to 16.0 Kg/cm^{2}G.

S6: Increase LP steam generated by reducing steam drum pressure

Oversized boiler plants and steam distribution systems utilizing saturated steam are potential candidates for reducing the steam system operating pressure. Steam systems can have large excess capacity in boilers, valves, pumps, and piping.

Steam pressure reduction affects mainly the high pressure part of the steam system. Within practical limits, pressure-reducing valves (PRVs) will adjust the pressure at lower levels to the previous set points. This means that most of the savings benefits from pressure reduction occur in the high-pressure section of the steam system.

S7: Reduce LP steam consumption by increasing main pressure of steam from PTT Chem (3.5 to 3.8 kg/cm^{2}G)

Increasing main pressure steam can not only be applied to the MP steam as mentioned in the previous measure (S1), but also it can be used in low pressure (LP) steam. The steam and cost savings together with investment cost of increasing main pressure steam from 3.5 to 3.8 kg/cm^{2}G to the LP steam.

S8: Improve boiler and distribution system controls for reducing steam consumption

The next equipment that can improve the steam utilization is the boiler and the distribution systems. All boilers require some form of active control to determine how long it should fire. For a variety of reasons, most controls currently in use are quite primitive compared to what is available, and improved controls are one of the most straightforward ways to reduce fuel use and emissions. The heating system maintenance company should perform an annual combustion efficiency test, which shows whether the heating and hot water system is running at maximum efficiency. It is also important that the heating system operator monitors the heating system daily and keeps a log that the managing agent reviews.

Moreover, proper maintenance can bring more than 20% of fuel savings because the boiler room operator should ensure that the boiler fire tubes are kept clean to ensure maximum efficiency. The heat transfer loss in dirty boiler fire tubes, as displayed in Fig. 4.9, rises tremendously as the layer of soot builds up.

a) Dirty boiler fire tubes b) Clean boiler fire tubes

Figure 4.10 Boiler fire tubes

S9: Reduce medium steam (MS) consumption by re-tubing waste heat boiler at incinerator [40]

Generally, the heat that is generated in a process by way of fuel combustion or chemical reaction, and then "dumped" into the environment could still be reused for some useful and economic purpose. The essential quality of heat is not the amount but rather its "value". The strategy of how to recover this heat depends in part on the temperature of the waste heat gases and the economics involved. Large quantity of hot flue gases is generated from boilers, kilns, ovens, and furnaces. If some of this waste heat could be recovered, a considerable amount of primary fuel could be saved. The energy lost in waste gases cannot be fully recovered. However, much of the heat could be recovered and loss minimized by re-tubing waste heat boiler at incinerator.

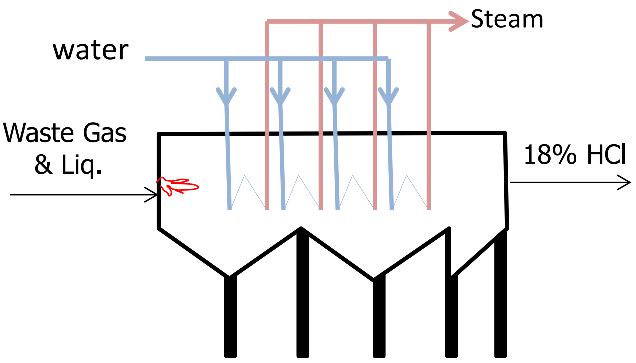


Figure 4.11 Incineration Process

In the incinerator (Fig 4.11) it can be seen that there is a next combustion chamber with a shell and tube exchanger inside. It is able to withstand high temperature and pressure. Because of fewer gaskets, the chance of leakage is reduced. Shell and tube heat exchanger provides larger clearances between exchange surfaces thus reduces the blockage possibility but if used for long period of time to cause coke on a surface of the pipe, clog will be occurred. It effect to less heat transfer and less steam production also. Therefore, re-tubing waste heat boiler at incinerator could be used to reduce steam consumption.

S10: Set PM clean heat exchanger to prevent plugging at air heater

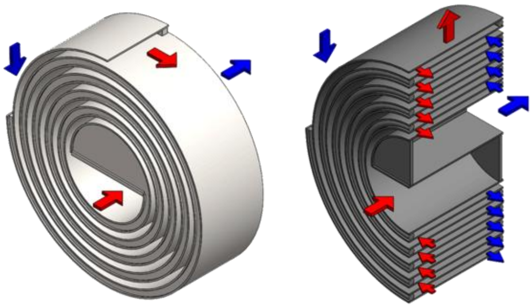


Figure 4.12 Spiral heat exchanger

Planning maintenance is critical to ensuring production and system uptime and will help to avoid equipment failure. The cost of prevention can be budgeted and is normally lower than emergency repairs. Without regular maintenance, a system can be subjected to unpredictable shutdowns, resulting from fouling or scaling of plates, clogging of the plate pack or gasket failure. If neglected for many years, gaskets can become brittle, and over times, this will affect their sealing performance across the plate pack, causing fluid to leak into the environment.

Besides, fouling and clogging issues force the fluids to make their way through a reduced space. The increases the overall pressures drop of the system, and can result in a higher energy bill. These together with scaling will also affect the heat transfer efficiency of the plate heat exchanger, because the plate surface will not have direct contract with fluid reducing the convection effect.

A clean unit runs efficiently at optimal conditions, which can result in energy savings. A clean heat exchanger produces a lower pressure drop on the system, requiring less effort on the pumps and other components. This helps in lowering energy, while increasing the heat-transfer rate and operating more efficiently.

S11: Install Heat exchanger to heat up water by using hot water from decanter water process (DPW) to pre-heat process water (PW) at heat up water system [41]

A heat exchanger is used for heat transfer from one fluid to another fluid but the fluid is not necessarily mixed together. In the PVC production process, plate type of heat exchanger is used, which bringing heat transfer plates many plates are arranged with constant distance then the fluid flows through the space between plates of each type in a switch channel. This device is often used to increase the temperature of air or fluid before entering the boiler. It usually made of stainless steel or thin titanium, which is resistant to corrosion as well. It has advantage that can be removed plates out to cleansing thoroughly, easy to maintenance as well as can be adjust the amount of heat transfer by increasing or decreasing the number of plates but gaskets are usually made of rubber or synthetic rubber so it is not suitable for apply at high temperature and high-pressure condition.

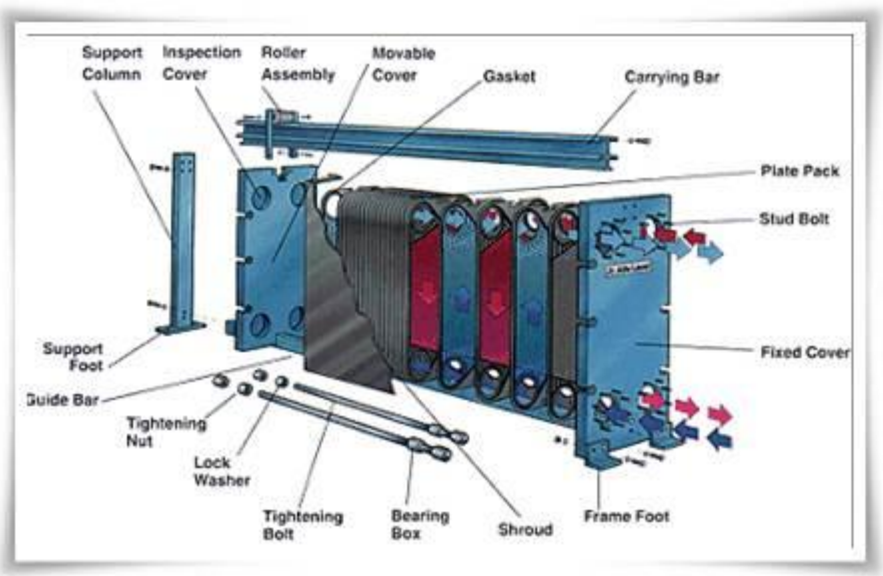


Figure 4.13 Plate heat exchanger

Heat exchangers heat through a metal barrier, which can allow for complete energy transfer on average, 80% of the sensible energy due to it has more area to transfer heat than other type. The remaining 20% of energy is lost to condensate and has to return to the boiler.

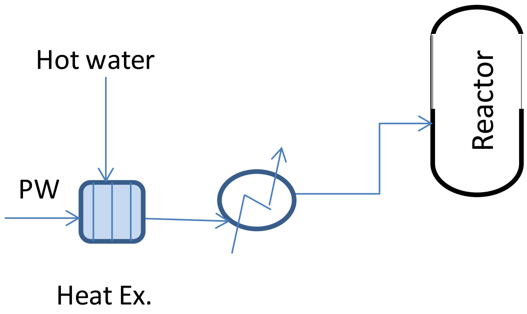


Figure 4.14 Position of Heat exchanger installed in process

The installation of a heat exchanger to exchange heat from the hot water that is derived from Decanter (DPW) to preheat process water (PW), this gives more benefits due to the reduced steam consumption to inject for preheat PW as well.

S12: Replace Heat exchanger to using steam to heat up water directly [41]

As mentioned earlier (measure S11), heat exchangers heat through a metal barrier, which can allow for complete energy transfer on average, 80% of the sensible energy. The remaining 20% of energy is lost to condensate and has to return to the boiler.

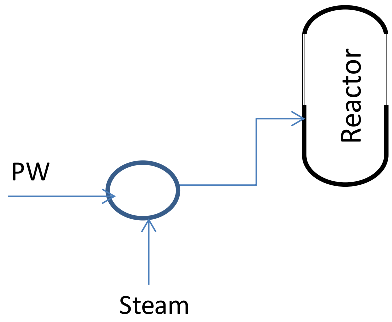


Figure 4.15 Position of improved in the process

On the other hand, direct steam injection heaters are more energy efficient by using 100% of the steam's energy to heat process fluids or utility water. Therefore, replacement heat exchangers using steam to heat up water directly will be using less steam or energy than by using a heat exchanger.

S13: Install Heat exchanger to heat up water by using hot water from decanter water process (DPW) to pre-heat process water (PW) at pre-heater system

As described above in measure S11, the installation of a heat exchanger to exchange heat from the hot water derived from the Decanter (DPW) to preheat process water (PW), gives more benefits due to reduced steam consumption to inject for preheat PW as well.

S14: Heating panel jet cleaning in dryer at PVC plant

The Thai PVC plastic resin industry employs a continuous fluidized bed dryer in order to get rid of the moisture contents in a PVC cake off. As previously explained, moisture trapped into product may cause several problems, for instance, mold and agglomeration which effect to the latter production sections.

A continuous fluidized bed dryer uses the principles of solid floating in hot air, which it always bakes on the grill in a dryer. The PVC cake from decanter is being poured into the top of the machine then it down on the grill. During its flow toward to bottom of the machine, the hot air from air heater through below of the grille. When the products flow to the bottom of the machine, it dry already and then transferred to silo.

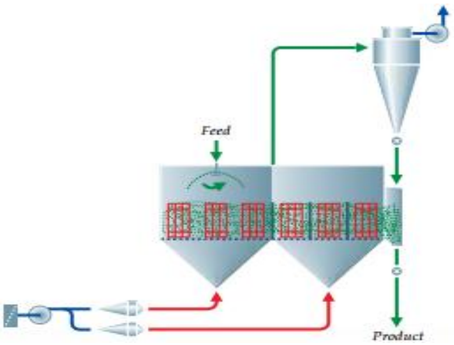


Figure 4.16 Fluid bed dryers

When applying the heating panel for a while, fouling at the heating panel, which is related to operating times, also an effects steam consumptions. Therefore, when high fouling cause to high steam loss. In the other hand, after clean heating panel (low fouling) can reduce steam consumption (steam loss) in this process. However, in the heating panel jet cleaning process, plant will be shut downed before implementation. Therefore, PVC loss cost for shut down plant will be including in total cost also.

a) Heating panel fouling panel b) Jet cleaning c) clean heating

Figure 4.17 Heating panel jet cleaning

S15: Study implements advanced process control (APC) at Stripping and Dryer unit to reduce energy consumption [42]

Model-based advanced process control (APC) strategies are common applications in the hydrocarbon processing industry. Nevertheless, APC and optimization practices may also greatly benefit relatively smaller plants. The principal aims of an APC are drive variables in a process to their optimum targets, keeping in mind the interaction among variables, effectively to deal with constraints, respond quickly to changes in optimum operating conditions and achieve economic objectives.

The purpose of APC and an Optimization Feasibility Study is to determine the envelope of plant operability and control strategies that will drive the plant to run at the optimum, maximum yield or conversion and/or maximum throughput, while simultaneously honoring process, equipment and operating constraints.

The major benefits of implement APC are reduced quality to give away against specification, increased production of more valuable products, lower pressure operation, less flue gas oxygen, easier and smoother operation, increased operating safety and reduced utility consumption. All benefits lead to reduced costs.

4.2.3 Measure or technology to improve natural gas efficiency

This topic is explains measure or technology that is used to improve natural gas utilization. It consists of four technologies which are:

G1: Reduce NG consumption by increasing cracking conversion from 53.5% to 53.8%

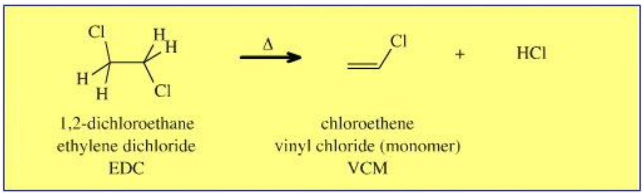


Figure 4.18 VCM reaction

In an ethylene dichloride (EDC) cracking furnace process, EDC is cracked and then turned into VCM products and hydrochloric acids (HCL) at 500^{o}C by using fuel gas and catalyst in the furnace. Increasing cracking conversion can be completed by reducing the amount of EDC input to cracker from 29.06 to 28.90 ton/hr and by increasing temperature for produced VCM production in the same rate. However, adding ethylene dichloride (EDC) too much, it effect to clog in tube due to coke occurred.

