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Development of Environmental and Emission Standards of Volatile Organic Compounds (VOCs) in Thailand

กรมควบคุมมลพิษ
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JICA

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The Development of Environmental and Emission Standards of Volatile Organic Compounds (VOCs) in Thailand is an important technical cooperation scheme that can help all levels of government, environmental groups, business, and others to develop concrete plans which address threats that the VOCs pose to the health and environment of Thailand.

Pollution Control Department (PCD) would like to thank the Japan International Cooperation Agency (JICA) for their kind support contributed to the technical cooperation scheme in which Japan International Cooperation Agency experts have been dispatched to work with PCD during March 2006-March 2008. JICA experts, especially Mr. Masato Ohno and Mr. Munehiro Fukuda are highly appreciated for their kind cooperation and hard work toward the success of the project.

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ABSTRACT

Development of environmental and emission standard of Volatile Organic Compounds (VOCs) in Thailand was started in March 2006. The ambient VOCs monitoring has been conducted by Pollution Control Department and Environmental Research and Training Center as part of their technical cooperation with Japan International Cooperation Agency (JICA). Sampling and analysis of VOCs were developed coupled with data quality control procedures in order to establish reliable VOCs database in the country. Measurement program has been set up with an objective to reveal the status of VOCs pollution in Thailand. These data was expected to be used as supporting data to establish the appropriate VOCs management policy including standards and mitigation measures of VOCs in Thailand.

Some VOCs that are identified as toxic air pollutants may have caused long-term health impacts on the population living in contaminated areas. Measurements of VOCs are thus necessary for future control efforts to improve the quality of life of people living in polluted areas. Measurement data is one of the most crucial tools to evaluate the air pollution problem from VOCs. Therefore, monitoring program need to be continued and expanded to other areas. Development of monitoring techniques as well as capacity building of personnel involved in the process is crucial for enhancing VOCs monitoring network. Reliability and comparability of data are also needed to be considered in measurement of VOCs and analysis of data. Monitoring sites were classified to residential, industrial, and roadside areas. Measurement data are also analyzed for their spatial distribution in order to elucidate the prevailing VOCs compounds in each area. Data indicated that most VOCs were site-specified pollutants in which their concentrations were greatly affected by local emission sources.

The detailed emission inventory studies were completed in 2008. The purposes of the studies were to identify the emission sources and estimate the amount of emissions in the specific area where selected VOCs industries located. Then, the result of detailed emission inventory studies, the meteorological data and VOCs ambient monitoring data were undergone to the diffusion model to establish the emission standards.

In 2007, Thailand's National Ambient Air Quality Standards for VOCs have been promulgated and consisted of 9 VOCs namely benzene, 1,3-butadiene, chloroform, dichloromethane, 1,2-dichloroethane, 1,2-dichloropropane, tetrachloroethylene, trichloroethylene, and vinyl chloride.

ABBREVIATIONS AND ACRONYMS

ACGIH	The American Conference of Governmental Industrial Hygienist
BAT	Best Available Technology
CO	Carbon monoxide
CSR	Corporate Social Responsibility
DCM	Dichloromethane
DEQP	Department of Environmental Quality Promotion
DIW	Department of Industrial Works
ECNEQ	Enhancement and Conservation of National Environmental Quality Act
EDC	1,2-Dichloroethane
ERTC	Environmental Research and Training Center
FIRE	Factor Information REtrieval Database System
GC	Gas Chromatography
GC/MS	Gas Chromatograph Mass Spectrophotometer
HAPs	Hazardous Air Pollutants
IARC	The International Agency for Research on Cancer
IEAT	Industrial Estate Authority of Thailand
IRIS	Integrated Risk Information System:US.EPA
JICA	Japan International Cooperation Agency
JSOH	Japan Society of Occupational Health
mg/m^3	Milligram per cubic meter
MONRE	Ministry of Natural Resources and Environment
MQL	Method Quantitation Limit
NAAQS	National Ambient Air Quality Standards
NEB	National Environment Board
NEQA	The Enhance and Conservation of National Environmental Quality Act, B.E. 2535
NOx	Nitrogen Oxides
ONEP	Office of the Natural Resources and Environmental Policy and Planning
PCD	Pollution Control Department
PCE	Tetrachloroethylene
PM	Particulate Matter
ppm	Part Per Million
PRTR	Pollutant Release and Transfer Registration
PVC	Polyvinyl Chloride
QA/QC	Quality assurance and quality control
SOP	Standard Operating Procedures
SOx	Sulfur oxides
SPM	Suspended Particulate Matter
TCE	Trichloroethylene
THC	Total Hydrocarbon
US EPA	United States Environmental Protection Agency
VCM	Vinyl Chloride Monomer
VOCs	Volatile Organic Compounds
VRU	Vapor Recovery Unit
WHO	World Health Organization
$\mu g/m^3$	Microgram per cubic meter

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1 Introduction

1.1 Background

Volatile Organic Compounds (VOCs) are generally referred to substances contain carbon and hydrogen having minimum vapor pressure 0.13 kPa at standard condition of 1 atm and 20 degree centigrade; under this definition, numerous organic compounds fall into this category. VOCs are released easily from a source to the ambient air and cause air pollution. In recent years, Thailand has faced environmental problems suspected to be caused by VOCs. Hence, understanding the current situation and taking appropriate measures are crucial. Two distinctive characteristics of VOCs should be noted; one being the harmful nature of inhaling the substances (called HAPs: Hazardous Air Pollutants) and another being contribute to stratospheric ozone distribution, tropospheric photochemical ozone formation. A comprehensive and multiple views supported by scientific data together with monitoring data are necessary to establish environmental and emission standards and to develop measures to mitigate air pollution caused by VOCs.

Under these circumstances, Pollution Control Department (PCD) requested Japan technical cooperation to develop environmental and emission standards for VOCs. In response, Japan International Cooperation Agency (JICA) agrees to dispatch an experts' team to implement the project named "The Project for Development of Environmental and Emission Standards of VOCs in the Kingdom of Thailand" from March 2006 to February 2008.

The policy makers have an important role in rendering their leadership support for establishment of appropriate measures for controlling, monitoring air pollution problem. The project output supports policy formulation requirement, not only to focus on policy instruments themselves, but to identify technical capacities needed in the related field and develop them to make policy instrument workable, in this case i.e. monitoring, modeling, risk assessment, emission countermeasures, inventory study, and enhance such capacities. Recognizing the necessity of VOCs control, policy makers are encouraged to play an important role in supporting measures against air pollution caused by VOCs.

1.2 Objectives

This report has been prepared in partial fulfillment of the output for the Technical Cooperation Project between the JICA and PCD entitled "Development of Environmental and Emission Standards of VOCs in the Kingdom of Thailand". The Project, which aims to enhance the capacity of PCD staff to take countermeasures against VOCs air pollution, has been carried out since March 2006 for the period of two years. The overall goal and project purpose are 1) development of concrete measures for VOCs air pollution and 2) strengthening capacity of PCD staff for taking measures against VOCs. The Project has been carried out with counterparts from Environmental Laboratory in the Environmental Quality and Laboratory Division; Ambient Air Quality Division, Automotive Air Pollution Division and Industrial Air Pollution Division in Air Quality and Noise Management Bureau of PCD. The contents of the report present the current situation and necessity of measures for VOCs pollution as well as the approach of establishing environmental and emission standards of VOCs in Thailand.

1.3 Air Toxic Pollution in Thailand

Thailand is facing serious air pollution problems, especially in urban areas, due to rapid industrialization, urbanization and motorization. The government has set the National Ambient Air Quality Standards (NAAQS) and implemented countermeasures for criteria air pollutants such as dust, suspended particulate matters (PM_{10} and $PM_{2.5}$), sulfur dioxide (SO_2), carbon monoxide (CO), nitrogen dioxide (NO_2) and ground-level ozone (O_3). Recently, the situation of air quality has gradually improved to a certain level for these substances. However, ozone and particulate matter are occasionally reported exceeding the NAAQS at many of the monitoring locations.

An emerging air pollution issue in Thailand is air toxic problem resulting from transportation and industrial activities. The average levels of selected VOCs (benzene range from 3.4-35 $\mu g/m^3$, toluene range from 28.9-559 $\mu g/m^3$) measured at outdoor sites in Bangkok were found to vary greatly, even over the relatively short period monitored (Gee, 1998). The transport and industrial sectors are major emission sources of air toxic pollution of the country. Emission sources of air toxic pollutants are mostly from automobiles, gas stations, storage tanks, petrochemical industries, oil refineries, chemical based factories, construction sites, forest fires, and open burning of solid wastes. In transport sector, two-stroke motorcycles, diesel trucks, and ageing buses contribute significantly to air toxic pollution in urban areas. In industrial sector, different scale enterprises and industrial complex contribute air toxic to atmosphere at different levels. In response to the air toxic pollution problems, Thai government has addressed the problem to some extent in the form of voluntary effort, law, regulation and enforcement on the location and operation of factories. Periodical monitoring of four selected compounds; benzene, toluene, ethylbenzene and xylenes; at five stations in Bangkok and Vicinity with special attention on mobile sources was started in 2004.

VOCs emitted from industries and vehicles are considered as the significant sources of photochemical reaction that result in tropospheric ozone formation. Furthermore some VOCs are hazardous air pollutants, which cause various acute health problem as well as carcinogenic risk. It also contributes to secondary formation of suspended particulate matters. Under these circumstances, the Thai government considered to control VOCs by setting environmental and emission standards as an important initially environmental control policy means. Based on the awareness that adequate pollution control measures could not be implemented by regulations alone, the government incorporated pollution control elements into its industrial and transportation policy.

Studies related to VOCs pollution have been conducted in Thailand. In 1998, research cooperation on investigation of VOCs was jointly conducted by the Industrial Estate Authority of Thailand, New Energy and Industrial Technology Development Organization of Japan, and Japan Environmental Management Association for Industry. The project aimed to transfer the technology on environmental monitoring, source study, impact assessment and source countermeasure at the model industrial estate to improve planning and countermeasure on air pollution by SOx, NOx and VOCs from industrial emission.

The Environmental Research and Training Center (ERTC) has conducted a research on the development of adequate air monitoring technology for VOCs since 2005. The outcome of this study is expected to set up the standard operating procedures of VOCs air monitoring (sampling & analysis) as well as to enhance research capacity on health risk analysis and produce reliable dataset of VOCs pollution in Thailand.

A study on changes in specifications for gasoline and diesel fuels in Thailand, conducted by the National Energy Policy Office in 2002 reported that changing of fuel property should result to decreasing in the potency-weighted exposure to toxic air pollutants due to significant reductions in particulate matters and benzene from diesel-fueled vehicles are expected.

According to the Ministry of Natural Resources and Environment, 40% of environmental complains nationwide are on odor and smell, and most of them are considered to be related to VOCs. Map Ta Phut incident in 1997 was a well known environmental problem related to VOCs. In this incident, some school children nearby the Map Ta Phut industrial estate were hospitalized due to serious air pollution. Source of the pollution was considered as VOCs. The school was then closed and moved to another location. There are various reports and claims regarding occurrence of fruit like smell (most likely aromatic VOCs) around the estate.

Under this situation, the Thai government considers VOCs as an important environmental issue. National Environment Board has instructed PCD to implement countermeasure for VOCs. As there was no environmental standard set for ambient VOCs, a systematic monitoring of VOCs in ambient had not been implemented, however, concentrations of certain VOCs were estimated to be at levels in which health risk cannot be ignored. Although VOCs have been a topic of scientific investigation for years, only few monitoring data was systematically quality assurances. It is important for the government to confirm the necessity of the countermeasures for solving air toxic pollution problem caused by VOCs.

1.4 Benefit of VOCs Emission Control

Various chemical compounds have been applied as raw materials in various industrial process, and composition of fuel. Most of organic chemicals are volatile into the air from both natural and man-made sources. VOCs can be classified according to its impact whether is considered as hazardous air pollutant or as precursor of a photochemical oxidant or as offensive odor substance. VOCs as hazardous air pollutant and VOCs as offending agent of offensive odor bring direct impact to a human health while VOCs as precursors of a photochemical oxidant bring indirect impact into a human health and has detrimental effect on the environment.

1.4.1 Health Benefit

The health effects of exposure to VOCs can vary greatly according to the toxicity and exposure of the compounds, which range from being highly toxic to having no known health effects. The health effects of VOCs depend on nature of the compound, the level of exposure, human health condition, and length of exposure.

Example of the health risk caused by individual VOCs are follow: benzene is characterized as a genotoxic carcinogen and no safe level of exposure can be recommended; 1,2-dichloroethane is evaluated as a chemical for which there is sufficient evidence of carcinogenicity in experimental animals and adequate evidence in humans; tetrachloroethylene is a possible carcinogenic to human(WHO, 2000). People at the highest risk of long-term exposure to these compounds are industrial workers who have prolonged exposure to the compounds in the workplace; cigarette smokers; and people who have prolonged exposure to emissions from heavy motor vehicle traffic. Level of benzene has been reported during short monitoring investigation in Bangkok, ambient air concentration of benzene was reported ranged from 3.4-35 mg/m^3(Gee, 1998).

Offensive odor substances are normally defined as substances causing unpleasant odors and disrupt the living environment. Although, offensive odor are not always means human health risk. However, both hazardous air pollutant and offending agent of offensive odor may bring both direct and indirect impact to a human health.

A policy on prevention of health impact is given priority. Therefore, hazardous VOCs air pollutants are given the first priority for controlling. As for health impact, there is different damage due to long-term exposure and short-term exposure. In general, long-term exposure to some VOCs can cause damage to the liver, kidneys and central nervous system. Short-term exposure can cause eye and respiratory tract irritation, headaches, dizziness, visual disorders, fatigue, loss of coordination, allergic skin reactions, nausea, and memory impairment. As for the carcinogenic risk, long-term exposure all through a life is the most crucial issue. Carcinogenicity and chronic effect of substances are considered in setting up the standard and regulation of individual species within this study.

Considering the direct and indirect health effects of VOCs on human health, the effective emission source control will benefit to public health. The available and appropriate control technology is also one of the criteria for setting up of a policy regulation.

1.4.2 Economic Benefit

Emission of gas or vapors from pressurized equipment due to leaks and various other unintended or irregular releases of gases, mostly from industrial activities is economic cost of lost commodities. For example emissions of VOCs such as benzene from oil refineries and chemical plants pose a long term health risk to workers and local communities and can cause a significant problem in term of repair and maintenance cost. To minimize and control leaks at process facilities operators carry out regular leak detection and repair activities. Routine inspections of process equipment with gas detectors can be used to identify leaks and estimate the leak rate in order to decide on appropriate corrective action. Proper routine maintenance of equipment reduces the likelihood of leaks then reducing lost of materials. As a result, VOCs emission control so called fugitive emission is one of the economic benefits especially, for emission of gas or vapors due to leaks and irregular releases of gases.

1.4.3 Environmental Benefit

A photochemical oxidant brings influence to the human body such as stimulation of eyes or a pain of a throat and death of a plant. Ozone is recognized as the most particular constituent of photochemical oxidant. It is identified that concentration level of ozone in ambient air is highly correlate with quantity of VOCs released into air in the daylight on a clear day. VOCs are identified not only as a precursor of a photochemical oxidant but also as a precursor of particulate matter.

As mentioned, particulate matter and ozone levels are a cause for concern and similar increasing trends have been observed in Bangkok's adjoining provinces and throughout other urban areas in Thailand. Therefore, successful controlling of VOCs would benefit to the environment in term of reducing the secondary pollutant formation.

2 Source Emission Inventory

The study consists of 3 phases. The emission inventory of 44 VOCs , listed in US.EPA method TO-14 together with 3 additional compounds namely formaldehyde, acetaldehyde and ethylene oxide are prepared using top down inventory approach for the 1st phase study. Twenty VOCs are prioritized and selected for the 2nd phase study. Selection criteria of target VOCs are set up based on toxicity of individual VOCs as defined by several international agencies and organization such as IARC (International Agency for Research on Cancer), IRIS (Integrated Risk Information System; US.EPA), ACGIH (The American Conference of Governmental Industrial Hygienist), and JSOH (Japan Society of Occupational Health). Target VOCs are also prioritized according to possibility of exposure taking into consideration the fact that a compound may also pose threat to the human health and/or surrounding environment if it is released to the environment in large quantity or present in high concentration in the environment even if it has low toxicity. Evaluation of exposure is performed using amount of consumption. These data will assist in elucidating spatial distribution and degree of the problem which might be potentially occurred from each VOCs. Data, collected in this phase are industry and source specific information taking into consideration potential emission sources and activities of each compounds as listed in the Factor Information Retrieval Data System (FIRE) of US.EPA which includes information about industries and emitting processes, the chemical emitted, and the emission factors themselves. Collected data are calculated with emission factor to evaluate emission amount of each VOCs. Results are categorized by types of emission source and industry to elucidate contribution of each emission sources. The 3rd phase of VOCs Emission Inventory Study is conducted for in-depth investigated in specific emission sources of 4 VOCs, which are benzene, trichloroethylene, dichloromethane and tetrachloroethylene. Meanwhile, the special study of vinyl chloride and 1,2-dichloroethane is also carried out. The result of the study is integrated for an evaluation for VOCs emission standard.

2.1 First stage emission inventory study

In the 1st phase study (Thailand Environmental Institute, 2006), emission inventory of 44 VOCs, listed in US.EPA method TO14 together with 3 additional compounds namely formaldehyde, acetaldehyde and ethylene oxide are prepared using top down inventory approach. The macro level analysis provides the overall picture of VOCs utilization in the country that can illustrate significance of each selected VOCs in supply chains of the country. General framework of demand-supply analysis is based on the macro data of VOCs production, import and export in order to identify consumption of VOCs in the country. Data on energy consumption such as types and quantity of fuel are also collected in the study. VOCs supply sources can be identified as imported and domestic supplies. On the other hand, the demands for chemicals comprise two major activities, consumption and export. The analytical basis is based on the following calculation.