G2: Reduce natural gas consumption by optimizing control CCL_4 in Ethylene Dichloride (EDC) feed cracker at EDC cracking furnace

As previously explained, EDC is decomposed and the transformed to a VCM product and hydrochloric acids (HCL) by consuming fuel gas in the cracking furnace process at 500^{o}C. Additionally, there is the catalyst additive which usually applied in small amount to the cracking process, Carbon tetrachloride (CCl_4). Carbon tetrachloride can breakdown EDC at temperature below 500^{o}C. It indicates that adding of CCl_4 in this process can reduce natural gas consumption due to reduce temperature of reaction. However, adding CCl_4 too much, it effect to clog in tube due to coke occurred as well. As a consequence, the quantity of CCl_4 should be optimized in order to reduce natural gas consumption and ignore this problem simultaneously. Moreover, the obstruction can be measured by measure pressure drop between pipe inlet and pipe outlet as shown in figure above (fig. 4.19)

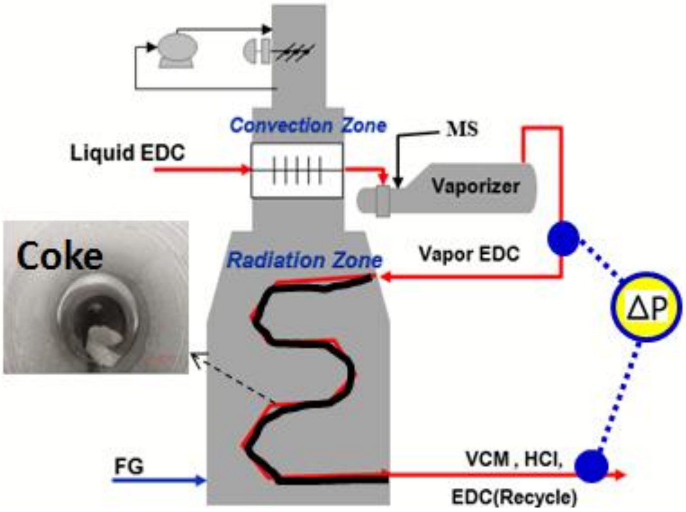


Figure 4.19 Coke in process

G3: Reduce NG consumption by coating furnace walls at incinerators [44]

A furnace is used to melt metals for casting or heat materials for changing the shape or changing properties. Furnaces are broadly classified into two types namely combustion types: (using fuels) and electrical type. In case of PVC industries is normally used combustion type furnace. It is depend upon the kind of combustion, it can be broadly classified as oil fired, coal fired or gas fired.

Moreover, additional heat losses frequently take place during operation. The important heat loss is wall or transmission losses, which are caused by the conduction of heat through the wall, roof, and floor of the heating device, as shown in Fig. 4.20. Once that heat reaches the outer skin of the furnaces and radiates to the surrounding area or carry away by air currents, it must be replaced by equal amount taken from the combustion gases. This process continuous as long as the furnace is elevated temperature.

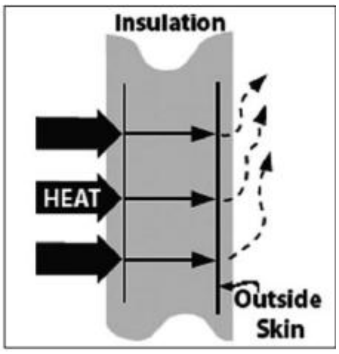


Figure 4.20 Wall losses

Definitely, the heat losses from furnace walls affect natural gas consumption. Therefore, heat losses can be reduced by increasing the wall thickness. In this case study, titanium oxides were used because it has high emissivity. Energy savings of the order of 8–20% have been report is used depending on the type of furnace and operating conditions.

G4: Reduce natural gas consumption by Optimizing fuel gas feed and fire tube cleaning at incinerator

An incinerator's function is to burn waste that occurs during the VCM process (liquid and gas wastes). Heat is released during the burning process. Moreover, heat that derived from this process used to produce steam for used in plant.

In addition, an incinerator is one device that not only uses more energy, but also loes more energy. Generally, control burning of incinerator by measuring temperature inside furnace when temperature reaches to set point, fuel gas will be decreased, adjusting the volume of air, as well as pressure control. Therefore, optimization of fuel gas feed and fire tube cleaning should be performed so as to reduce natural gas consumption in process.

4.3 Calculation results

So as to complete the energy efficiency improvements, the measure or technology is first performed, as explained in Section 4.2. After finishing the measure step, the calculations of each measure were estimated in this section. The calculation results can be divided into two (2) parts. The first part showed the value of energy, cost saving and carbon dioxide emission reduction of each measure and another one was about the total cost and cost of conserved energy of each measure as shown in the following:

RESULT
ENERGY, COST SAVINGS OF EACH MEASURE AND CO_2 EMISSION REDUCTION

The equations used to the calculate values in the energy and cost saving table (Table 4.4) are:

$$\text{Electricity saving after improved of each unit } \left(\frac{\text{kWh}}{\text{yr}}\right) = \text{Electricity used before improved of each unit } \left(\frac{\text{kWh}}{\text{yr}}\right) \times \text{Electricity saved (percent)} \qquad (3.1)$$

$$\text{Steam saving after improved of each unit } \left(\frac{\text{GJ}}{\text{yr}}\right) = \text{Steam saving of each unit } \left(\frac{\text{ton} - \text{steam}}{\text{yr}}\right) \times \text{Latent heat of steam } \left(\frac{\text{GJ}}{\text{ton} - \text{steam}}\right) \qquad (3.2)$$

$$\text{Natural gas saving after improved of each unit } \left(\frac{\text{GJ}}{\text{yr}}\right) = \text{Natural gas used before improved of each unit } \left(\frac{\text{GJ}}{\text{yr}}\right) \times \text{Natural gas saved (percent)} \qquad (3.3)$$

$$\text{Energy saving of case study } \left(\frac{\text{kWh}}{\text{yr}}, \frac{\text{GJ}}{\text{yr}}\right) = \text{Energy saving after improved of each unit } \left(\frac{\text{kWh}}{\text{yr}}, \frac{\text{GJ}}{\text{yr}}\right) \times \text{amount of unit in case study} \qquad (3.4)$$

$$\text{Energy saving of Thai PVC production} \left(\frac{\text{kWh}}{\text{yr}}, \frac{\text{GJ}}{\text{yr}}\right) = \text{Energy saving of case study } \left(\frac{\text{kWh}}{\text{yr}}, \frac{\text{GJ}}{\text{yr}}\right) \times \text{Prodiction ratio (1.248)} \qquad (3.5)$$

$$\text{Cost saving } \left(\frac{\text{million baht}}{\text{yr}}\right) = \text{Energy saving of Thai PVC production } \left(\frac{\text{kWh}}{\text{yr}}, \frac{\text{GJ}}{\text{yr}}\right) \times \text{Price of Energy} \qquad (3.6)$$

$$CO_2 \text{ emission reduction } (CO_2) = CO_2 \text{ emission factor } \times \text{Total energy saving (kWh or GJ)} \qquad (2.6)^*$$

Note: *Equation 2.1 was explained in chapter 2
CO_2 emission factor is equal to 0.4202 CO_2/kWh or 116.727 CO_2/GJ was explained in chapter 2

Table 4.4 Represents the energy, cost savings and CO_2 emission reduction of each measure in the Thai PVC resin industry. There are ranked by their cost of conserved energy (CCE).

No.	Measure/technology	Electricity used before improved of each unit (kWh/yr)*	Electricity saved (percent) **	Electricity saved after improved of each unit (kWh/yr)	Operating time (hr/yr)*	Number unit in case study*	Electricity saving of case study (kWh/yr)	Electricity saving of Thai PVC production (kWh/yr)	Cost saving (Baht/yr)***	Carbon dioxide emission reduction (ton-CO_2/yr)
Electricity										
E1	Monitoring leakage and improvement in compress air system	4,888,800	17%	831,096	8,760	1	831,096	1,037,208	4,363,533	436
E2	Adjust set point pressure for load/unload condition in Air Compressor system	4,888,800	12%	586,656	8,760	1	586,656	732,147	3,079,409	308
E3	Membrane washing and Bus bar cleaning at CA plant	80 kA	*1.2 volts	192,000	2,000	10	1,920,000	2,396,160	10,023,137	1,007
E4	Membrane replacement at CA plant	80 kA	*3 volts	480,000	2,000	10	4,800,000	5,990,400	24,930,703	2,517
E5	Install VSD at cooling fan B to reduce electricity consumption	4,888,800	6%	293,328	8,760	10	2,933,280	3,660,733	15,222,343	1,538
E6	Reduce power consumption by replace new cooling fan blade at VCM production plant	3,647,664	20%	729,533	8,760	1	729,533	910,457	3,212,589	383
E7	Replace and improve cooling fan at air compressor system VCM	1,384,000	20%	276,800	8,760	3	830,400	1,036,339	3,424,027	435
E8	Replace blade of cooling fan with new type at PVC production plant	690,288	20%	138,058	8,760	5	690,288	861,479	2,736,094	362
E9	CA (Chlor-Alkali) Energy saving by Bi-polar electrolyzer replacement	69,955,619	*10%	6,995,562	8,760	1	6,995,562	8,730,461	-15,993,857	3,669

*** Electricity price equal to 4.208 Baht/kWh in 2012 (ref. No. 45)

Note: * Information from case study ** Information from KEMA in appendix B, C (ref No. 27)

Table 4.4 Represents the energy, cost savings and CO_2 emission reduction of each measure in the Thai PVC resin industry. There are ranked by their cost of conserved energy (CCE) (Cont').

No.	Measure/technology	Steam saving of each unit (Ton-steam/yr)*	Latent heat of steam (GJ/ton-steam)*	Price of steam (Baht/ton-steam)*	Steam saving after improved of each unit (GJ/yr)	Number unit in case study*	Steam saving of case study (GJ/yr)	Steam saving of Thai PVC production (GJ/yr)	Cost saving (baht/yr)	Carbon dioxide emission reduction (ton-CO_2/yr)
Steam										
S1	Increase NaOH concentration inlet from 31.7% to 35.0% and adjust condition	389	2.766	810	1,076	1	1,076	1,343	393,116	157
S2	Set PM flushing heat exchanger for prevent plugging at VCM plant	1,158	2.766	810	3,203	5	16,015	19,987	5,851,070	2,333
S3	Reduce steam consumption by adjust condition of stripping column at PVC plant	370	2.766	810	1,023	5	5,117	6,386	1,865,458	745
S4	Reduce steam consumption at dryer and waste water stripping column by optimum dryer temperature	1,427	2.766	810	3,947	5	19,735	24,630	7,194,609	2,875
S5	Reduce MP steam consumption by increasing steam main pressure	2,800	2.766	810	7,745	1	7,745	9,666	2,793,374	1,128
S6	Increase LP steam generated by reducing OC steam drum pressure	10,409	2.766	810	28,791	2	57,583	71,863	20,768,348	8,388
S7	Reduce LP steam consumption by increasing steam main pressure	8,260	2.766	810	22,847	1	22,847	28,513	8,240,181	3,328
S8	Improved boiler and distribution system controls for reduced steam consumption	1,066	2.766	810	2,949	5	14,743	18,399	4,450,389	2,148
S9	Reduce MS consumption by re-tubing waste heat boiler at incinerator	2,943	2.766	810	8,140	2	16,281	20,318	3,995,673	2,372

Note: * Information from case study ** Information from KEMA in appendix B, C (ref No. 27)

Table 4.4 Represents the energy, cost savings and CO_2 emission reduction of each measure in the Thai PVC resin industry. There are ranked by their cost of conserved energy (CCE) (Cont').

No.	Measure/technology	Steam saving of each unit (Ton-steam/yr)*	Latent heat of steam (GJ/ton-steam)*	Price of steam (Baht/ton-steam)*	Steam saving after improved of each unit (GJ/yr)	Number unit in case study*	Steam saving of case study (GJ/yr)	Steam saving of Thai PVC production (GJ/yr)	Cost saving (baht/yr)	Carbon dioxide emission reduction (ton-CO_2/yr)
S10	Set PM clean heat exchanger to prevent plugging	281	2.766	810	777	5	3,886	4,850	920,951	566
S11	Install Heat exchanger for DPW pre-heat PW at PVC plant	3,334	2.766	810	9,222	5	46,109	57,544	10,001,481	6,717
S12	Replace Heat exchanger to using steam directly for heat up water at PVC plant	1,738	2.766	810	4,807	5	24,037	29,998	5,110,433	3,502
S13	Install Heat exchanger for heat up water by using hot water from DPW to pre-heat PW at pre-heater system	1,190	2.122	800	2,525	5	12,626	15,757	781,342	1,839
S14	Heating panel jet cleaning at dryer	3,500	2.766	810	9,681	5	48,405	60,409	2,612,213	7,051
S15	Study implement APC at Stripping & Dryer unit to reduce energy consumption	1,968	2.766	810	5,443	5	27,217	33,967	-153,658	3,965

Note: * Information from case study ** Information from KEMA in appendix B, C (ref No. 27)

Table 4.4 Represents the energy, cost savings and CO_2 emission reduction of each measure in the Thai PVC resin industry. There are ranked by their cost of conserved energy (CCE) (Cont').

No.	Measure/technology	Natural gas used before improved of each unit (GJ/yr)*	Natural gas saved (percent) **	Natural gas saved after improved of each unit (GJ/yr)	Price of Natural gas (baht/MMBtu) *	Number unit in case study*	Natural gas saving of case study (GJ/yr)	Natural gas saving of Thai PVC production (GJ/yr)	Cost saving (baht/yr)	Carbon dioxide emission reduction (ton-CO_2/yr)
Natural Gas										
G1	Reduce NG consumption by increase cracking conversion	1,635,744	0.03	49,072	409	2	98,145	122,485	47,482,982	14,297
G2	Reduce NG consumption by optimizes control CCl_4 in Ethylene Dichloride(EDC) feed cracker furnace	1,234,553	0.04	49,382	409	2	98,764	123,258	47,782,149	14,387
G3	Reduce NG consumption by coating furnace wall at incinerator	1,232,543	0.08	98,603	409	2	197,207	246,114	83,932,479	28,728
G4	Reduce NG consumption by optimizes fuel gas feed and fire tube cleaning at incinerator	23,382	-	*3,663	409	2	7,326	9,143	-1,752,270	1,067

Note: * Information from case study ** Information from KEMA in appendix B, C (ref No. 27)

RESULT
TOTAL COST OF EACH MEASURE AND COST OF CONSERVED ENERGY

The equations used to calculate the values in the investment cost table (Table 4.5).
These are:

$$\text{Equipment and Labor cost}\left(\frac{\text{Baht}}{\text{yr}}\right) = \text{Energy saving}\left(\frac{\text{kWh}}{\text{yr}},\frac{\text{GJ}}{\text{yr}}\right) \times \text{cost unit for equip. and labor cost}\left(\frac{\$}{\text{kwh}},\frac{\$}{\text{GJ}}\right) \times \text{exchange rate}\left(\frac{\text{baht}}{\$}\right) \quad (3.7)$$

$$\text{Annualized capital cost}\left(\frac{\text{baht}}{\text{yr}}\right) = \text{Capital cost} \times \frac{\text{d}}{1-(1+\text{d})^{-\text{n}}} \quad (2.2)^*$$

$$\text{Total cost of each unit (baht)} = \text{Annual equipment and Labor cost}\left(\frac{\text{baht}}{\text{yr}}\right) + \text{Annualized capital cost}\left(\frac{\text{baht}}{\text{yr}}\right) \quad (3.8)$$

$$\text{Investment cost of case study} = \text{Total investment cost of each unit} \times \text{amount of unit in case study} \quad (3.9)$$

$$\text{Investment cost of Thai PVC production} = \text{Investment cost of case study} \times \text{PVC production ratio (1.248)} \quad (3.10)$$

$$\text{Cost Conserved Energy}\left(\frac{\text{baht}}{\text{kWh}}\right) = \frac{\text{Annualized capital cost (baht)}+\text{Annual change in O\&M costs (baht)}}{\text{Annual energy savings (kWh)}} \quad (2.1)^*$$

Note: Electricity price equal to 4.208 baht/kWh
Steam price at 8 kg/cm^2 (2.766 MJ/ton-steam) equal to 810 baht/ton-steam
Natural gas price equal to 409 baht/MMBtu (1MMBtu=1.055 GJ)
*Equation 2.1 was explained in chapter 2

Table 4.5 Represents the total cost of each measure in Thai PVC resin industry. These are ranked by their cost of conserved energy (CCE).

No.	Measure/technology	Electricity saving (kWh/yr)	Cost units for O&M cost ($/kWh-saved)**	Annual O&M cost (baht)**	Life time of energy efficiency measure (year)***	Capital cost (baht)*	Annualized capital cost (baht/yr)	Total cost of each unit (baht/yr)	Number unit in case study	Total cost of case study (baht/yr)	Total cost of Thai PVC production (baht/yr)	Cost of Conserved Energy (baht/kWh)
Electricity												
E1	Monitoring leakage and improvement in compress air system	831,096	0.001	831	1	-	-	831	1	831	1,037	0.001
E2	Adjust set point pressure for load/unload condition in Air Compressor system	586,656	0.002	1,173	1	-	-	1,173	1	1,173	1,464	0.002
E3	Membrane washing and Bus bar cleaning at CA plant	192,000	-	*48,000	*1	-	-	48,000	10	480,000	599,040	0.250
E4	Membrane replacement at CA plant	480,000	0.003	1,440	*2	300,000	220,435	221,875	10	2,218,748	2,768,997	0.462
E5	Install VSD at cooling fan B to reduce electricity consumption	293,328	0.001	293	10	450,000	145,559	145,852	10	1,458,519	1,820,231	0.497
E6	Reduce power consumption by replace new cooling fan blade at VCM production plant	729,533	0.001	730	10	2,200,000	711,620	712,349	1	712,349	889,012	0.976
E7	Replace and improve cooling fan at air compressor system	276,800	0.001	277	10	2,320,000	750,435	750,712	3	2,252,136	2,810,666	2.712
E8	Replace blade of cooling fan with new type at PVC production plant	138,058	0.001	138	10	1,532,000	495,546	495,684	5	2,478,420	3,093,068	3.590
E9	CA (Chlor-Alkali) Energy saving by Bi-polar electrolyzer replacement	6,995,562	0.004	27,982	*15	138,000,000	42,224,933	42,252,915	1	42,252,915	52,731,638	6.040

* Information from case study

** Information from Appendix B, C

*** In study, to assumed life time of adjust condition measure and install new equipment measure cases equal to 1 and 10 years, respectively.

Table 4.5 Represents the total cost of each measure in the Thai PVC resin industry. These are ranked by their cost of conserved energy (CCE) (Cont')

No.	Measure/technology	Steam saving (GJ/yr)	Cost units for O&M cost ($/Therm) **	Annual O&M cost (baht)**	Life time of energy efficiency measure (year)***	Capital cost (baht)*	Annualized capital cost (baht/yr)	Total cost of each unit (baht/yr)	Number unit in case study	Total cost of case study (baht/yr)	Total cost of Thai PVC production (baht/yr)	Cost of Conserved Energy (baht/kWh)
Steam												
S1	Increase NaOH concentration inlet from 31.7% to 35.0% and adjust condition	1,343	0.007	99	1	-	-	99	1	99	124	0.092
S2	Set preventative maintenance (PM) flushing heat exchanger for prevent plugging at VCM plant	19,987	0.007	1,475	1	-	-	1,475	5	7,375	9,204	0.092
S3	Reduce steam consumption by adjust condition of stripping column at PVC plant	6,386	0.055	3,704	1	-	-	3,704	5	18,520	23,113	0.724
S4	Reduce steam consumption at dryer and waste water stripping column by optimum dryer temperature	24,630	0.055	14,286	1	-	-	14,286	5	71,430	89,145	0.724
S5	Reduce MP steam consumption by increasing steam main pressure	9,666	0.292	29,765	1	-	-	29,765	1	29,765	37,147	3.843
S6	Increase LP steam generated by reducing OC steam drum pressure	71,863	0.292	221,301	1	-	-	221,301	2	442,602	552,367	3.843
S7	Reduce LP steam consumption by increasing steam main pressure	28,513	0.292	87,806	1	-	-	87,806	1	87,806	109,582	3.843
S8	Improved boiler and distribution system controls for reduced steam consumption	18,399	0.013	2,523	1	748,800	748,800	751,323	5	3,756,615	4,688,256	50.961
S9	Reduce MS consumption by retubing waste heat boiler at incinerator	14,030	0.041	6,067	1	1,560,000	1,560,000	1,566,067	5	3,132,134	3,908,903	96.190

* Information from case study

** Information from Appendix B, C

*** In study, to assumed life time of adjust condition measure and install new equipment measure cases equal to 1 and 10 years, respectively.

Table 4.5 Represents the total cost of each measure in the Thai PVC resin industry. These are ranked by their cost of conserved energy (CCE) (Cont')

No.	Measure/technology	Steam saving (GJ/yr)	Cost units for O&M cost ($/Therm) **	Annual O&M cost (baht)**	Life time of energy efficiency measure (year)***	Capital cost (baht)*	Annualized capital cost (baht/yr)	Total cost of each unit (baht/yr)	Number unit in case study	Total cost of case study (baht/yr)	Total cost of Thai PVC production (baht/yr)	Cost of Conserved Energy (baht/kWh)
S10	Set PM clean heat exchanger to prevent plugging	4,850	0.007	358	5	973,440	399,677	400,035	5	2,000,173	2,496,215	102.942
S11	Install Heat exchanger for DPW pre-heat PW at PVC plant	57,544	0.064	38,840	10	16,848,000	5,449,712	5,488,552	5	27,442,760	34,248,565	119.034
S12	Replace Heat exchanger to using steam directly for heat up water at PVC plant	29,998	0.055	17,400	10	9,048,000	2,926,697	2,944,097	5	14,720,486	18,371,167	122.482
S13	Install Heat exchanger for heat up water by using hot water from DPW to pre-heat PW at pre-heater system	15,757	0.263	43,705	10	9,360,000	3,027,618	3,071,323	5	15,356,614	19,165,054	243.254
S14	Heating panel jet cleaning at dryer	60,409	0.041	26,121	1	12,055,680	12,055,680	12,081,801	5	60,409,005	75,390,438	249.598
S15	Study implement APC at Stripping & Dryer unit to reduce energy consumption	33,967	0.055	19,702	10	24,960,000	8,073,647	8,093,349	5	40,466,747	50,502,501	297.364

Note:

The measure S14, during implementation should be to shut down the PVC production plant first. Therefore, the total cost must include PVC loss costs also.

The measure S15, assumes that the program will be replaced by a new program in 10 years.

* Information from case study

** Information from Appendix B, C

*** In study, to assumed life time of adjust condition measure and install new equipment measure cases equal to 1 and 10 years, respectively.

Table 4.5 represents the total cost of each measure in the Thai PVC resin industry. These are ranked by their cost of conserved energy (CCE). (Cont')

No.	Measure/technology	Natural gas saving (GJ/yr)	Cost units for O&M cost ($/Therm) **	Annual O&M cost (baht)**	Life time of energy efficiency measure (year)***	Capital cost (baht)*	Annualized capital cost (baht/yr)	Total cost of each unit (baht/yr)	Number unit in case study	Total cost of case study (baht/yr)	Total cost of Thai PVC production (baht/yr)	Cost of Conserved Energy (baht/kWh)
Natural Gas												
G1	Reduce NG consumption by increase cracking conversion	122,485	0.013	1,592	1	-	-	1,592	2	3,184	3,974	0.016
G2	Reduce NG consumption by optimizes control CCl4 in Ethylene Dichloride(EDC) feed cracker furnace	123,258	0.015	1,849	1	-	-	1,849	2	3,698	4,615	0.019
G3	Reduce NG consumption by coating furnace wall at incinerator	246,114	0.064	15,751	*2	12,480,000	9,170,087	9,199,621	2	18,399,242	22,962,254	46.650
G4	Reduce NG consumption by optimizes fuel gas feed and fire tube cleaning at incinerator	9,143	0.11	1,006	*1	4,243,200	4,243,200	4,244,206	2	8,488,412	10,593,538	579.335

* Information from case study

** Information from Appendix B, C

*** In study, to assumed life time of adjust condition measure and install new equipment measure cases equal to 1 and 10 years, respectively.

Table 4.4 indicates that the energy, cost savings and carbon dioxide emission reduction of each measure in the Thai PVC resin industry. These are ranked by their cost of conserved energy (CCE). Therefore, the highest energy and cost saving of electricity, steam and natural gas is given by measure E4: Membrane replacement at CA plant, measure S6: Increase LP steam generated by reducing OC steam drum pressure and measure G3: Reduce NG consumption by coating furnace wall at incinerator, respectively. The highest CO_2 emission reduction of electricity, steam, and natural gas are CA (Chlor-Alkali) Energy saving by Bi-polar electrolyzer replacement measure (E9), Increase LP steam generated by reducing OC steam drum pressure measure (S6) and Reduce NG consumption by coating furnace wall at incinerator measure (G3), respectively.

Furthermore, the total costs and cost of conserved energy obtained by applying each measure to the Thai PVC resin industry in the way described above in the methodology section is presented in Table 4.5. It shows that the Monitoring leakage and improvement in compress air system is the most economic potential measure (E1), Increase NaOH concentration inlet from 31.7% to 35.0% and adjust condition (S1) and Reduce NG consumption by increase cracking conversion measure (G1) are have the least CCE of electricity, steam and natural gas efficiency improvement, respectively. Moreover, the measure E9: CA (Chlor-Alkali) Energy saving by Bi-polar electrolyzer replacement, measure S13: Heating panel jet cleaning at dryer and measure G3: Reduce NG consumption by coating furnace wall at incinerator are highest total cost to capture the electricity, steam and natural gas efficiency improvement, respectively.

4.4 Energy Conservation Supply curve

So as to complete the measure or technology and calculation result section, the energy conservation supply curves (ECSCs) for the Thai PVC resin industry are constructed in this section. The Electricity Conservation Supply Curve (ECSC) and the Fuel Conservation Supply Curve (FCSC) were expressed independently. There are twenty-eight (28) energy efficiency measures, namely, nine (9) of which are electricity saving measures and nineteen (19) of which are fuel saving measures. Notice that, the fuel saving measure consists of two parts, which are Steam efficiency improvement (SCSC) and Natural gas efficiency improvement (NCSC), respectively.

4.4.1 Electricity Conservation Supply Curve

Tables 4.4 and 4.5 represent the list of nine (9) electricity efficiency measures in Thai PVC resin industry. These are ranked by their cost of conserved electricity (CCE) and their annual net cost savings that eight energy efficiency measures fall under the electricity price line for Thai PVC resin industries in 2013 (4.208 baht/kWh). Thus, these measures the CCE are less than the average price. In another words, the investment cost on these eight energy efficiency measures to save one kWh of steam is less than purchasing one kWh of steam with the given price. This is so-called "cost effectiveness" of an energy efficiency measure (economic potential).