Supply = Demand
Production + Import = Consumption + Export
Domestic Consumption = Production + Import – Export

The macro data on demand-supply analysis of each VOCs from 2001-2005 is as indicated in Table 1. There are insufficient data for some VOCs due to limitation in data availability. Since some chemicals share similar harmonized code, thus, import-export data of individual compound cannot be distinguished. As for dichloromethane and tetrachloroethylene, there has limited import-export data and production data available. However, there are 34 VOCs in which sufficient data are collected. Generally, these VOCs are major chemicals with significant demand for several applications. Thus, their supply sources from either import or domestic production are usually recorded, systematically.

Table 1 Macro data on demand-supply analysis of VOCs from 2001-2005

NO.	Target VOCs	CAS No.	H-S code	2005				2004				2003				2002				2001			
				export	import	production	consumption	export	import	production	consumption	export	import	production	consumption	export	import	production	consumption	export	import	production	consumption
				(Tonnes)	(Tonnes)	(Tonnes)	(Tonnes)	(Tonnes)	(Tonnes)	(Tonnes)	(Tonnes)	(Tonnes)	(Tonnes)	(Tonnes)	(Tonnes)	(Tonnes)	(Tonnes)	(Tonnes)	(Tonnes)	(Tonnes)	(Tonnes)	(Tonnes)	(Tonnes)
1	Vinyl chloride	75-01-4	2903210002	5,678	98,626	697,000	789,948	7,505	136,235	630,000	758,730	-	96,074	604,000	700,074	-	94,747	567,000	661,747	2,676	108,961	n.a.	n.a.
2	Vinylidene Chloride(Dichloroethylene)	75-35-4	3904500009	-	58	-	58	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	Freon 113 (Trichlorotrifluoroethane)	76-13-1	2903430000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	Chloroform	67-66-3	2903130002	24	142	n.a.	n.a.	18	115	50	147	16	123	n.a.	n.a.	8	167	n.a.	n.a.	23	229	n.a.	n.a.
5	1,2-Dichloroethane	107-06-2	2903150004	-	336,126	-	336,126	-	223,300	-	223,300	1	247,100	-	247,099	-	221,930	-	221,930	-	216,216	-	216,216
6	Benzene	71-43-2	2902200006	398,019	3,150	742,000	347,131	331,688	12,212	706,000	386,524	218,549	2	580,000	361,453	214,499	14,558	502,000	302,059	190,187	2,139		
7	Toluene	108-88-3	2902300008	32,896	27,407	179,000	173,511	77,794	40,091	217,000	179,297	216,449	79	339,000	122,630	178,357	207	288,000	109,850	137,514	4,016		
8	Methyl Chloroform	71-55-6	2903190001	-	-	-	-	-	-	-	-	-	24	-	24	-	34	-	34	-	-	-	-
9	Freon12 (Dichlorodifluoromethane)	75-71-8	2903420000	18	1,157	-	1,139	1	1,164	-	1,163	9	1,395	-	1,386	57	4,247	-	4,190	-	2,779	-	2,779
10	Carbon Tetrachloride	56-23-5	2903140003	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11	Methly Chloride (Chloromethane)	74-87-3	2903110001	-	-	-	-	-	132	-	132	-	226	-	226	-	232	-	232	3	78	-	75
12	Trichloroethylene	79-01-6	2903220003	35	5,832	-	-	48	7,889	-	-	1	7,471	-	-	7	7,364	-	-	0	6,209	-	-
13	Freon114	76-14-2	2903440000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
14	cis-1,3-Dichloropropene*	10061-01-5	2903290xxx	0	6	n.a.	n.a.	-	123	n.a.	n.a.	1	12	n.a.	n.a.	-	14	n.a.	n.a.	-	3	n.a.	n.a.
15	Methyl Bromide(Bromomethane)	74-83-9	2903300202	-	336	-	336	-	738	-	738	-	608	-	608	-	922	-	922	-	682	-	682
16	Trans-1,3-Dichloropropene*	10061-02-6	2903290xxx	0	6	n.a.	n.a.	-	123	n.a.	n.a.	1	0	n.a.	n.a.	-	14	n.a.	n.a.	-	3	n.a.	n.a.
17	Ethyl Chloride (Chloroethane)	75-00-3	2903110002	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
18	Ethylbenzene	100-41-4	2902600003	-	105	-	105		177	-	177	-	136	-	136	-	124	-	124	-	92	-	92
19	Freon11	75-69-4	2903410000	-	102	-	102	-	218	-	218	1	476	-	475	0	797	-	797	7	1,509	-	1,502
20	o-Xylene	95-47-6	2902410000	37,034	549	71,185	34,700	24,549	884	65,010	41,345	36,309	3	64,967	28,661	14,807	4,037	43,518	32,748	1,960	1,025	32,236	31,301
21	Dichloromethane	75-09-2	2903120001	56	8,332	n.a.	n.a.	23	10,930	n.a.	n.a.	21	9,328	n.a.	n.a.	12	8,791	n.a.	n.a.	15	8,584	n.a.	n.a.
22	m-Xylene	108-38-3	2902420001	-	0	0	0	-	0	0	0	-	0	0	0	-	0	0	0	-	-	-	-
23	1,1-Dichloroethane**	75-34-3	2903190xxx	-	46	n.a.	n.a.	-	-	n.a.	n.a.	-	-	n.a.	n.a.	-	-	n.a.	n.a.	-	-	n.a.	n.a.
24	p-Xylene	106-42-3	2902430002	263,866	154,700	1,132,000	1,022,834	235,648	139,770	1,041,000	945,122	297,080	80,980	1,057,000	840,900	276,769	40,116	906,000	669,347	227,519	70,290		
25	cis-1,2-Dichloroethylene	156-59-2	2903290001	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
26	Styrene	100-42-5	2902500001	21,322	85,840	502,000	566,518	24,547	100,918	467,000	543,371	22,787	88,786	475,000	540,999	19,830	78,566	448,000	506,736	9,693	53,917		
27	1,2-Dichloropropane**	78-87-5	2903190xxx	-	46	n.a.	n.a.	-	-	n.a.	n.a.	-	-	n.a.	n.a.	-	-	n.a.	n.a.	-	-	n.a.	n.a.
28	1,1,2,2-Tetrachloroethane	79-34-5	2903190003	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
29	1,1,2-Trichloroethane	79-00-5	2903190002	0	19	-	19	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
30	1,3,5-Trimethylbenzene***	108-67-8	2902900xxx	7,096	2,167	n.a.	n.a.	114,342	1,892	n.a.	n.a.	70,715	1,594	n.a.	n.a.	25,263	1,244	n.a.	n.a.	7,096	538	n.a.	n.a.
31	1,2-Dibromoethane(1,2-Ethylene dibromide)	106-93-4	2903300303	1	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
32	1,2,4-Trimethylbenzene***	95-63-6	2902900xxx	7,096	2,167	n.a.	n.a.	114,342	1,892	n.a.	n.a.	70,715	1,594	n.a.	n.a.	25,263	1,244	n.a.	n.a.	7,096	538	n.a.	n.a.
33	Tetrachloroethylene	127-18-4	2903230004	2	1,117	n.a.	n.a.	-	1,388	n.a.	n.a.	-	1,069	n.a.	n.a.	-	1,370	n.a.	n.a.	-	1,463	n.a.	n.a.
34	m-Dichlorobenzene	541-73-1	2903610xxx	-	44	n.a.	n.a.	-	66	n.a.	n.a.	-	723	n.a.	n.a.	-	421	n.a.	n.a.	-	224	n.a.	n.a.
35	Monochlorobenzene	108-90-7	2903610101	1	102	-	101	0	80	-	80	1	104	-	103	9	370	-	361	1	361	-	360
36	o-Dichlorobenzene	95-50-1	2903610201	-	0	-	-	0	1	-	1	-	1	-	1	-	1	-	1	-	0	-	-
37	Benzyl Chloride	100-44-7	2903690002	10	324	-	314	-	259	-	259	-	271	-	271	-	280	-	280	-	92	-	92
38	p-Dichlorobenzene	106-46-7	2903610202	0	523	-	523	-	756	-	756	-	530	-	530	-	507	-	507	-	284	-	284
39	Hexachloro-1,3-butadiene	87-68-3	2901290xxx	3,262	3,194	n.a.	n.a.	12	2,001	n.a.	n.a.	0	5,323	n.a.	n.a.	1,461	1,937	n.a.	n.a.	11,413	14,011	n.a.	n.a.
40	1,2,4-Trichlorobenzene	120-82-1	2903690xxx	-	-	n.a.	n.a.	-	-	n.a.	n.a.	-	-	n.a.	n.a.	-	-	n.a.	n.a.	-	618	n.a.	n.a.
41	Acrylonitrile	107-13-1	2926100000	2	124,638	-	124,636	-	111,101	-	111,101	-	97,164	-	97,164	-	93,267	-	93,267	51	92,438	-	92,387
42	1,3 Butadiene	106-99-0	2901240004	26,872	14,708	192,200	180,036	27,892	18,337	188,000	178,445	31,703	11,789	173,400	153,486	33,133	9,899	n.a.	n.a.	29,271	4,858	n.a.	n.a.
43	3-Chloro-1-Propane**	107-05-1	2903190xxx	0	46	n.a.	n.a.	-	-	n.a.	n.a.	-	-	n.a.	n.a.	-	-	n.a.	n.a.	-	-	n.a.	n.a.
44	4-Ethyltoluene***	622-96-8	2902900xxx	7,096	2,167	n.a.	n.a.	114,342	1,892	n.a.	n.a.	70,715	1,594	n.a.	n.a.	25,263	1,244	n.a.	n.a.	7,096	538	n.a.	n.a.
45	Formaldehyde	50-00-0	2912110002	43	38	124	119	39	28	n.a.	n.a.	218	35	n.a.	n.a.	34	33	n.a.	n.a.	178	876	n.a.	n.a.
46	Acetaldehyde	75-07-0	2912120003	0	48	-	48	0	0	-	0	5	0	-	0	-	0	-	0	-	0	-	0
47	Ethylene oxide	75-21-8	2910100000	0	464	-	464	10	429	-	419	16	311	-	295	5	419	-	414	3	324	-	321

Source : Customs Department, PTIT Special Annual Issue 2005, Department of Agriculture, Department of Industrial Works, Aromatics Thai(Plc.), Thai Petrochemical Industries(Plc.), Bangkok Synthetics Co., Ltd.