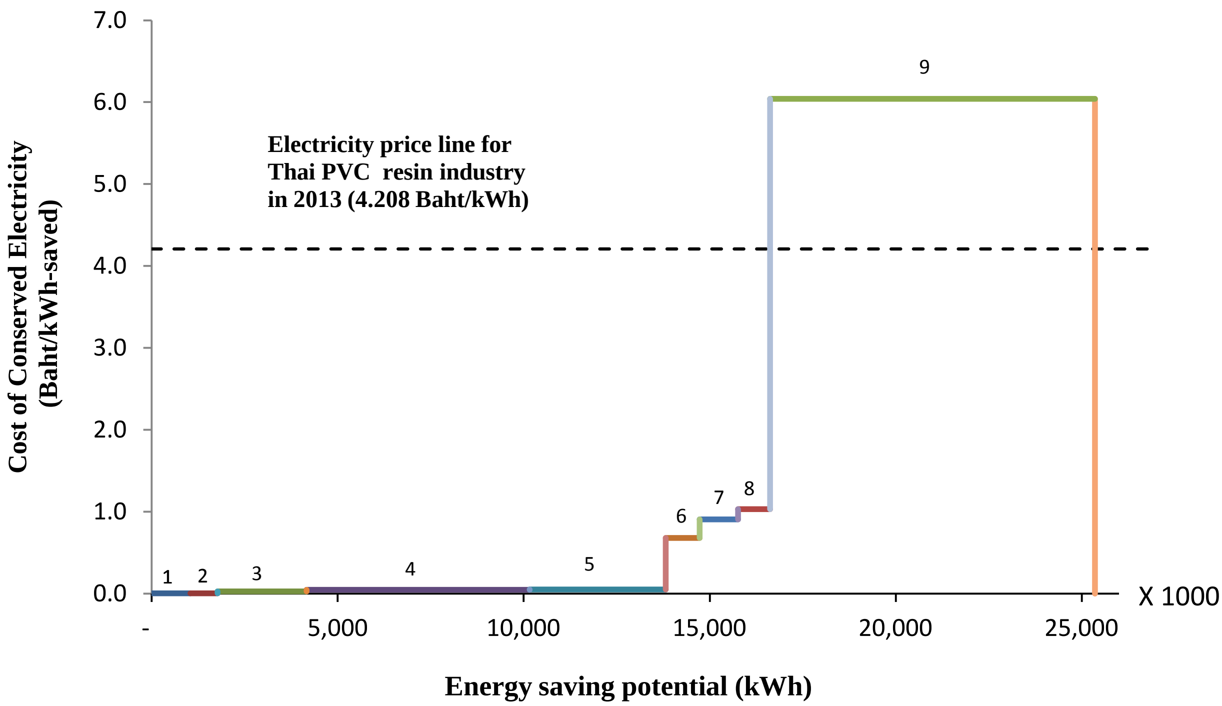


Figure 4.21 Electricity Conservation Supply Curve

The electricity savings and CO_2 emission reduction obtained by applying each measure to the Thai PVC resin industry in the way described above in the methodology section is also presented in Tables 4.4 and 4.5. It showed that Monitoring leakage and improvement in compress air system measure (E1) with the least CCE, followed by Adjust set point pressure for load/unload condition in Air Compressor system and Membrane washing and Bus bar cleaning at CA (Chlor-Alkali) plant measure. Obviously, the measure E9; energy saving by Bi-polar electrolyzer replacement for CA (Chlor-Alkali); can save the highest of electricity and CO_2 emission reduction about 8,730,461 kWh, 3,669 tCO_2

respectively and followed by measure E5, Membrane replacement at CA plant, which were around 5,990,400 kWh, 2,517 tCO_2 respectively.

However, according to Fig. 4.21 and Table 4.7, the eight (8) energy-efficiency measures that fall under the electricity price line for Thai PVC resin industry in 2013 (4.208 Baht/kWh). Therefore, for these measures the CCE is less than the average electricity price. Conversely, the investment cost on these 8 energy-efficiency measures to save 1 kWh of electricity is less than purchasing 1 kWh of electricity with the given price. So, the measure E9 is non-cost effective.

Table 4.6 Economic and technical potential for electricity savings and CO_2 emission reduction in Thai PVC resin industry for the base year 2013

	Electricity saving potential ($\times 10^3$ kWh/yr)		Carbon dioxide emission reduction (tCO_2/yr)	
	Technical potential	Economic potential	Technical potential	Economic potential
Base year :2013	25,355	16,625	10,654	6,986

Table 4.6 summarizes the results of electricity savings and carbon dioxide emission reduction associated with the total technical electricity saving potential of 25,355 MWh per year and the amount of CO_2 emission reduction of 10,654 tCO_2. The economic electricity-efficiency improvement potential for Thai PVC resin industry in 2013 was equal to 16,624 MWh per year and amount of CO_2 emission reduction was 6,986 tCO_2. Therefore, if the Thai PVC resins industry follows these implementations, it may reduce cost loss of electricity up to 66,991,836 baht.

4.4.2 Steam Conservation Supply Curve

In order to improve the steam efficiency utilization, the measure or technology is first explained in section 4.2.2. After performing the first step, the Steam Conservation Supply Curve (SCSC) was then created in this topic.

The list of these 15 steam efficiency measures in Thai PVC resin industries was presented in Tables 4.4 and 4.5, which are ranked by their cost of conserved energy (CCE) and their annual net cost saving that fourteen (14) energy efficiency measures fall under the steam price line for Thai PVC resin industries in 2013 (292.84 baht/GJ). Therefore, these measures the CCE are less than the average price. In another words, the cost of investing on these all energy efficiency measures to save one GJ of steam is less than purchasing one

GJ of steam with the given price. This is named as “cost effectiveness” of an energy efficiency measure (economic potential). So, the measure S15 is non-cost effective.

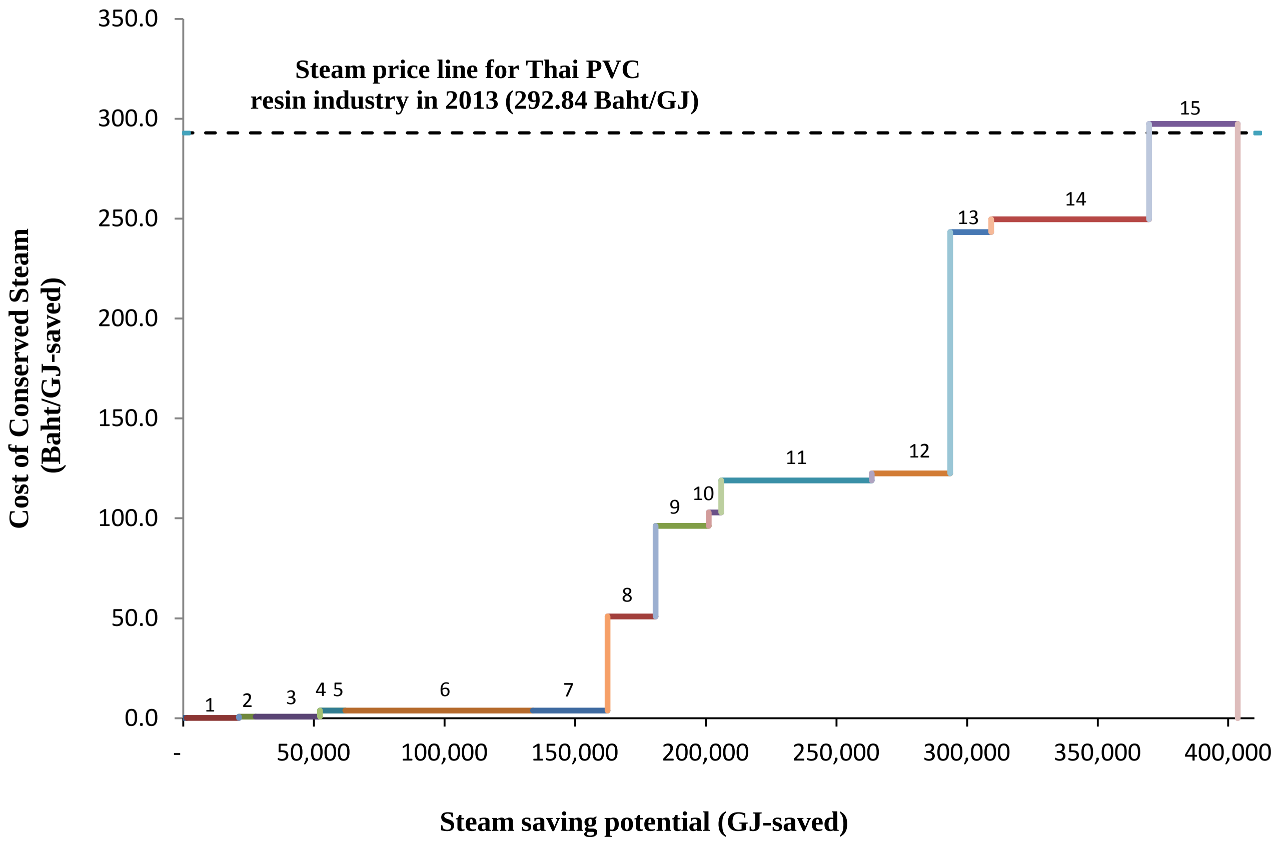


Figure 4.22 Steam Conservation Supply Curve

Fifteen (15) energy efficiency measures, as shown in Tables 4.4 and 4.5 were used to construct the Steam Conservation Supply Curve (SCSC). Furthermore, the steam saving and CO_2 emission reduction obtained by applying each measure to Thai PVC resin industry in a way described above in methodology section is also presented in table 4.4 and 4.5. It revealed that Increase NaOH concentration inlet from 31.7% to 35.0% and adjust condition measure is the most economic potential measure with the least CCE, followed by Set PM flushing heat exchanger for prevent plugging at VCM plant and Reduce steam consumption by adjust condition of stripping column at PVC plant measure. As shown in Figure 4.22, fourteen (14) energy-efficiency measures fall under the steam price line for Thai PVC resin industry in 2013 (292.84 baht/GJ). Table 4.7 Economic and technical potential for steam saving and CO_2 emission reduction in Thai PVC resin industry for the base year 2013.

Table 4.7 Economic and technical potential for steam saving and CO_2 emission reduction in Thai PVC resin industry for the base year 2013

	Steam saving potential (GJ/yr)		Carbon dioxide emission reduction (tCO_2/yr)	
	Technical potential	Economic potential	Technical potential	Economic potential
Base year :2013	403,631	369,664	47,115	43,150

Table 4.7 summarizes the results of steam savings and carbon dioxide emission reduction associated with the savings. It shows that the total technical and economic steam saving potential for Thai PVC resin industry in 2013 were 403,631 and 369,664 GJ per year, respectively and amount of CO_2 emission reduction were 47,115 and 43,150 tCO_2, respectively. Therefore, if the Thai PVC resins industry follows by this instruction, it can reduce cost loss of steam reaching to around 74,978,640 baht/yr.

4.4.3 Natural gas Conservation Supply Curve

To improve the natural gas utilization, the measure or technology is firstly explained in section 4.2.3. Then, the Natural gas Conservation Supply Curve (SCSC) is then constructed which was provided in this section.

From Tables 4.4 and 4.5 showed the list of these 4 electricity efficiency measures in Thai PVC resin industries which are ranked by their cost of conserved electricity (CCE) and their annual net cost saving that eight energy efficiency measures fall under the natural gas price line for Thai PVC resin industries in 2013 (387.68 baht/GJ). Therefore, this measures the CCE is less than the average price. In contrast, the cost of investing on these all energy efficiency measures to save one GJ of steam is less than purchasing one GJ of natural gas with the given price. This is called “cost effectiveness” of an energy efficiency measure (economic potential). So, the measure G4 is non-cost effective.

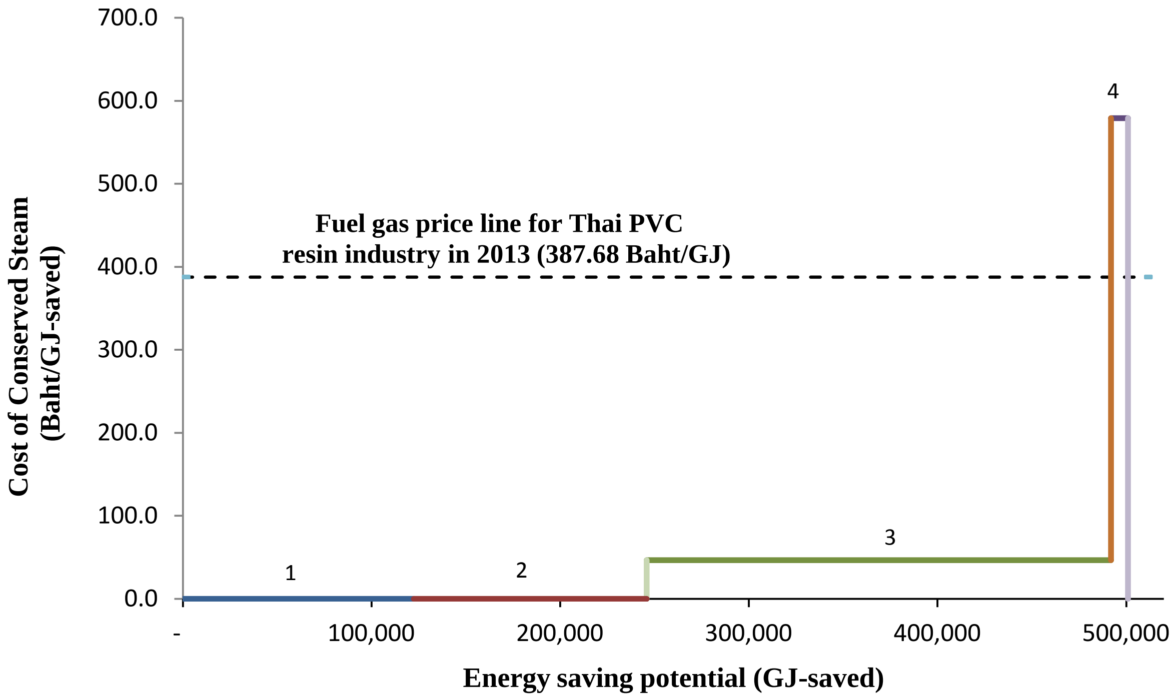


Figure 4.23 Natural Gas Conservation Supply Curve

Fig. 4.23 reveals that to Reduce FG consumption by increasing cracking conversion was the most economic potential measure with the least CCE, followed by Reduce Fuel gas consumption by Optimize control CCl_4 in EDC feed Cracker at VCM plant and Furnace wall coating agent spraying. As a result, measure G4 is non-cost effective.

Table 4.8 Economic and technical potential for natural gas savings and CO_2 emission reduction in Thai PVC resin industry for the base year 2013

	Natural gas saving potential (GJ/yr)		Carbon dioxide emission reduction (tCO_2/yr)	
	Technical potential	Economic potential	Technical potential	Economic potential
Base year :2013	501,000	491,857	58,480	57,413

Additionally, the results of natural gas savings and carbon dioxide emission reduction associated with savings are summarized in Table 4.8. It presented that the total technical and economic saving potential for Thai PVC resin industry in 2013 were 501,000 GJ per year and amount of CO_2 emission reduction were 58,480 tCO_2. Consequently, if the Thai PVC resins industry allows all these improvements, the cost loss of natural gas can be thus reduced to about 179,197,610 baht/yr.

4.5 Total cost savings

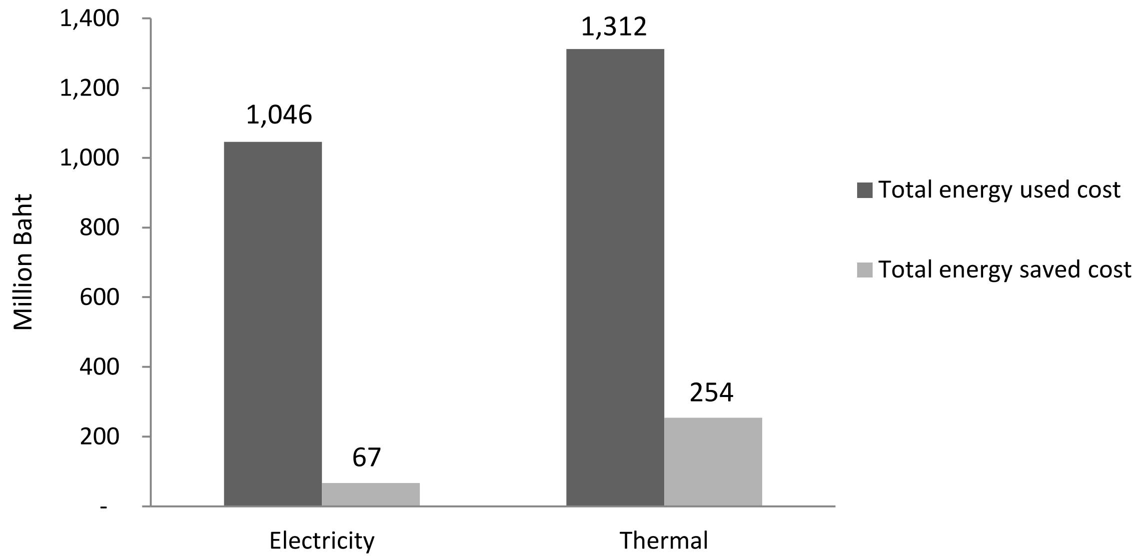


Figure 4.24 Total cost of energy used and energy savings in Thai PVC resin industry

As previously mentioned, the potential for the efficiency of the Polyvinyl Chloride resin production processes and carbon dioxide reduction emissions in Thailand can be analyzed by gathering data from the case study and employing the bottom-up approach. In this topic, the total cost of energy uses and energy saved in the views of electric and thermal energy in Thai PVC resin industry were summed up as shown in Fig. 4.24. It distinctly exhibited that the cost of electricity and fuel used in Thai PVC resin industry were equal to 1,046 and 1,312 million baht respectively based on the energy price of electricity, steam, and fuel in 2013 were around 4.208 baht per kWh, 810 baht/ton-steam and 409 baht/MMBtu, respectively. Besides, this figure also pointed that if implement of economic potential measures are used in Thai PVC resin industry, the value of electricity saving and fuel saving (thermal) will be equal to 67 and 254 million baht, respectively.

CHAPTER 5
CONCLUSION

5.1 Conclusion

The bottom-up Energy Conservation Supply Curves (i.e. ECSC and FCSC) were constructed for the Thai PVC resin industry to estimate the savings potential and costs of energy-efficiency improvements by taking into account the costs and energy savings of different technologies. The information of energy used and detail of each technology was derived from the case study (Factory A)

In this study to analyze twenty-eight (28) energy efficiency technologies and measures for the Thai PVC resin industry for base year 2013. Using a bottom-up CSC models, the cumulative technical and economic (cost-effective) potential of electricity, and fuel savings (steam and natural gas) as well as the carbon dioxide (CO_2) emissions reduction potentials for the Thai PVC resin industry are estimated by the implementation of the studied efficiency measures. The enlargement, energy saving of each measure and carbon dioxide emission reduction of case study to Thai PVC resin industry using production ratio (1.248) to scale up before constructing the energy conservation supply curves.

5.1.1 Energy conservation supply curves and CO_2 emission reduction

The energy conservation supply curves indicated the technical and economic potential of energy saving and carbon dioxide emission reduction potential in the Thai PVC resin industry as demonstrated in Table 5.1.

Table 5.1 Technical and economic potential for energy savings and CO_2 emission reduction in Thai PVC resin industry for the base year 2013

Base year :2013	Energy saving potential (MWh, GJ/yr)		Carbon dioxide emission reduction (tCO_2/yr)	
	Technical potential	Economic potential	Technical potential	Economic potential
Electricity	25,355 MWh	16,625 MWh	10,654	6,986
Steam	403,631 GJ/yr	369,664 GJ/yr	47,115	43,150
Natural gas	501,000 GJ/yr	491,857 GJ/yr	58,480	57,413
Total	-	-	116,249	107,549

Table 5.1 reveals that the technical and economic potential of electricity in Thai PVC resin industry are 25,355 and 16,624 MWh, respectively. The technical and economic potential of fuel (steam and natural gas) are 904,631 and 861,521 GJ/yr. Moreover, the total CO_2 emission reductions of technical and economic potential are 116,249 and 107,549 ton-CO_2/yr. Notice that if the Thai PVC resins industry follows all lists of measure implementations.

5.1.2 Total cost saving

Table 5.2 Total cost of energy used and energy savings in Thai PVC resin industry

Base year :2013	Cost (million baht/yr)		
	Energy used	Saving energy	% energy saved
Electricity	1,046	66	6.31%
Thermal	1,312	254	19.36%
Total	2,358	310	13.15 %

Table 5.2 expresses the value of energy saving potential in Thai PVC resin industry was equal to 310 million baht per year compared with the value of energy used of 2,358 million Baht per year or accounting for 13.15% of the total energy used. Moreover, the total cost of energy in Thai PVC resin industry derived from electricity and fuel (thermal) were equivalent to 1,046 and 1,312 million baht respectively. While the values of saving potentials in electricity and fuel (thermal) were equal to 66 and 254 million baht which covered about 6.31% and 19.36% of the electricity and fuel costs respectively.

5.2 Future work

Future studies in this subject can make efforts to find and include more energy efficiency technologies in CSCs. Moreover, the cost and energy saving of energy efficiency technologies will change over time. This should be taken into account in the future studies. Finally, one of the most important issues that could be studied energy policy scenarios can be developed in order to assess the effect of policy measures on energy efficiency improvement in Thai PVC resin industry. However, better understanding of investment behavior in Thai PVC resin industry will help to obtain accurate results from policy analysis by taking better assumptions.

REFERENCES

[1]. Energy, Ministry of Energy, Department of Alternative Energy Development and Efficiency 2012. Energy end used by economic 2012, Online available: http://www.dede.go.th/dede/index.php?option=com_content&view=article&id=1841&Itemid=318&lang=en [assessed on: June 2013]

[2]. 67th Session of the UNGA,PM Speaks with Investors, October 2012, Volume 22, No. 10, page 1-12

[3]. Kenan Institute Asia, Thailand SME sectors and the Proposed EU-Thailand FTA: Winners, losers and policy recommendation, DCI-Asie 2008, page 169-403

[4]. Ali Hasanbeigi, et al., Energy efficiency improvement and CO2 emission reduction opportunities in the cement industry in China, Energy Policy, Volume 57, June 2013, Pages 287–297

[5]. Pornphimol Winyuchakrit, et al., Thailand's low-carbon scenario 2030: Analyses of demand side CO_2 mitigation options, Energy for Sustainable Development 15 (2011), page 460–466

[6]. Maarten Neelis, et al., Analysis of energy use and carbon losses in the chemical industry, Applied Energy 84 (2007), page 853–862

[7]. Ernst Worrell, et.al., Energy efficiency and carbon dioxide emissions reduction opportunities in the US iron and steel sector, Energy 26 (2001), page 513–536

[8]. IEA information paper, Chemical and Petrochemical Sector (2009), Potential of best practice technology and other measures for improving energy efficiency, page 20-25

[9]. Maarten Neelis, et.al., Energy efficiency developments in the Dutch energy-intensive manufacturing industry, 1980–2003, Energy Policy, volume 35 (2007), page 6112–6131

[10]. D. Saygin, et.al., Long-term energy efficiency analysis requires solid energy statistics: The case of the German basic chemical industry, Energy , volume 44 (2012), page 1094-1106

[11]. International Energy Agency (IEA), chemical and petrochemical sector, September 2009, available online available : www.iea.org/about/copyright.asp [Assessed on: July 2013]

[12]. Euroheat and Power, Euroheatcool work package 1, The European heat market, final report, Brussels, Belgium (2006), page 1-20

[13]. Department of Alternative Energy Development and Efficiency (DEDE), A Study on Energy Efficiency Index in Petrochemical Industry, 2012.

[14]. S.L. Rosen, Fundamental Principles of Polymeric Materials, 2nd edition, John Wiley & Sons, Singapore, 1993.

[15]. Y. Saeki, et al., Technical progresses for PVC production, Prog. Polym. Sci. 27 (2002), page 2055–2131

[16]. American Plastics Council, adapted from Modern Plastics Encyclopedia, (1995)

[17]. Albright LF, Chem Engng (1967); volume 74 (May), page 151–8.

[18]. Albright LF. Chem Engng (1967); volume 74 (June), page 145–52.

[19]. Saeki Y. Production processes of polymers. Tokyo: Kogyo Chosakai Publishing; 1971. P.1–17

[20]. Saeki Y. In: Saeki Y, Omi S, editors, New production processes of polymer. Tokyo: Kogyo Chosakai Publishing; 1994. P.15–43

[21]. S.L. Rosen, Fundamental Principles of Polymeric Materials, 2nd edition, John Wiley & Sons, Singapore, 1993.

[22]. M.P. Stevens, Polymer Chemistry, Oxford University Press, New York, 1991.

[23]. G. Odian, Principle of Polymerization, John Wiley & Sons, New York, 1991, p.259.

[24]. D.Braun, H. Cherdron, W. Kern, Practical Molecular Organic Chemistry, Harwood Academic Publishers, London, 1984, p. 135.

[25]. Kenan Institute Asia, Thailand SME Sectors and the Proposed EU-Thailand FTA: Winners, losers and policy recommendation, DCI-Asie 2008, page.169-403

[26]. Emission factors for greenhouse gas inventories, Intergovernmental Panel on Climate Change (IPCC), Fourth Assessment Report (AR4), 2007. 4 April 2014

[27]. KEMA, Inc. California Industrial Existing Construction Energy Efficiency Potential Study, Lawrence Berkeley Nation Laboratory (LBNL) and Quantum Consulting, Pacific Gas and Electric Company, San Francisco, California, Volume 2 of 2 – Appendices, May 2006

[28]. King, Julie. MichiganTech, Department of Chemical Engineering McKane, A. and Medaris, B. *The Compressed Air Challenge – Making a difference for US industry*. 2003. Online available: http://eetd.lbl.gov/ea/indpart/publications/lbnl_52771.pdf [assessed on: December 2013]

[29]. US Department of Energy (US DOE), Energy Efficiency and Renewable Energy. *Improving Compressed Air System Performance.* DEO/GO-102003-1822. 2003. Online available: www.oit.doe.gov/bestpractices/compressed_air [assessed on: December 2013]

[30]. yandech, Compressed Air Leakage, 2011, Online available: http://www.bloggang.com/mainblog.php?id=compressedairenergysaving&month=25-08-2011&group=1&gblog=1[assessed on: June 2014]

[31]. J.J. Krol, Enschede, The Netherlands, 1997, MONOPOLAR AND BIPOLAR ION EXCHANGE MEMBRANES, Mass Transport Limitations.

[32]. chloralkali process, online available: http://en.wikipedia.org/wiki/Chloralkali_process [Assessed on May 2014]

[33]. Carbon Trust works, Variable speed drives Introducing energy saving opportunities for business, March 2007.