Remarks : '-' = 0 (zero) tonne

: '0' = the value is too small that is less than 1 tonne

: H-S code ended with xxx = chemical's data might be included within other derivatives in a family

: Chemicals No.14, 16(marked with *) share the same data as derived from the same group of 2903290xxx, No.23, 27(**) share the same data of 2903190xxx, and No.30, 32, 44(***) share the same data of 2902900xxx

: 'n.a.' = data is not available

The demand-supply analysis indicates that major VOCs utilization in Thailand is those related to petrochemical industry, such as benzene and *p*-xylene. Some VOCs are consumed in a small amount or discontinued for the import and use, domestically. These reductions might be caused by their high toxicity and banning of chemical or replacing to other chemical as results of international agreement such as those ozone depleting substances under the Montreal Protocol (Freon 113, Freon 114), etc. Examples of demand-supply analysis are given for vinyl chloride, benzene, toluene and *p*-xylene as illustrated in Figure 1 – Figure 4.

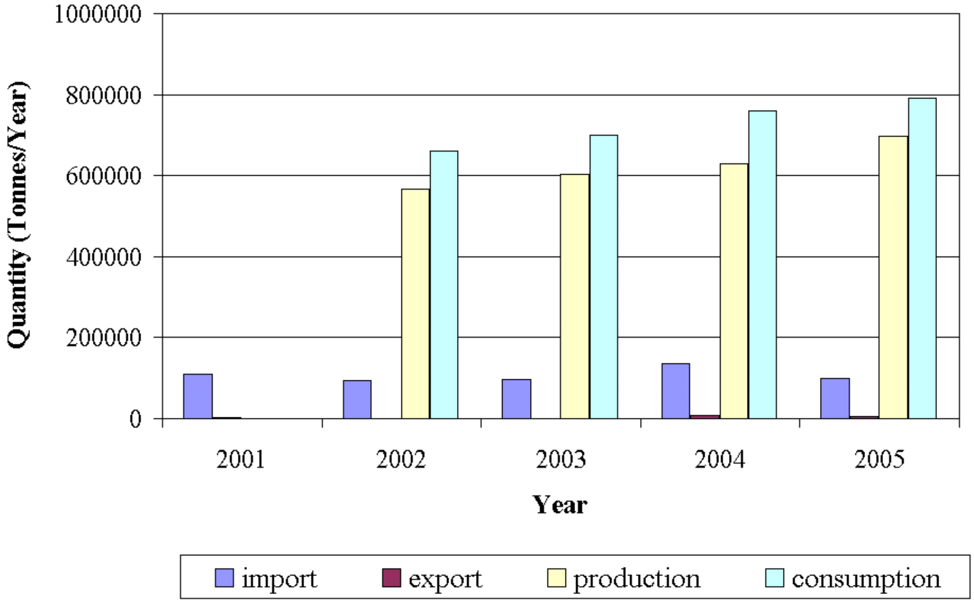


Figure 1 Demand-supply of vinyl chloride

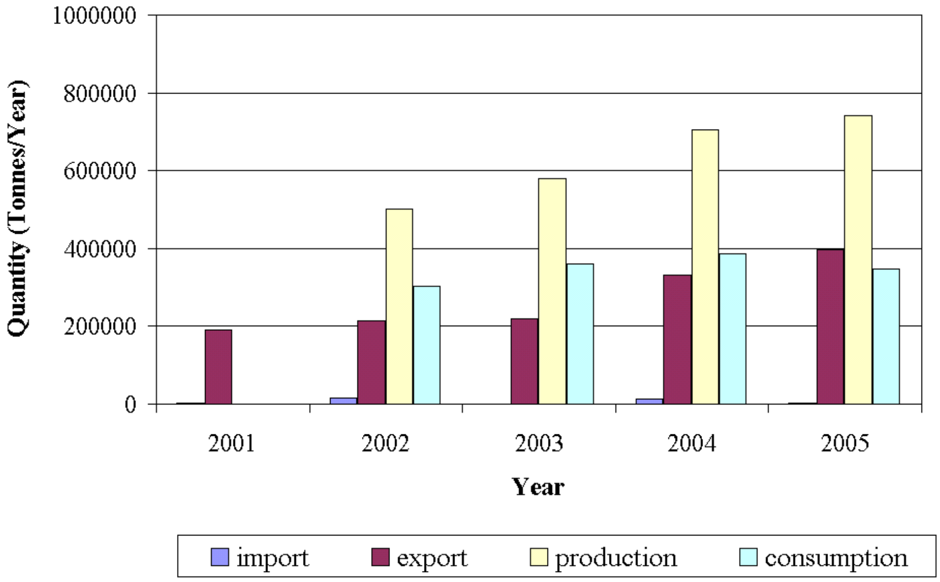


Figure 2 Demand-supply of benzene

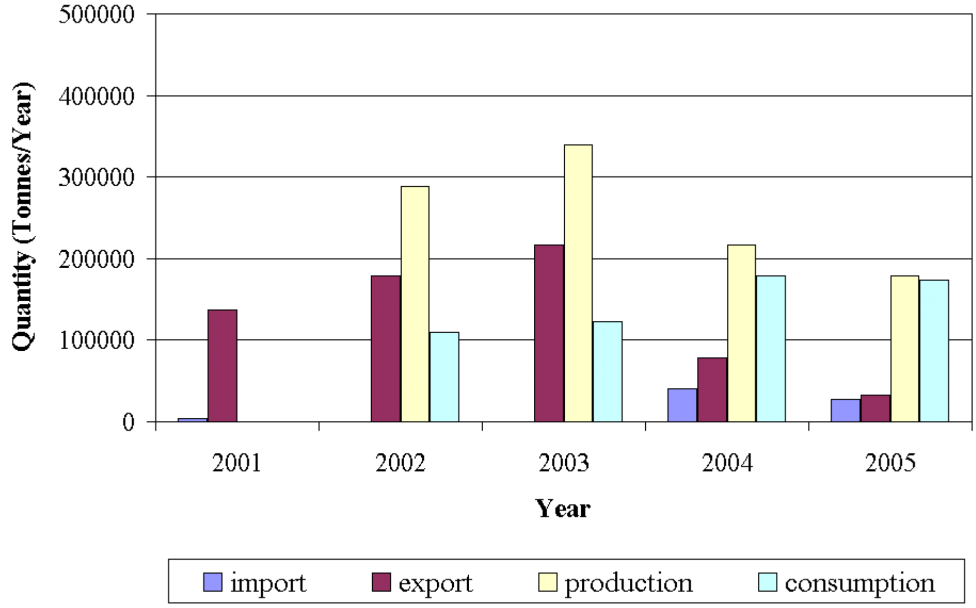


Figure 3 Demand-supply of toluene

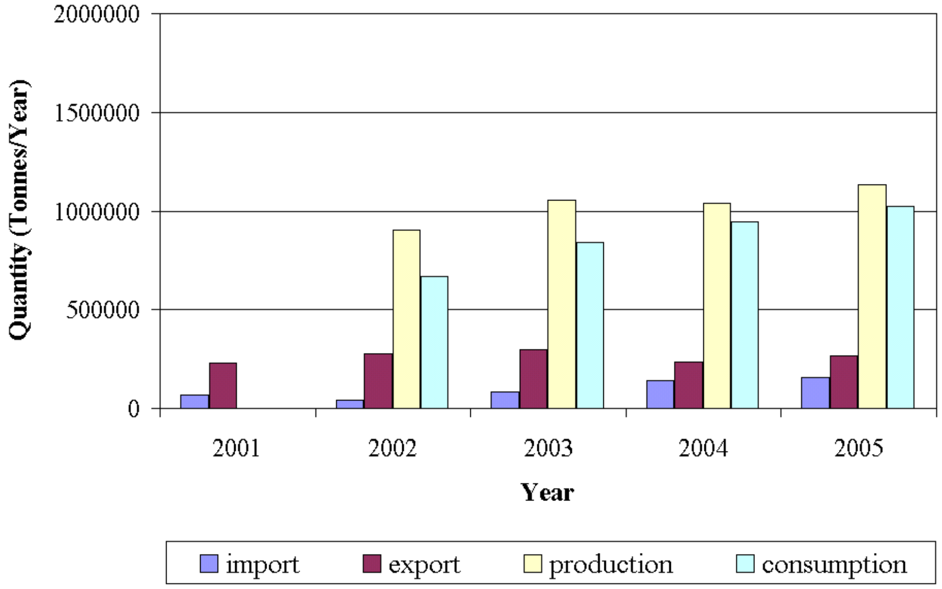


Figure 4 Demand-supply of *p*-xylene

In addition to the demand-supply analysis, key players in the supply chain of the 47 selected VOCs should also be reviewed in order to identify potential emission sources and significant areas that should be further investigated. In this regard, industrial-related VOC sources are focused. There are a number of industries producing or consuming VOCs in Thailand. These activities are considered important sources of VOC emissions which can be identified by the utilization patterns as follows.