[34]. GEA Polacel Cooling Towers, Cooling tower technology, online available: http://www.gea-energytechnology.com/opencms/opencms/pcl/en/CoolingTowers/Coolingtechnology.html [assessed on: June 2014]

[35]. R. Saidur etc., A STUDY OF ENERGY EFFICIENCY, ECONOMIC AND ENVIRONMENTAL BENEFITS OF A COOLING TOWER, International Journal of Mechanical and Materials Engineering (IJMME), Vol. 5 (2010), No. 1, 87-94

[36]. Chlorine Engineers Corporation Itd., 2010.,Principles of IEM Electrolyzer , Online available:http://www.chlorine-eng.co.jp/en/product/electrolysis/ion-exchange-membrane.html, [assessed on: 2 June 2014]

[37]. Preventive maintenance program Guide for small public water systems using groundwater, November 2011, Office of Drinking Water publications are online at https://fortress.wa.gov/doh/eh/dw/publications/publications.cfm [assessed on: July 2014]

[38]. J. D. Seader et.al, Henley, Separation Process Principles, Wiley, 2006, pg. 194

[39]. GEA Niro, Industrial drying systems, Process Engineering Division of the GEA Group, http://www.niro.com/niro/cmsresources.nsf/filenames/BNA%20919_GB_Niro%20POLYMER%20brochure.pdf/$file/BNA%20919_GB_Niro%20POLYMER%20brochure.pdf [assessed on: July 2014]

[40]. Waste Incineration - An Effective Waste Management Process online available: http://www.wasteincineration.net [assessed on: May 2014]

[41]. Heat exchangers, 2012, pp.1-17, online available: http://www.completesengineering.com/style/article_heat%20xechanger1.pdf [assessed on: May 2014]

[42]. Yokogawa Electric Corporation, ADVANCED PROCESS CONTROL SOLUTIONS, Technical Information, 1st Edition Oct. 2001

[43]. K. Nagasubramanian, F.P. Chlanda and K.J. Liu, Use of bipolar membranes for generation of acid and base - an engineering and economic analysis, J. Membrane Sci., volume 2 (1977), page 109-124

[44]. Syllabus, Bureau of Energy Efficiency, WASTE HEAT RECOVERY, online available:http://www.em-ea.org/Guide%20Books/book2/2.8%20Waste%20Heat%20Recovery.pdf [assessed on: June 2014]

[45]. Metropolitan electricity Authority, Thailand (2012) online available: http://www.mea.or.th/profile/index.php?l=th&tid=3&mid=2986&pid=2985 [assessed on: June 2014]

APPENDIXES

APPNDIX A
MEASURE DATA

Measure data provided by Lawrence Berkeley National Laboratories. Data was developed from numerous secondary sources by industry and end use. Data were developed for both cross-cutting technologies (technologies that are applicable across various industry types) and industry-specific technologies. Values for the various measures are provided in Appendix B for electricity and Appendix C for natural gas. Following are descriptions of measures included in the study.

A.1 Electric Measure Descriptions

Cross-Cutting Electricity Efficiency Measures

Replace motors: This measure refers to the replacement of existing motors with high-efficiency motors. High-efficiency motors reduce energy losses through improved design, better materials, tighter tolerances, and improved manufacturing techniques. With proper installation, high efficiency motors can run cooler than standard motors and can consequently have higher service factors, longer bearing life, longer insulation life, and less vibration.

Adjustable-speed drives (ASDs): ASDs better match motor speed to load and can therefore lead to significant energy savings compared to constant-speed motors. Typical energy savings associated with ASDs range from seven (7) to sixty (60) percent.

Motor practices: This measure refers to proper motor maintenance. The purposes of motor maintenance are to prolong motor life and to foresee a motor failure. Motor maintenance measures can be categorized as either preventive or predictive. Preventive measures, whose purpose is to prevent unexpected downtime of motors, include electrical consideration, voltage imbalance minimization, motor ventilation, alignment, and lubrication, and load consideration. The purpose of predictive motor maintenance is to observe ongoing motor temperature, vibration, and other operating data to identify when it becomes necessary to overhaul or replace a motor before failure occurs. The savings associated with ongoing motor maintenance could range from two (2) to thirty (30) percent of total motor system energy use.

Compressed air—operation and maintenance (O&M): Inadequate maintenance can lower compression efficiency and increase air leakage or pressure variability, as well as lead to increased operating temperatures, poor moisture control, and excessive contamination. Improved maintenance will reduce these problems and save energy. Proper maintenance includes regular motor lubrication, replacement of air lubricant separators, fan, and pump inspection, and filter replacement.

Compressed air controls: The objective of any control strategy is to shut off unneeded compressors or delay bringing on additional compressors until needed. Energy savings for sophisticated controls have been around twelve (12) percent annually. Available controls for compressed air systems include start/stop, load/unload, throttling, multi-step, variable speed, and network controls.

Compressed air system optimization: This is a general measure that refers to compressed air system improvements (besides sizing, controls, and maintenance) that allow it to perform at maximum energy efficiency. Such improvements could include reducing leaks, better load management, minimizing pressure drops throughout the system, reducing air inlet temperatures, and recovering waste compressor heat for other facility applications.

Compressed air sizing: This measure refers to the proper sizing of compressors, regulators, and distribution pipes. Over sizing of compressors can result in wasted energy. By properly sizing regulators, compressed air will be saved that is otherwise wasted as excess air. Pipes must be sized correctly for optimal performance or resized to fit the current compressor system. Increasing pipe diameters typically reduces annual energy consumption by three (3) percent.

Pumps—O&M: Inadequate maintenance can lower pump system efficiency, cause pumps to wear out more quickly, and increase costs. Better maintenance will reduce these problems and also save energy. Proper pump system maintenance includes bearing inspection and repair, bearing lubrication, replacement of worn impellers, and inspection and replacement of mechanical seals.

Pumps—controls: The objective of pump control strategies is to shut off unneeded pumps or, alternatively, to reduce pump load until needed. In addition to energy savings, proper pump control can lead to reduced maintenance costs and increased pump life.

Pumps—system optimization: This is a general measure that refers to pump system improvements (besides sizing, controls, and maintenance) that allow it to perform at maximum energy efficiency. Such improvements could include pump demand reduction, high-efficiency pumps, impeller trimming, and installing multiple pumps for variable loads.

Pumps—sizing: Pumps that are sized inappropriately result in unnecessary losses. Where peak loads can be reduced, pump size can also be reduced. Replacing oversized pumps with pumps that are properly sized can save fifteen (15) to twenty-five (25) percent of the electricity consumption of a pumping system (on average for U.S. industry).

Fans—O&M: This measure refers to the improvement of general O&M practice for fans, such as tightening belts, cleaning fans, and changing filters regularly.

Fans—controls: The objective of fan control strategies is to shut off unneeded fans or, alternatively, to reduce fan load until needed. In addition to energy savings, proper fan control can lead to reduced maintenance costs and increased pump life.

Fans—system optimization: This measure refers to general strategies for optimizing fans from a systems perspective, and includes such actions as better inlet and outlet design and reduction of fan sizing, where appropriate.

Fans—improve components: This measure refers to the improvement of fan components, such as replacing standard V-belts with cog V-belts and upgrading to the most energy-efficient motors possible.

Replace T-12 by T-8 and electronic ballasts: T-12 tubes consume significant amounts of electricity and also have extremely poor efficacy, lamp life, lumen depreciation, and color rendering index. Replacing T-12 lamps with T-8 lamps (smaller diameter) approximately doubles the efficacy of the former. Electronic ballasts save twelve (12) to thirteen (30) percent power over their magnetic predecessors; typical energy savings associated with replacing magnetic ballasts by electronic ballasts are estimated to be roughly twenty-five (25) percent.

Metal halides/fluorescents: Metal halide lamps can replace mercury or fluorescent lamps with energy savings of fifty (50) percent. For even further savings, high-intensity fluorescent lamps can be installed, which can yield fifty (50) percent electricity savings over standard metal halide (high intensity discharge) systems.

Switch off/O&M: Lighting is often left on, even when the area or room is not occupied. Sensors can be installed, but savings can also be realized by training personnel to switch off lights (and other equipment) when not needed. Furthermore, adapting switching to the use pattern of the building will enable to control the lighting in those areas where it is needed (e.g., in many assembly areas a single switch controls all lighting, even when lighting would only be needed in a few zones within the assembly hall).

Controls/sensors: Lights can be shut off during non-working hours by automatic controls, such as occupancy sensors, which turn off lights when a space becomes unoccupied. Manual controls can also be used in addition to automatic controls to save additional energy in small areas.

Super T-8s: Super T-8 fluorescent systems are a further development of (standard) T-8 tubes. Super T-8s combine further improvement of the fluorescent tube (e.g., barrier coating, improved fill, enhanced phosphors) with electronic ballasts in a single system.

HVAC (stands for Heating, Ventilation, and Air Conditioning) management system: An energy monitoring and control system supports the efficient operation of HVAC systems by monitoring, controlling, and tracking system energy consumption. Such systems continuously manage and optimize HVAC system energy consumption while also providing building engineers and energy managers with a valuable diagnostic tool for tracking energy consumption and identifying potential HVAC system problems.

Cooling system improvements: The efficiency of chillers can be improved by lowering the temperature of the condenser water, thereby increasing the chilled-water temperature differential. This can reduce pumping energy requirements. Another possible efficiency measure is the installation of separate high-temperature chillers for process cooling.

Duct/pipe insulation/leakage: Duct leakage can waste significant amounts of energy in HVAC systems. Measures for reducing duct leakage include installing duct insulation and performing regular duct inspection and maintenance, including ongoing leak detection and repair. Improved duct and pipe insulation can prevent excessive heat/cooling dissipation, thereby improving system energy efficiency.

Cooling circulation pumps – variable-speed drives (VSDs): VSDs better match motor speed to load and can therefore lead to significant energy savings compared to constant-speed drives. This measure considers the installation of VSDs on cooling circulation pumps.

DX tune up/advanced diagnostics: The tune-up includes cleaning the condenser and evaporator coils, establishing optimal refrigerant levels, and purging refrigerant loops of entrained air. The qualifying relative performance range for a tune-up is between sixty (60) and eighty-five (85) percent of the rated efficiency of the unit.

DX packaged system: A single-package A/C unit consists of a single package (or cabinet housing) containing a condensing unit, a compressor, and an indoor fan/coil. An additional benefit of package units is that there is no need for field-installed refrigerant piping, thus minimizing labor costs and the possibility of contaminating the system with dirt, metal, oxides, or non-condensing gases.

Window film: Low-emittance windows are an effective strategy for improving building insulation. Low-emittance windows can lower the heat transmitted into a building and therefore increase its insulating ability. There are two types of low-E glass, high solar transmitting (for regions with higher winter utility bills), and low solar transmitting (for regions with higher summer utility bills).

Programmable thermostat: A programmable thermostat controls temperature settings of space heating and cooling, and allows optimizing settings based on occupancy and building use. This will reduce unnecessary heating and cooling outside hours of building use. It may also help in building cooling using nighttime cooling.

Chiller O&M/tune up: This measure refers to the proper inspection and maintenance of chilled-water systems. This can include setting correct head pressure, maintaining correct levels of refrigerant, and selecting and running appropriate compressors for part load. Energy saving can also be achieved by cleaning the condensers and evaporators to prevent scale buildup.

Setback temperatures (weekends and off duty): Setting back building temperatures (i.e., turning building temperatures down in winter or up in summer) during periods of non-use, such as weekends or non-production times, can lead to significant savings in HVAC energy consumption.

Replace V-belts: Inventory data suggest that 4 percent of pumps have V-belt drives, many of which can be replaced with direct couplings to save energy. Based on assessments in several industries, the savings associated with V-belt replacement are estimated at 4 percent.

ENERGY STAR transformers: This measure refers to the replacement of existing transformers, where feasible, by the latest ENERGY STAR-certified transformers. ENERGY STAR transformers ensure a high level of energy efficiency.

Sector-Specific Electricity Efficiency Measures

SIC 30: Rubber and Miscellaneous Plastic Products

O&M—extruders/injection molding: Improved operation and maintenance procedures of extruders, optimization of extruder settings, optimization of the extruder screw shape, optimization of the shape/thickness of the product, and reduction of standby time.

Extruders/injection molding—multi-pump: The use of multiple pumps and an appropriate control system reduces energy use of the extruder when not working at full capacity, only using the pump(s) needed.

Direct drive extruders: Use of a direct drive, instead of a gearbox or belt, will reduce the losses by approximately 15 percent in extruders.

Injection molding—impulse cooling: Impulse cooling regulates the cooling water use increasing the cooling rate and reducing productivity (and downtime).

Injection molding—direct drive: Use of a direct drive, instead of a gearbox or belt, will reduce the losses by approximately 20 percent in injection molding machines.

A.2 Natural Gas Measure Descriptions

Cross-Cutting Efficiency Measures

Boilers

Improved process control: Flue gas monitors are used to maintain optimum flame temperature and monitor levels of carbon monoxide (CO), oxygen, and smoke in the flue gas. By combining an oxygen monitor with an intake airflow monitor, it is also possible to detect small leaks. Monitoring allows for improved control of the fuel/air mixture so that energy efficiency is maximized and pollutant emissions are minimized.

Maintain boilers: Burners and condensate return systems can wear or get out of adjustment over time, which can cost a steam system up to thirty (30) percent of its original efficiency over two (2) to three (3) years. Regular maintenance can ensure steam systems are operating at maximum efficiency.

Flue gas heat recovery/economizer: Heat from flue gases can be recovered using an economizer and used to preheat the feed water flowing into the boiler. By using waste heat to preheat feed water, the fuel consumption of the boiler can be reduced. This measure is fairly common in large boiler systems.

Blowdown steam heat recovery: When water is blown from high-pressure boilers as part of regular blow down procedures, the pressure reduction often produces substantial amounts of low-grade steam. This low-grade steam can be used for space heating and feed water preheating.

Upgrade burner efficiency: A boiler will run only as well as the burner performs. A poorly designed boiler with an efficient burner may perform better than a well designed boiler with a poor burner. An efficient burner provides the proper air-to-fuel mixture throughout the full range of firing rates, without constant adjustment. An efficient natural gas burner requires only two (2) to three (3) percent excess oxygen or ten (10) to fifteen (15) percent excess air in the flue gas, to burn fuel without forming excessive carbon monoxide.

Water treatment: Water impurities can form scale on heat transfer tubes and surfaces and lead to corrosion of system components, which can steadily degrade the energy efficiency of a steam system. Water treatment can reduce scale and corrosion, and therefore help to maintain a steam system's optimal energy performance over time.