1) **VOCs utilization in chemical production and formulation**

- *VOCs used as petrochemical feedstocks* – Emission sources are typically unit operation, transportation, storage and handling of the VOCs and their downstream products such as plastic pellets and synthetic fiber.

- *VOCs used as ingredients for chemical formulation* – Emission sources are similar to the earlier group, however, the processes are generally involved with mixing and packaging only with exclusion of chemical reaction.

2) **VOCs application in various activities**

- *VOCs used as solvent and chemical products* – Emissions may be resulted from application of products containing VOCs in airborne environment, such as degreasing, solvent extraction, as well as utilization of chemical products containing VOCs, for example, paints and adhesive products.

- *VOCs used as refrigerants* **–** Although refrigerants are generally used in closed-loop units, emissions maybe resulted from release during utilization and discarding.

Since there are a variety of industrial processes and applications releasing VOCs to the environment, physical distribution of industrial facilities identified as potential emission sources was reviewed in order to illustrate major areas where the sources are concentrated. In this regard, the potential emission sources were identified into factory types classified by Department of Industrial Work code. Identified factory types provides distribution of VOC-related industries, comprising numbers of factories for each type of focused industries and the locations (provinces) where the factories established.

It should be noticed that the major areas locating a number of VOC-related industries and applications in Thailand are Bangkok and its vicinities as well as many industrial provinces, such as Chonburi and Rayong provinces. Further, the petroleum refinery and plastic manufacturing factories are often found in these areas. Although some activities can be seen in a large number, for example printing and automotive repairing (car body spraying), the size of these practices could be seen mostly in small and medium scale, comparing with other large factories, such as refinery and plastic manufacturing.

2.2 Second stage emission inventory study

In the 2^{nd} Inventory Study (Thailand Environmental Institute, 2007), emissions of prospective priority 20 VOCs were estimated. The VOC emission value of a VOC source is derived from multiplying the data value with the factor given for each source. VOC emissions from the conditions are given in the FIRE Database (Factor Information REtrieval). This study also represents the results in condition, when the emission control device is assumed to be nonexistence. It is listed under "worst case". FIRE is a database, belonging to the US.EPA, giving air pollution emissions factors of particular activities related to VOCs production, consumption and emission. For example, the results of benzene emission inventory is shown in Table 2, the major source of benzene emission is "vehicles" which accounts for more than 3/4 of total emission.

Table 2 Inventory study results of benzene

Source	Emission (ton/year)	%
Vehicle	1,588	77.5
(Gas/uncontrol)	(1,343)	(65.6)
(Diesel)	(181)	(8.8)
(Gas/control)	(64)	(3.1)
Industrial combustion source	122	6.0
Gasoline storage and transportation	323	15.8
Other sources	15	0.7

The results of 1,3-butadiene emission inventory is shown in Table 3, half of 1,3-butadiene emission is derived from "vehicles" and the another half is derived from "fuel input (natural gas)". The "fuel input (natural gas)" seems to be higher ratio than the present state of Thailand, which is different due to a quotation from the US databases through this inventory study. It is, however, well known also in Japan that the contribution of diesel vehicles is the biggest (65% of all at the Pollutant Release and Transfer Register (PRTR) estimate in 2005).

Table 3 Inventory study results of 1,3-butadiene

Source	Emission (ton/year)	%
Vehicle	190	51.3
(Diesel)	(157)	(42.4)
(Gas/uncontrol)	(30)	(8.2)
(Gas/control)	(3)	(0.7)
Fuel input (natural gas)	181	48.7
(4-Cycle, rich-burn)	(129)	(34.7)
(4-Cycle, lean-burn)	(52)	(14.0)
Fuel burned	0.2	0.05

In total, 20 VOCs prioritized and selected in this phase. They are vinyl chloride, chloroform, 1,2-dichloroethane, benzene, toluene, carbon tetrachloride, trichloroethylene, ethyl benzene, dichloromethane, *p*-xylene, styrene, 1,2-dibromoethane, tetrachloroethylene, benzyl chloride, *p*-dichlorobenzene, acrylonitrile, 1,3-butadiene, formaldehyde, acetaldehyde, and ethylene oxide.

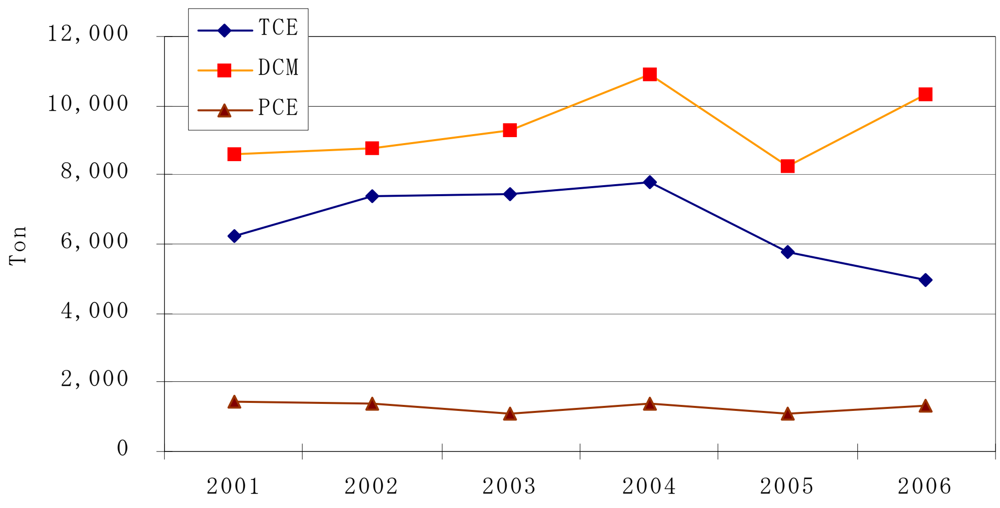
2.3 Third stage emission inventory study

The 3rd phase inventory study consists of two parts; the first part included the special study targeting vinyl chloride and 1,2-dichloromethane in the Map Ta Phut area, and the second part targeting benzene, dichloromethane (DCM), trichloroethylene (TCE), benzene, tetrachloroethylene (PCE) in the nationwide (Thailand Environmental Institute, 2008). Relating to the third inventory study, the Project also developed an air dispersion model on VOCs based on meteorological data and profound understanding on the target industry; thus the Project greatly contributes to develop the effective countermeasures against VOCs emission. The selection of DCM, TCE and PCE is made based upon 3 criteria, which are 1) high usage volume, 2) high emission volume and 3) possible detection frequency of ambient air monitoring data. The result of the study is expected to be integrated for an evaluation for selected VOCs emission standard. Details inventory report of priority VOCs was developed as one of the major outputs in the project.

The focused area of the survey is initially limited in Bangkok Metropolitan Region, which covers Bangkok, Nonthaburi, Nakhonpathom, Samutsakhon, Samutprakan, and Pathumthani; however, areas of surveys are expanded to Ayutthaya, Chachoengsao, Rayong, Chonburi and Phetchaburi provinces so as to obtain such important information. Random selection method for surveys in all facilities is applied. The random selections of facilities are made from the medium and large industrial factories, which are listed in the factory database of the Ministry of Industry, Thailand.

Each individual VOCs is surveyed in targeted facilities to obtain such information. Most of the surveys are conducted by a means of on site in-person interview; however, there is the other survey method using in the study, which is phone interview. According to the results obtained from the 1st and 2nd Phase emission inventory combine with the data retrieved from FIRE database the target facilities using four compounds are selected; 1) benzene/gasoline storage tank, 2) hot oil boiler/combustion sector in industrial factory, 3) dry cleaning sector in dry cleaning facility and/or hotel, 4) degreasing facility and other related facilities.

In conclusion, a wide range of industries were surveyed during the 3rd phase, including factories using TCE as degreasing agent for their metal parts or factories using TCE as intermediate agent in pharmaceutical products. Since TCE, DCM, and PCE are not produced in Thailand, statistical data from custom department implies the volume of the solvent used. Figure 5 shows such volume of usage, i.e. imported volume minus exported volume.



Source: Custom Department

Figure 5 Trend of TCE, DCM, and PCE usage

The questionnaire results of inventory study for different industrial sector are complied. Total number of factory nationwide using the specified substances in each industrial sector is estimated. Unit consumption of the specified substances per factory was computed from the 3rd phase emission inventory study data. The data was standardized to consumption in ton per year. Then, the national consumption of the specified substances by each industrial sector is calculated.