Load control: A boiler economic load allocation system optimizes the loading of multiple boilers by providing steam to a common header so as to obtain the lowest cost per unit of steam. Modern, multiple burner load control, coupled with air trim control can result in steam system fuel savings of three (3) to five (5) percent.

Improved insulation: Advancements in insulating materials have produced a new generation of insulation with low heat capacity and better insulating capabilities. Energy savings of six (6) to twenty-six (26) percent can be achieved by upgrading boiler insulation and installing improved heater circuit controls, (improved controls are often necessary to maintain proper output temperatures for older firebrick systems).

Steam trap maintenance: A simple program of checking steam traps to ensure they are operating properly can save significant amounts of energy. Without regular maintenance, steam traps can malfunction, wasting up to ten (10) percent of the energy consumed by a steam system.

Automatic steam trap monitoring: Attaching automated monitors to steam traps allows for the quick diagnosis and correction of steam trap malfunction. This measure can lead to energy savings above and beyond the energy savings achieved through regular steam trap maintenance.

Leak repair: As with steam traps, steam distribution pipes often have leaks that go unnoticed without a regular program of pipe inspection and maintenance. In addition to detecting and repairing leaks, thereby reducing wasted energy, this measure can also prevent small problems from developing into major leaks, which are often more difficult and expensive to repair.

Condensate return: Returning the hot condensate that occurs within a steam system to the boiler can save energy and reduce the need to treat boiler feed water. The substantial savings in energy costs and purchased chemical costs associated with this measure often make the building of a return piping system financially attractive.

HVAC

Improve ceiling insulation: Installing fiberglass or cellulose insulation material in floor, wall, or roof cavities will reduce heat transfer across these surfaces. The type of building construction limits insulation possibilities. Choice of insulation material will vary depending on the roof construction type.

Install high-efficiency (ninety-five (95) percent) condensing furnace/boiler: High-efficiency condensing gas furnaces and boilers have AFUEs of greater than ninety (90) percent compared to base efficiencies in the eighty (80) percent range. For furnaces, efficiencies above ninety (90) percent can be achieved with a number of technologies, pulse combustion being just one of many design approaches. Condensing boilers are available which operate with thermal efficiencies as high as ninety-five (95) percent or more. These condensing units achieve their high efficiency by operating with stack gas temperatures around 100 °F.

Stack heat exchanger: Air-to-air heat exchangers can be used to transfer heat between the intake ventilation air stream and the HVAC exhaust air stream. During periods when the outside air is colder than the inside air, the heat exchanger transfers heat from the exhaust air to the incoming air reducing heating energy use. When the outside air is warmer than the inside air, the heat exchanger transfers heat from the incoming air to the exhaust air, lowering the temperature of the incoming air, and reducing cooling energy use.

Duct insulation: Insulation material inhibits the transfer of heat through the air-supply duct.Several types of ducts and duct insulation are available, including flexible duct, pre-insulated flexible duct, duct board, duct wrap, tacked or glued rigid insulation, and water proof hard shell materials for exterior ducts.

Energy management system install: An energy management system (EMS) is a complete building control system, which usually includes controls for both lighting and HVAC systems. The HVAC control system may include on/off scheduling and warm-up routines. The complete lighting and HVAC control systems are generally integrated using a personal computer with control system software.

EMS optimization: Energy management systems are frequently underutilized and have hundreds of minor inefficiencies throughout the system. Optimization of the existing system frequently results in substantial savings to the measures controlled by the EMS (e.g., lighting, HVAC) by minimizing waste.

Sector-Specific Natural Gas Efficiency Measures

SIC 30: Rubber and Miscellaneous Plastic Products

Process controls and management: This is a general measure to implement computer-based process controls, where applicable, to monitor, and optimize various processes from an energy consumption perspective. In general, by monitoring key process parameters, processes can be fine tuned to minimize energy consumption while still meeting quality and productivity requirements. Control systems can also reduce the time required to perform complex tasks and can often improve product quality and consistency and optimize process operations. This measure could include the installation of controls based on neural networks, knowledge-based systems, or improved sensor technology.

Heat recovery: This is a general measure to recover waste heat from processes wherever possible for use in other processes and/or facility applications, such as process feed preheating, space heating, water heating, and process air preheating.

APPENDIX B
ELECTRIC MEASURE INPUT DATA

B.1 MEASURE COSTS

Measure	Measure Description	Cost unit	Unit Labor cost (O&M cost)
100	Base Compressed	$/kWh	$0.000
101	Compressed Air-O&M	$/kWh	$0.001
102	Compressed Air - Controls	$/kWh	$0.002
103	Compressed Air - System Optimization	$/kWh	$0.001
104	Compressed Air- Sizing	$/kWh	$0.000
105	Comp Air - Replace 1-5 HP motor	$/kWh	$0.005
106	Comp Air - ASD (1-5 hp)	$/kWh	$0.007
107	Comp Air - Motor practices-1 (1-5 HP)	$/kWh	$0.002
108	Comp Air - Replace 6-100 HP motor	$/kWh	$0.003
109	Comp Air - ASD (6-100 hp)	$/kWh	$0.000
110	Comp Air - Motor practices-1 (6-100 HP)	$/kWh	$0.000
111	Comp Air - Replace 100+ HP motor	$/kWh	$0.001
112	Comp Air - ASD (100+ hp)	$/kWh	$0.001
113	Comp Air - Motor practices-1 (100+ HP)	$/kWh	$0.000
114	Power recovery	$/kWh	$0.000
115	Refinery Controls	$/kWh	$0.000
116	Energy Star Transformers	$/kWh	$0.006
200	Base Fans	$/kWh	$0.000
201	Fans - O&M	$/kWh	$0.000
202	Fans - Controls	$/kWh	$0.008
203	Fans - System Optimization	$/kWh	$0.005
204	Fans- Improve components	$/kWh	$0.000

Reference: KEMA, Inc. California Industrial Existing Construction Energy Efficiency Potential Study, Lawrence Berkeley Nation Laboratory (LBNL) and Quantum Consulting, Pacific Gas and Electric Company, San Francisco, California, Volume 2 of 2 – Appendices, May 2006

B.1 MEASURE COSTS (Cont.)

Measure	Measure Description	Cost unit	Unit Labor cost (O&M cost)
205	Fans - Replace 1-5 HP motor	$/kWh	$0.005
206	Fans - ASD (1-5 hp)	$/kWh	$0.007
207	Fans - Motor practices-1 (1-5 HP)	$/kWh	$0.002
208	Fans - Replace 6-100 HP motor	$/kWh	$0.003
209	Fans - ASD (6-100 hp)	$/kWh	$0.000
210	Fans - Motor practices-1 (6-100 HP)	$/kWh	$0.000
211	Fans - Replace 100+ HP motor	$/kWh	$0.001
212	Fans - ASD (100+ hp)	$/kWh	$0.001
213	Fans - Motor practices-1 (100+ HP)	$/kWh	$0.000
214	Optimize drying process	$/kWh	$0.005
215	Power recovery	$/kWh	$0.000
216	Refinery Controls	$/kWh	$0.000
217	Energy Star Transformers	$/kWh	$0.006
300	Base Pumps	$/kWh	$0.000
301	Pumps - O&M	$/kWh	$0.000
302	Pumps - Controls	$/kWh	$0.002
303	Pumps - System Optimization	$/kWh	$0.006
304	Pumps - Sizing	$/kWh	$0.002
305	Pumps - Replace 1-5 HP motor	$/kWh	$0.005
306	Pumps - ASD (1-5 hp)	$/kWh	$0.007
307	Pumps - Motor practices-1 (1-5 HP)	$/kWh	$0.002
308	Pumps - Replace 6-100 HP motor	$/kWh	$0.003
309	Pumps - ASD (6-100 hp)	$/kWh	$0.000
310	Pumps - Motor practices-1 (6-100 HP)	$/kWh	$0.000
311	Pumps - Replace 100+ HP motor	$/kWh	$0.001
312	Pumps - ASD (100+ hp)	$/kWh	$0.001
313	Pumps - Motor practices-1 (100+ HP)	$/kWh	$0.000
314	Power recovery	$/kWh	$0.000

Reference: KEMA, Inc. California Industrial Existing Construction Energy Efficiency Potential Study, Lawrence Berkeley Nation Laboratory (LBNL) and Quantum Consulting, Pacific Gas and Electric Company, San Francisco, California, Volume 2 of 2 – Appendices, May 2006 [27]

B.1 MEASURE COSTS (Cont.)

Measure	Measure Description	Cost unit	Unit Labor cost (O&M cost)
315	Refinery Controls	$/kWh	$0.000
316	Energy Star Transformers	$/kWh	$0.006
400	Base Drives	$/kWh	$0.000
401	Bakery - Process (Mixing) - O&M	$/kWh	$0.000
402	O&M/drives spinning machines	$/kWh	$0.003
403	Air conveying systems	$/kWh	$0.003
404	Replace V-Belts	$/kWh	$0.001
405	Drives - EE motor	$/kWh	$0.001
406	Gap Forming paper machine	$/kWh	$0.001
407	High Consistency forming	$/kWh	$0.001
408	Optimization control PM	$/kWh	$0.001
409	Efficient practices printing press	$/kWh	$0.001
410	Efficient Printing press (fewer cylinders)	$/kWh	$0.005
411	Light cylinders	$/kWh	$0.006
412	Efficient drives	$/kWh	$0.001
413	Clean Room - Controls	$/kWh	$0.002
414	Clean Room - New Designs	$/kWh	$0.012
415	Drives - Process Controls (batch + site)	$/kWh	$0.002
416	Process Drives - ASD	$/kWh	$0.000
417	O&M - Extruders/Injection Moulding	$/kWh	$0.000
418	Extruders/injection Moulding-multipump	$/kWh	$0.009
419	Direct drive Extruders	$/kWh	$0.028
420	Injection Moulding - Impulse Cooling	$/kWh	$0.006
421	Injection Moulding - Direct drive	$/kWh	$0.009
422	Efficient grinding	$/kWh	$0.021
423	Process control	$/kWh	$0.000
424	Process optimization	$/kWh	$0.003
425	Drives - Process Control	$/kWh	$0.001

Reference: KEMA, Inc. California Industrial Existing Construction Energy Efficiency Potential Study, Lawrence Berkeley Nation Laboratory (LBNL) and Quantum Consulting, Pacific Gas and Electric Company, San Francisco, California, Volume 2 of 2 – Appendices, May 2006 [27]

B.1 MEASURE COSTS (Cont.)

Measure	Measure Description	Cost unit	Unit Labor cost (O&M cost)
426	Efficient drives - rolling	$/kWh	$0.001
427	Drives - Optimization process (M&T)	$/kWh	$0.001
428	Drives - Scheduling	$/kWh	$0.001
429	Machinery	$/kWh	$0.001
430	Efficient Machinery	$/kWh	$0.001
431	Energy Star Transformers	$/kWh	$0.006
500	Base Heating	$/kWh	$0.000
501	Bakery - Process	$/kWh	$0.005
502	Drying (UV/IR	$/kWh	$0.007
503	Heat Pumps - Drying	$/kWh	$0.016
504	Top-heating (glass)	$/kWh	$0.000
505	Efficient electric melting	$/kWh	$0.003
506	Intelligent extruder (DOE)	$/kWh	$0.001
507	Near Net Shape Casting	$/kWh	$0.001
508	Heating - Process Control	$/kWh	$0.001
509	Efficient Curing ovens	$/kWh	$0.007
510	Heating - Optimization process (M&T)	$/kWh	$0.001
511	Heating - Scheduling	$/kWh	$0.001
512	Energy Star Transformers	$/kWh	$0.006
550	Base Refrigeration	$/kWh	$0.000
551	Efficient Refrigeration - Operations	$/kWh	$0.001
552	Optimization Refrigeration	$/kWh	$0.010
553	Energy Star Transformers	$/kWh	$0.006
600	Base Other Process	$/kWh	$0.000
601	Other Process Controls (batch + site)	$/kWh	$0.002
602	Efficient desalter	$/kWh	$0.004
603	New transformers welding	$/kWh	$0.005
604	Efficient processes (welding, etc.)	$/kWh	$0.005

Reference: KEMA, Inc. California Industrial Existing Construction Energy Efficiency Potential Study, Lawrence Berkeley Nation Laboratory (LBNL) and Quantum Consulting, Pacific Gas and Electric Company, San Francisco, California, Volume 2 of 2 – Appendices, May 2006 [27]

B.1 MEASURE COSTS (Cont.)

Measure	Measure Description	Cost unit	Unit Labor cost (O&M cost)
605	Process control	$/kWh	$0.001
606	Power recovery	$/kWh	$0.000
607	Refinery Controls	$/kWh	$0.000
608	Energy Star Transformers	$/kWh	$0.006
700	Base Centrifugal Chiller	$/ton	$0.000
701	Centrifugal Chiller	$/ton	$0.000
702	Window Film - Chiller	$/sf-window	$0.000
703	EMS - Chiller	$/ton	$0.000
704	Cool Roof - Chiller	$/sf-roof	$0.000
705	Chiller Tune Up/Diagnostics	$/ton	$0.000
706	Cooling Circ. Pumps - VSD	$/ton	$0.000
707	Energy Star Transformers	$/kWh	$0.000
710	Base DX Packaged System, EER=10.3, 10	$/ton	$0.000
711	DX Tune Up/ Advanced Diagnostics	$/ton	$0.000
712	DX Packaged System, EER=10.9, 10	$/ton	$0.000
713	Window Film - DX	$/sf-window	$0.000
714	Evaporative Pre-Cooler	$/ton	$160.000
715	Prog. Thermostat - DX	$/ton	$15.000
716	Cool Roof - DX	$/sf-roof	$0.000
717	Energy Star Transformers	$/kWh	$0.000
800	Base Lighting	fixture	$0.000
801	RET 2L4' Premium T8, 1EB	fixture	$9.400
802	CFL Hardwired, Modular 36W	fixture	$15.450
803	Metal Halide, 50W	fixture	$55.450
804	Occupancy Sensor, 4L4' Fluorescent	fixture	$1.575
805	Energy Star Transformers	$/kWh	$0.000
900	Base Other	$/kWh	$0.000
901	Replace V-belts	$/kWh	$0.000

Reference: KEMA, Inc. California Industrial Existing Construction Energy Efficiency Potential Study, Lawrence Berkeley Nation Laboratory (LBNL) and Quantum Consulting, Pacific Gas and Electric Company, San Francisco, California, Volume 2 of 2 – Appendices, May 2006 [27]

B.1 MEASURE COSTS (Cont.)

Measure	Measure Description	Cost unit	Unit Labor cost (O&M cost)
902	Membranes for wastewater	$/kWh	$0.003
903	Energy Star Transformers	$/kWh	$0.006

Reference: KEMA, Inc. California Industrial Existing Construction Energy Efficiency Potential Study, Lawrence Berkeley Nation Laboratory (LBNL) and Quantum Consulting, Pacific Gas and Electric Company, San Francisco, California, Volume 2 of 2 – Appendices, May 2006 [27]

B.2 MEASURE SAVING

Measure	Measure Description	SIC 30
100	Base Compressed	0%
101	Compressed Air-O&M	17%
102	Compressed Air - Controls	12%
103	Compressed Air - System Optimization	20%
104	Compressed Air- Sizing	9%
105	Comp Air - Replace 1-5 HP motor	6%
106	Comp Air - ASD (1-5 hp)	6%
107	Comp Air - Motor practices-1 (1-5 HP)	5%
108	Comp Air - Replace 6-100 HP motor	4%
109	Comp Air - ASD (6-100 hp)	6%
110	Comp Air - Motor practices-1 (6-100 HP)	2%
111	Comp Air - Replace 100+ HP motor	3%
112	Comp Air - ASD (100+ hp)	6%
113	Comp Air - Motor practices-1 (100+ HP)	2%
114	Power recovery	0%
115	Refinery Controls	0%
116	Energy Star Transformers	20%
200	Base Fans	0%
201	Fans - O&M	2%
202	Fans - Controls	30%
203	Fans - System Optimization	21%
204	Fans- Improve components	5%
205	Fans - Replace 1-5 HP motor	6%
206	Fans - ASD (1-5 hp)	6%
207	Fans - Motor practices-1 (1-5 HP)	5%
208	Fans - Replace 6-100 HP motor	4%
209	Fans - ASD (6-100 hp)	6%

Reference: KEMA, Inc. California Industrial Existing Construction Energy Efficiency Potential Study, Lawrence Berkeley Nation Laboratory (LBNL) and Quantum Consulting, Pacific Gas and Electric Company, San Francisco, California, Volume 2 of 2 – Appendices, May 2006

B.2 MEASURE SAVING (Cont.)

Measure	Measure Description	SIC 30
210	Fans - Motor practices-1 (6-100 HP)	2%
211	Fans - Replace 100+ HP motor	3%
212	Fans - ASD (100+ hp)	6%
213	Fans - Motor practices-1 (100+ HP)	2%
214	Optimize drying process	0%
215	Power recovery	0%
216	Refinery Controls	0%
217	Energy Star Transformers	20%
300	Base Pumps	0%
301	Pumps - O&M	10%
302	Pumps - Controls	30%
303	Pumps - System Optimization	33%
304	Pumps - Sizing	20%
305	Pumps - Replace 1-5 HP motor	6%
306	Pumps - ASD (1-5 hp)	6%
307	Pumps - Motor practices-1 (1-5 HP)	5%
308	Pumps - Replace 6-100 HP motor	4%
309	Pumps - ASD (6-100 hp)	6%
310	Pumps - Motor practices-1 (6-100 HP)	2%
311	Pumps - Replace 100+ HP motor	3%
312	Pumps - ASD (100+ hp)	6%
313	Pumps - Motor practices-1 (100+ HP)	2%
314	Power recovery	0%
315	Refinery Controls	0%
316	Energy Star Transformers	20%
400	Base Drives	0%
401	Bakery - Process (Mixing) - O&M	0%
402	O&M/drives spinning machines	0%
403	Air conveying systems	0%

Reference: KEMA, Inc. California Industrial Existing Construction Energy Efficiency Potential Study, Lawrence Berkeley Nation Laboratory (LBNL) and Quantum Consulting, Pacific Gas and Electric Company, San Francisco, California, Volume 2 of 2 – Appendices, May 2006 [27]

B.2 MEASURE SAVING (Cont.)

Measure	Measure Description	SIC 30
404	Replace V-Belts	0%
405	Drives - EE motor	0%
406	Gap Forming paper machine	0%
407	High Consistency forming	0%
408	Optimization control PM	0%
409	Efficient practices printing press	0%
410	Efficient Printing press (fewer cylinders)	0%
411	Light cylinders	0%
412	Efficient drives	0%
413	Clean Room - Controls	0%
414	Clean Room - New Designs	0%
415	Drives - Process Controls (batch + site)	0%
416	Process Drives - ASD	0%
417	O&M - Extruders/Injection Moulding	10%
418	Extruders/injection Moulding-multipump	30%
419	Direct drive Extruders	50%
420	Injection Moulding - Impulse Cooling	21%
421	Injection Moulding - Direct drive	20%
422	Efficient grinding	0%
423	Process control	0%
424	Process optimization	0%
425	Drives - Process Control	0%
426	Efficient drives - rolling	0%
427	Drives - Optimization process (M&T)	0%
428	Drives - Scheduling	0%
429	Machinery	0%
430	Efficient Machinery	0%
431	Energy Star Transformers	20%
500	Base Heating	0%

Reference: KEMA, Inc. California Industrial Existing Construction Energy Efficiency Potential Study, Lawrence Berkeley Nation Laboratory (LBNL) and Quantum Consulting, Pacific Gas and Electric Company, San Francisco, California, Volume 2 of 2 – Appendices, May 2006 [27]

B.2 MEASURE SAVING (Cont.)

Measure	Measure Description	SIC 30
501	Bakery - Process	0%
502	Drying (UV/IR	0%
503	Heat Pumps - Drying	0%
504	Top-heating (glass)	0%
505	Efficient electric melting	0%
506	Intelligent extruder (DOE)	0%
507	Near Net Shape Casting	0%
508	Heating - Process Control	0%
509	Efficient Curing ovens	0%
510	Heating - Optimization process (M&T)	0%
511	Heating - Scheduling	0%
512	Energy Star Transformers	20%
550	Base Refrigeration	0%
551	Efficient Refrigeration - Operations	0%
552	Optimization Refrigeration	0%
553	Energy Star Transformers	20%
600	Base Other Process	0%
601	Other Process Controls (batch + site)	0%
602	Efficient desalter	0%
603	New transformers welding	0%
604	Efficient processes (welding, etc.)	0%
605	Process control	0%
606	Power recovery	0%
607	Refinery Controls	0%
608	Energy Star Transformers	20%
700	Base Centrifugal Chiller	0%
701	Centrifugal Chiller	12%
702	Window Film - Chiller	10%
703	EMS - Chiller	10%

Reference: KEMA, Inc. California Industrial Existing Construction Energy Efficiency Potential Study, Lawrence Berkeley Nation Laboratory (LBNL) and Quantum Consulting, Pacific Gas and Electric Company, San Francisco, California, Volume 2 of 2 – Appendices, May 2006 [27]

B.2 MEASURE SAVING (Cont.)

Measure	Measure Description	SIC 30
704	Cool Roof - Chiller	10%
705	Chiller Tune Up/Diagnostics	8%
706	Cooling Circ. Pumps - VSD	6%
707	Energy Star Transformers	20%
710	Base DX Packaged System, EER=10.3, 10	0%
711	DX Tune Up/ Advanced Diagnostics	10%
712	DX Packaged System, EER=10.9, 10	6%
713	Window Film - DX	10%
714	Evaporative Pre-Cooler	10%
715	Prog. Thermostat - DX	10%
716	Cool Roof - DX	10%
717	Energy Star Transformers	20%
800	Base Lighting	0%
801	RET 2L4' Premium T8, 1EB	31%
802	CFL Hardwired, Modular 36W	72%
803	Metal Halide, 50W	58%
804	Occupancy Sensor, 4L4' Fluorescent	20%
805	Energy Star Transformers	20%
900	Base Other	0%
901	Replace V-belts	0%
902	Membranes for wastewater	0%
903	Energy Star Transformers	20%

Reference: KEMA, Inc. California Industrial Existing Construction Energy Efficiency Potential Study, Lawrence Berkeley Nation Laboratory (LBNL) and Quantum Consulting, Pacific Gas and Electric Company, San Francisco, California, Volume 2 of 2 – Appendices, May 2006 [27]

APPENDIX C
NATURAL GAS MEASURE INPUT DATA

C.1 MEASURE COSTS

Measure	Measure Description	Cost unit	Unit Labor cost (O&M cost)
100	Base Boiler	$/Therm	$0.000
101	Improved process control	$/Therm	$0.013
102	Maintain boilers	$/Therm	$0.001
103	Flue gas heat recovery/economizer	$/Therm	$0.029
104	Blowdown steam heat recovery	$/Therm	$0.026
105	Upgrade burner efficiency	$/Therm	$0.017
106	Water treatment	$/Therm	$0.007
107	Load control	$/Therm	$0.015
108	Improved insulation	$/Therm	$0.064
109	Steam trap maintenance	$/Therm	$0.046
110	Automatic steam trap monitoring	$/Therm	$0.037
111	Leak repair	$/Therm	$0.012
112	Condensate return	$/Therm	$0.080
200	Base HVAC	$/Therm	$0.000
201	Improve ceiling insulation	$/Therm	$0.055
202	Install HE(95%) cond furnace/boiler	$/Therm	$0.711
203	Stack heat exchanger	$/Therm	$0.263
204	Duct insulation	$/Therm	$0.128
205	EMS install	$/Therm	$0.292
206	EMS optimization	$/Therm	$0.007
300	Base Process Heat	$/Therm	$0.000
301	Process Controls&Management	$/Therm	$0.055
302	Heat Recovery	$/Therm	$0.639

*Therm = 100,000 BTU

Reference: KEMA, Inc. California Industrial Existing Construction Energy Efficiency Potential Study, Lawrence Berkeley Nation Laboratory (LBNL) and Quantum Consulting, Pacific Gas and Electric Company, San Francisco, California, Volume 2 of 2 – Appendices, May 2006

C.1 MEASURE COSTS

Measure	Measure Description	Cost unit	Unit Labor cost (O&M cost)
303	Efficient burners	$/Therm	$0.164
304	Process integration	$/Therm	$0.730
305	Efficient drying	$/Therm	$0.427
306	Closed hood	$/Therm	$0.292
307	Extended nip press	$/Therm	$0.642
308	Improved separation processes	$/Therm	$0.183
309	Thermal oxidizers	$/Therm	$1.752
310	Flare gas controls and recovery	$/Therm	$0.730
311	Fouling control	$/Therm	$0.041
312	Efficient furnaces	$/Therm	$0.096
313	Oxyfuel	$/Therm	$0.438
314	Batch cullet preheating	$/Therm	$0.234
315	Preventative maintenance	$/Therm	$0.007
316	Combustion controls	$/Therm	$0.088
317	Optimize furnace operations	$/Therm	$0.110
318	Insulation/reduce heat losses	$/Therm	$0.292

*Therm = 100,000 BTU

Reference: KEMA, Inc. California Industrial Existing Construction Energy Efficiency Potential Study, Lawrence Berkeley Nation Laboratory (LBNL) and Quantum Consulting, Pacific Gas and Electric Company, San Francisco, California, Volume 2 of 2 – Appendices, May 2006

C.2 MEASURE SAVING

Measure	Measure Description	SIC 30
100	Base Boiler	0%
101	Improved process control	3%
102	Maintain boilers	10%
103	Flue gas heat recovery/economizer	2%
104	Blowdown steam heat recovery	1%
105	Upgrade burner efficiency	1%
106	Water treatment	1%
107	Load control	4%
108	Improved insulation	8%
109	Steam trap maintenance	13%
110	Automatic steam trap monitoring	5%
111	Leak repair	4%
112	Condensate return	10%
200	Base HVAC	0%
201	Improve ceiling insulation	24%
202	Install HE(95%) cond furnace/boiler	18%
203	Stack heat exchanger	5%
204	Duct insulation	2%
205	EMS install	10%
206	EMS optimization	1%
300	Base Process Heat	0%
301	Process Controls&Management	5%
302	Heat Recovery	25%
303	Efficient burners	0%
304	Process integration	0%
305	Efficient drying	0%
306	Closed hood	0%

*Therm = 100,000 BTU

Reference: KEMA, Inc. California Industrial Existing Construction Energy Efficiency Potential Study, Lawrence Berkeley Nation Laboratory (LBNL) and Quantum Consulting, Pacific Gas and Electric Company, San Francisco, California, Volume 2 of 2 – Appendices, May 2006

C.1 MEASURE COSTS

Measure	Measure Description	SIC 30
307	Extended nip press	0%
308	Improved separation processes	0%
309	Thermal oxidizers	0%
310	Flare gas controls and recovery	0%
311	Fouling control	0%
312	Efficient furnaces	0%
313	Oxyfuel	0%
314	Batch cullet preheating	0%
315	Preventative maintenance	0%
316	Combustion controls	0%
317	Optimize furnace operations	0%
318	Insulation/reduce heat losses	0%

*Therm = 100,000 BTU

Reference: KEMA, Inc. California Industrial Existing Construction Energy Efficiency Potential Study, Lawrence Berkeley Nation Laboratory (LBNL) and Quantum Consulting, Pacific Gas and Electric Company, San Francisco, California, Volume 2 of 2 – Appendices, May 2006