For degreasing and cleaning facility for TCE and PCE, emission factor was set at 0.8, assuming 20 % of solvent is eventually disposed as sludge and absorbed waste to activated carbon. FIRE database has value ranging from 0.79 to 0.83 for open type bath and conveyer type system. Other application of TCE and PCE as solvent, emission factor was set at 0.8. As for degreasing facility for DCM, emission factor was also set at 0.9, assuming 10 % of solvent is eventually disposed as sludge and absorbed waste to activated carbon. FIRE database has value ranging from 0.87 to 0.91 for uncontrolled type bath and conveyer type system. Other application of DCM as solvent, emission factor was also set at 0.9. Chemical factories (bulk chemical and other) are using TCE for its closed process. Therefore the emission in this case is assumed low and factor was set at 0.1. Relevant emission factor in FIRE was not identified. In conclusion the national level emission of DCM, TCE and PCE by industrial sector is shown in Table 4.

Table 4 National level emission by industrial sector

	TCE emission (ton/year)	Ratio to total	PCE emission (ton/year)	Ratio to total	DCM emission (ton/year)	Ratio to total
Auto & auto parts	494	6.5%			763	13.7%
Electric & Electronics	2156	28.2%			4261	76.3%
Machineries						
• 289 Compress and mold	832	10.9%				
• Metal plating	2620	34.3%				
• Machineries other than 289	1481	19.4%	5.4	0.4%	36	0.6%
Dry cleaning						
• Independent shop			357	29.5%		
• Hotel (medium to large)			848	70.0%		
Other						
• 46 medical					13	0.2%
• 54 glass	0.5	0.0%				
• 83 watch						
• 86 sport						
• 2801 garment	2.0	0.0%				
• 4101printing	14	0.2%				
• 4201 chemical (bulk)	13	0.2%				
• 4201 chemical (others)					64	1.1%
• 5004 petroleum	14	0.2%				
• 5305 polymer	12	0.2%			14	0.3%
• Paint remover					432	7.7%
Grand total	**7640**		**1211**		**5583**	

3 Monitoring and Analysis

3.1 Method of ambient monitoring

Analysis of VOCs is complicated because they occurred in a wide range of concentrations in the environment. Therefore it is essential to secure a quality of sampling and a reliability of analysis by laboratories in the country. Therefore, standardization of sampling and analysis method of VOCs and QA/QC protocol are established. Official sampling and analysis method of ambient measurement are designated in order to assure the quality and comparability of the measured data. Details of the Standard Operating Procedures (SOP) of VOCs monitoring and analytical method were developed as one of the major outputs in the project.

It should be noted that VOCs measurement requires not only well trained specialists but also budget because of time-consuming and costly operation. Therefore monitoring sites of VOCs in air should be selected carefully to properly illustrate VOCs situation in consideration with limitation of budget and human resource, and diffusion characteristic of VOCs. Monitoring site of VOCs is classified according to its land use pattern as general area, roadside area and industrial area.

Prior to the formulation of the sampling plan, current practices in foreign countries such as Japan, US and EU were reviewed. All together 25 monitoring sites were set under four categories, namely, 1) Residential area 2) Roadside area 3) Near source or industrial area and 4) Background. Criteria for site selection were as follows:

- Residential area: Population of each district in Bangkok
- Roadside area: Traffic data in Bangkok
- Near source or industrial area: Odor complain record, initial inventory study, meteorological condition, previous measurement and data related to VOCs.

Monitoring sites were placed in the area of Map Ta Phut sub-district, Rayong province and in Bangkok and vicinity areas. All types of sampling sites were cover. Location of sampling sites is shown in Figure 6.

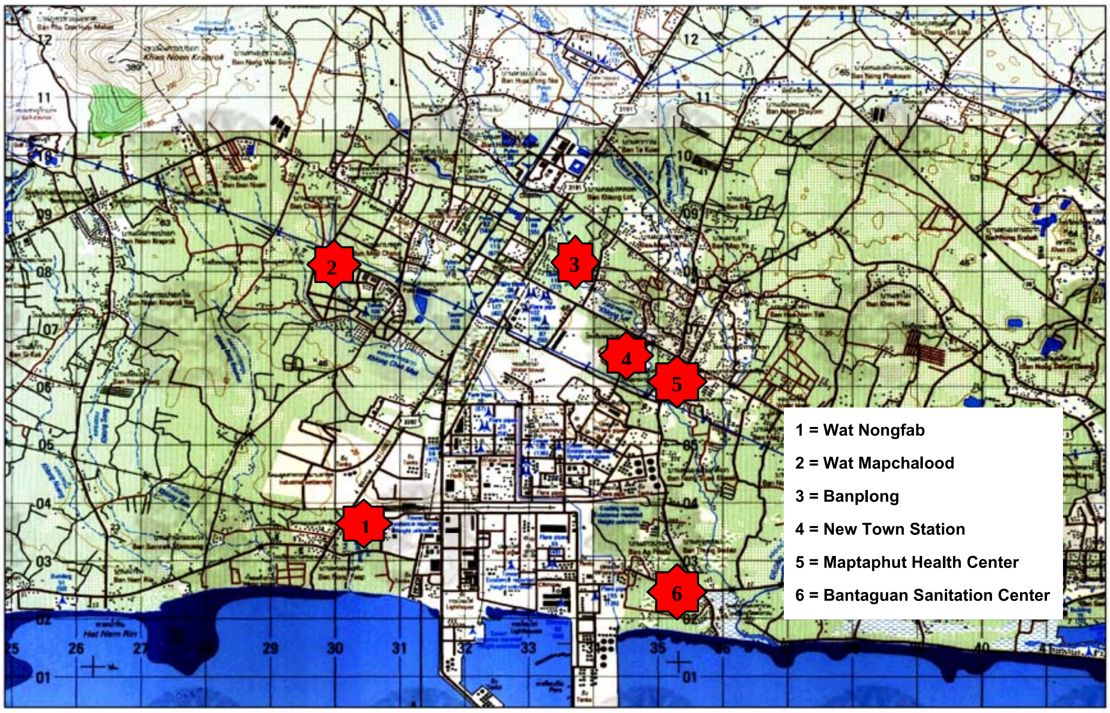


Figure 6 PCD ambient VOCs monitoring sites in Rayong province

There were 17 monitoring sites in Bangkok and vicinity area. Seven of them were operated by PCD and were located near the potential emission sources of VOCs as presented in Figure 7. Other monitoring sites (10 sites) were operated by ERTC where ambient air samples were taken in the residential and roadside areas as presented in Figure 8. Details of sampling site were as listed in Table 5.

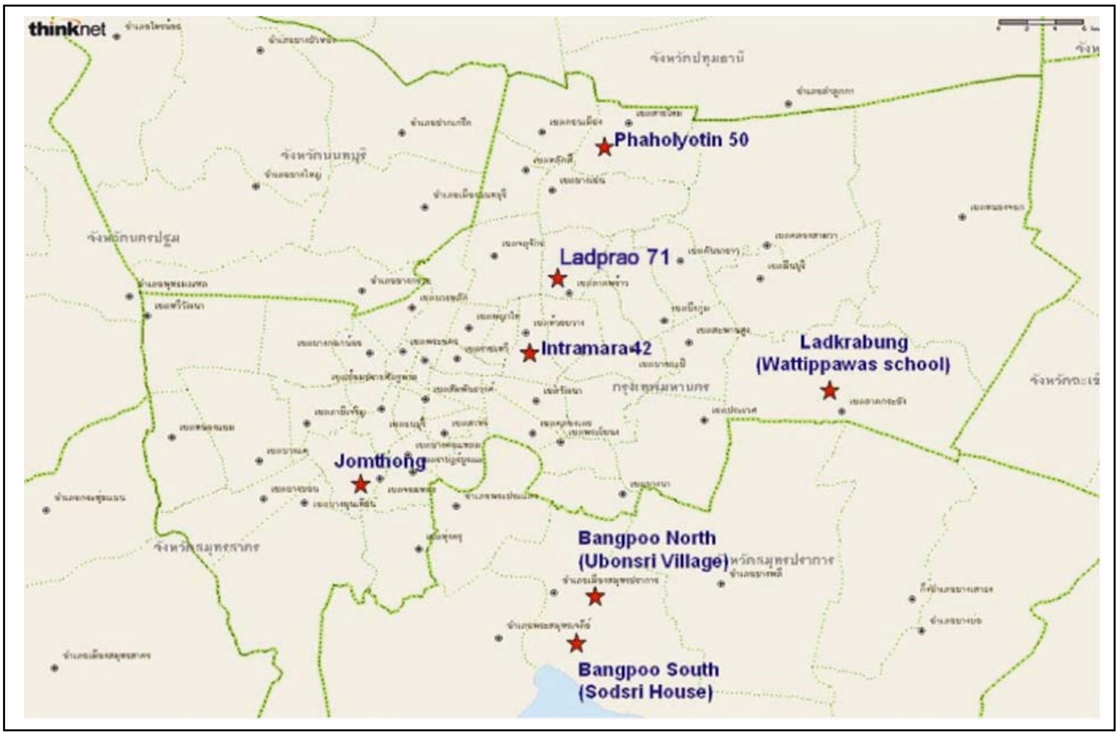


Figure 7 PCD ambient VOCs monitoring site in Bangkok and vicinity area

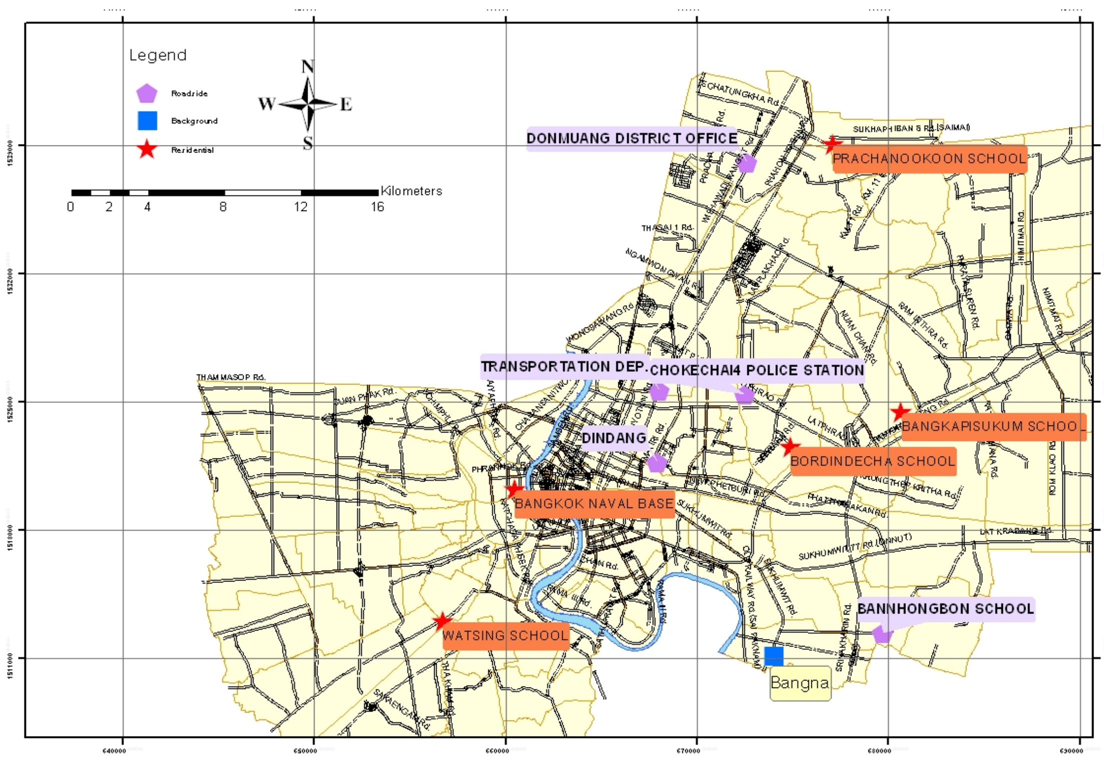


Figure 8 ERTC ambient VOCs monitoring sites in Bangkok area

Table 5 VOCs monitoring sites

Sites	Agency	UTM	
		X (WGS84)	Y (WGS84)
Roadside (Bangkok)			
1. Donmuang District Office	ERTC	672318	1538355
2. Transportation Department	ERTC	667714	1525914
3. Chokechai 4 Police Station	ERTC	672180	1525636
4. Dindang station	ERTC	667609	1522005
5. Bannhongbon School	ERTC	679577	1512599
Residential (Bangkok)			
1. Bangkapisukum school	ERTC	680340	1524712
2. Bordindecha School	ERTC	674557	1522832
3. Watsing School	ERTC	656372	1513271
4. Bangkok Naval base	ERTC	660128	1520475
5. Prachanookoon School	ERTC	676790	1539354
City Background			
1. Bangna	ERTC	673673	1511376
Near source (Bangkok & vicinity)			
1. Wattippawas school (Lad Krabung)	PCD	695087	1523863
2. Bangpoo North (Ubonsri Village)	PCD	680786	1499958
3. Bangpoo South (Sodsri House)	PCD	678406	1495933
4. Chom thong	PCD	674513	1535699
5. Lad prao 71	PCD	675006	1528831
6. Phaholyothin 50	PCD	674510	1535698
7. Intramara 42	PCD	669715	1523975
Near source (Map Ta Phut)			
1. Map Ta Phut Health Center	PCD	735198	1405891
2. Bantaguan Sanitation Center	PCD	735522	1402762
3. Map Ta Phut New Town Station	PCD	734643	1406326
4. Wat Mapchalood	PCD	730905	1407345
5. Watnongfab School	PCD	729828	1403346
6. Banplong Community	PCD	734099	1408033
Reference Background			
1. Khao Laem Dam	PCD	457138	1634504

3.2 Method of stationary source monitoring

The point source measurement method is set up together with emission standards for particular VOCs species. The official measurement method has been developed through discussion among concerned organizations and stakeholders.
Sampling and analysis procedures of EDC and VCM were developed in the VOCs project. Followings are the procedures based on the VOCs monitoring and source sampling in the VOCs project.

- Sampling apparatus; Tedlar bag, Adsorbent Tube
  Average 3-hour period
  1-hour period × consecutive 3 times
- Sampling frequency: once in every 3 months
- Analytical method: GC, GC/MS

3.3 Method of mobile source monitoring

The inspection methodology has been developed through discussion among concerned organizations and stakeholders. A canister is used for a sampling of VOCs from vehicle exhaust. A sample was taken at every emission phase in a driving cycle; low, middle and high emission in the case of a hot mode. GC/MS is used for the quantitative measurement of VOCs. Three parameters of THC, NOx and CO are measured at the Automotive Emission Laboratory of PCD according to the usual methods by their automated system.

4 Establishment of Environmental Standards

4.1 Environmental standards

*Environmental standard*s are set as "desirable standards for protecting human health and protecting the living environment" and they became policy targets. Even before enactment of the Basic Laws for Environmental Pollution Control, observation of pollutant concentrations in the environment and epidemiological surveys were implemented, and these data together with scientific data from WHO and other international agencies were used in order to provide the basis for setting environmental standards.

The Enhancement and Conservation of National Environmental Quality Act, B.E. 2535 (hereafter referred to NEQA) defines an environmental quality standard as follows:

"Environmental Quality Standards" mean the parameters of quality standards for water, air, noise and other conditions of the environment which are determined as the general criteria for enhancement and conservation of environmental quality." (Section 4)

Section 32 of NEQA also prescribes that an environmental quality standard should be set in consideration of the following points.
"The prescription of environmental quality standards pursuant to the foregoing paragraph shall be based upon scientific knowledge, principles, criteria and evidence related thereto and shall also take into account the practicability of such standards from the viewpoint of economic, social and technological considerations."(Section 32)

4.2 Principal of setting up environmental standard

There are hundreds of VOCs present in the atmosphere, the target VOCs for environmental standards and emission inventory should be prioritized. Major concerns for target VOCs selection are toxicity and possibility of exposure. Selection criteria of target VOCs is based on toxicity of individual VOCs species as defined by several international agencies working on human health. In order to properly assess the toxicity of a chemical substance, data from credible organizations are utilized as reference. With regards to this matter, 3 main principle of setting up the environmental standards are applied as follows.

4.2.1 Screening matrix of prospective priority VOCs

Criteria used by some of internationally recognized institutions are applied in this case. Classification of toxicity according to its carcinogenicity, defined by IARC (The International Agency for Research on Cancer), US.EPA (United States Environmental Protection Agency), ACGIG (The American Conference of Governmental Industrial Hygienist) and JSOH (Japan Society of Occupational Health) and chronic toxicity for each VOCs, defined by WHO (World Health Organization) and IRIS (Integrated Risk Information System : US.EPA) are utilized. Priorities are given to the VOCs having carcinogenic property as listed in Table 6 and to the VOCs which is met with the inhalation chronic toxicity criteria as designated in Table 7.

Table 6 Criteria of target VOCs according to its carcinogenicity

	IARC*	EPA**	ACGIH***	JSOH****
Criteria	1, 2A	A, B	A1, A2	1, 2A

*IARC: The International Agency for Research on Cancer: Toxicity are classified into 5 classes as follows:
1: The agent is carcinogenic to humans; 2A: The agent is probably carcinogenic to humans; 2B: The agent is possibly carcinogenic to humans; 3: The agent is not classifiable as to its carcinogenicity in to humans, and 4:The agent is probably not carcinogenic to humans
**Evaluation under USNTP of USEPA: Toxicity is divided as follows:
A: The agent is carcinogenic to humans with enough epidemiological evidences, and B: The agent is probably carcinogenic to humans but with limited epidemiological evidences
***Evaluation by ACGIH: Toxicity is classified into 5 classes as follows:
A1: The agent is carcinogenic to humans; A2: Carcinogenesis to humans is suspected with limited epidemiological evidences or animal study; A3: Carcinogenesis is perceived with animal study; A4: The agent is not classifiable as to its carcinogenesis into humans; A5: The agent is not suspected of carcinogenesis to humans
****Evaluation by JSOH: Toxicity is classified into 3 classes as follows:
1: The agent is carcinogenic to humans; 2A: The agent is probably carcinogenic to humans with enough evident; and 2B:The agent is possibly carcinogenic to humans without enough evident.

Table 7 Criteria of target VOCs according to its inhalation chronic toxicity

	WHO	IRIS
Status	Environmental standards guideline values	RfC (reference concentration) Concentration or quantity that may not cause adverse effect even if the substance is inhaled or taken into one’s body in his/her whole lifetime. Inhalation RfC is used in this case.
Criteria	less than 0.1 mg/m^3	unit: mg/m^3 smaller the value, higher the inhalation chronic toxicity

Selection criteria of target VOCs is set up based on toxicity of individual VOCs species and amount of its consumption in Thailand. Priority is given to carcinogenic substance and chemical having large amount of consumption which might lead to high possibility in environmental exposure. Matrix of selection of target VOCs is summarized in Table 8.

Table 8 Screening matrix of prospective priority VOCs

	1st Target VOCs	selection	Detected in existing monitoring results	Import and Export in 2005 (ton/year)			Production in 2005	Exposure (Import+production)	Inhalation chronic toxicity(mg/m^3)		Carcinogenicity			
				Export	Import	Net			WHO	IRIS	IARC	EPA	ACGIH	JSOH
				Quantity	Quantity		ton/year		*1	*2	*5	*6	*7	*8
1	Vinyl Chloride	○	○	5,677.8	98,626.0	92,948.2	697,000	795,626.0	0.01	0.0011	1	A	A1	1
2	Vinylidene Chloride			0.0	57.0	57.0		57.0		0.2				
3	Freon 114		○	0.0	0.0	0.0		0.0						
4	Chloroform	○	○	24.2	141.7	117.5		141.7	0.024	0.00043	2B	B	A3	2B
5	1,2-Dichloroethane	○	○	0.0	336,125.9	336,125.9		336,125.9	0.061	0.00038	2B	B	A3	2A
6	Benzene	○	○	398,019.0	3,150.1	-394,868.9	742,000	745,150.1	0.0017	0.0013	1	A	A1	1
7	Toluene	○	○	32,896.0	27,407.3	-5,488.7	179,000.0	206,407.3			3		A4	
8	Methyl Chloroform		○	0.0	0.0	0.0		0.0			3		A4	
9	Freon 12			17.5	1,157.4	1,139.9		1,157.4						
10	Carbon Tetrachloride	○	○	0.0	0.0	0.0		0.0		0.00067	2B	B	A2	2B
11	Methyl Chloride		○	0.0	0.0	0.0		0.0			3		A4	
12	Trichloroethylene	○	○	35.1	5,831.6	5,796.5		5,831.6	0.023		2A	B	A5	2B
13	Freon 11			0.0	0.0	0.0		0.0					A4	
14	cis-1,3-Dichloropropene		○	0.1	6.0	5.9		6.0		0.02				
15	Methyl Bromide			0.0	336.2	336.2		336.2			3		A4	
16	Trans-1,3-Dichloropropene			0.1	6.0	5.9		6.0		0.02				
17	Ethyl Chloride			0.0	0.0	0.0		0.0			3		A3	
18	Ethylbenzene	○	○	0.0	105.0	105.0		105.0	22		2B	B	A3	2B
19	Freon 11		○	0.0	102.5	102.5		102.5						
20	o-Xylene		○	37,034.3	549.4	-36,484.9		549.4						

Table 8 Screening matrix of prospective priority VOCs (cont'd)

	1st Target VOCs	selection	Detected in existing monitoring results	Import and Export in 2005 (ton/year)			Production in 2005	Exposure (Import+production)	Inhalation chronic toxicity(mg/m^3)		Carcinogenicity			
				Export	Import	Net			WHO	IRIS	IARC	EPA	ACGIH	JSOH
				Quantity	Quantity		ton/year		*1	*2	*5	*6	*7	*8
21	Dichloromethane	○	○	0.056	8,332.5	8,332.4		8,332.5		2.1E-02	2B	B	A3	2B
22	m-Xylene		○	0.0	0.022	0.0		0.0						
23	1,1-Dicholoroethane			0.0	45.9	45.9		45.9					A4	
24	p-Xylene	○	○	263,866.3	154,700.1	-109,166.2	1,132,000	1,286,700.1						
25	cis-1,2-Dicholoroethylene		○	0.0	0.0	0.0		0.0						
26	Styrene	○	○	21,322.3	85,840.3	64,518.0	502,000	587,840.3			2B		A4	2B
27	1,2-Dichloropropane		○	0.0	45.9	45.9		45.9		0.004				
28	1,1,2,2-Tetrachloroethane		○	2.5	0.0	-2.5		0.0						
29	1,1,2-Trichloroethane			0.0	18.9	18.9		18.9		0.0063	3		A3	
30	1,3,5-Trimethylbenzene		○	7,096.0	2,167.0	-4,929.0		2,167.0						
31	1,2-Dibromoethane	○	○	0.09	0.0	-0.1		0.0			2A	B	A3	2A
32	1,2,4-Trimethylbenzene		○	7,096.0	2,167.0	-4,929.0		2,167.0						
33	Tetrachloroethylene	○	○	2.1	1,116.7	1,114.6		1,116.7	0.2		2A	B	A3	2B
34	m-Dichlorobenzene		○	0.0	44.3	44.3		44.3						
35	Monochlorobenzene		○	1.1	102.5	101.4		102.5					A3	
36	o-Dichlorobenzene		○	0.0	20.0	20.0		20.0			3		A4	
37	Benzyl Chloride	○	○	10.1	324.0	313.9		324.0			2A		A3	2A
38	p-Dichlorobenzene	○	○	0.1	522.6	522.5		522.6			2B	B	A3	2B
39	Hexachloro-1,3-butadiene					0.0		0.0						
40	1,2,4-Trichlorobenzene		○	0.0	0.0	0.0		0.0						

Table 8 Screening matrix of prospective priority VOCs (cont'd)

	1st Target VOCs	selection	Detected in existing monitoring results	Import and Export in 2005 (ton/year)			Production in 2005	Exposure (Import+production)	Inhalation chronic toxicity(mg/m^3)		Carcinogenicity			
				Export	Import	Net			WHO	IRIS	IARC	EPA	ACGIH	JSOH
				Quantity	Quantity		ton/year		*1	*2	*5	*6	*7	*8
41	Acrylonitrile	○		2.2	124,637.9	124,635.7		124,637.9	0.0005	0.00015	2B	B	A3	2A
42	1,3 Butadiene	○	○	26,871.9	14,708.6	-12,163.3		14,708.6		0.00033	2A	A	A2	1
43	3-Chloro-1-Propane			6.5	0.0	-6.5		0.0			3		A3	
44	4-Ethyltoluene					0.0		0.0						
45	Formaldehyde	○		43.2	38.4	-4.8	123,940.0	123,978.4		0.00077	1	B	A2	2A
46	Acetaldehyde	○	○	0.2	48.0	47.8		48.0	0.019	0.0045	2B	B	A3	2B
47	Ethylene oxide	○		0.2	464.4	464.2		464.4			1	A	A2	1
	Total	20												

Remarks:

*1: Guideline figure of environment standard

*2: IRIS: Integrated Risk Information System, VSD (Virtually Safe Dose, USEPA)

*3: ACGIH: The American Conference of Governmental Industrial Hygienist (working environment air standard)

*4: JSOH: Japan Society of Occupational Health (working environment air standard)

*5: IARC: The International Agency for Research on Cancer: Toxicity are classified into 5 classes as follows:

1: The agent is carcinogenic to humans; 2A: The agent is probably carcinogenic to humans; 2B: The agent is possibly carcinogenic to humans; 3: The agent is not classifiable as to its carcinogenicity in to humans, and 4:The agent is probably not carcinogenic to humans

*6: Evaluation under USNTP of USEPA: Toxicity is divided as follows:

A: The agent is carcinogenic to humans with enough epidemiological evidences, and B: The agent is probably carcinogenic to humans but with limited epidemiological evidences

*7: Evaluation by ACGIH: Toxicity is classified into 5 classes as follows:

A1: The agent is carcinogenic to humans; A2: Carcinogenesis to humans is suspected with limited epidemiological evidences or animal study; A3: Carcinogenesis is perceived with animal study; A4: The agent is not classifiable as to its carcinogenesis into humans; A5: The agent is not suspected of carcinogenesis to humans

*8: Evaluation by JSOH: Toxicity is classified into 3 classes as follows:

1: The agent is carcinogenic to humans; 2A: The agent is probably carcinogenic to humans with enough evident; and 2B:The agent is possibly carcinogenic to humans without enough evident.

Chemical No. 14, 16 and No. 23, 27 and No. 30, 32 share the same data as derived from the chemical's data that included other derivatives in a family

Initial substances have been selected from the viewpoint of harmfulness and possibility of environmental monitoring. The most of selected substances come from a list of US. EPA Compendium Method TO-14 and 5 substances are added. The next flowchart is a method to make a short list of target VOCs as example in Figure 9.

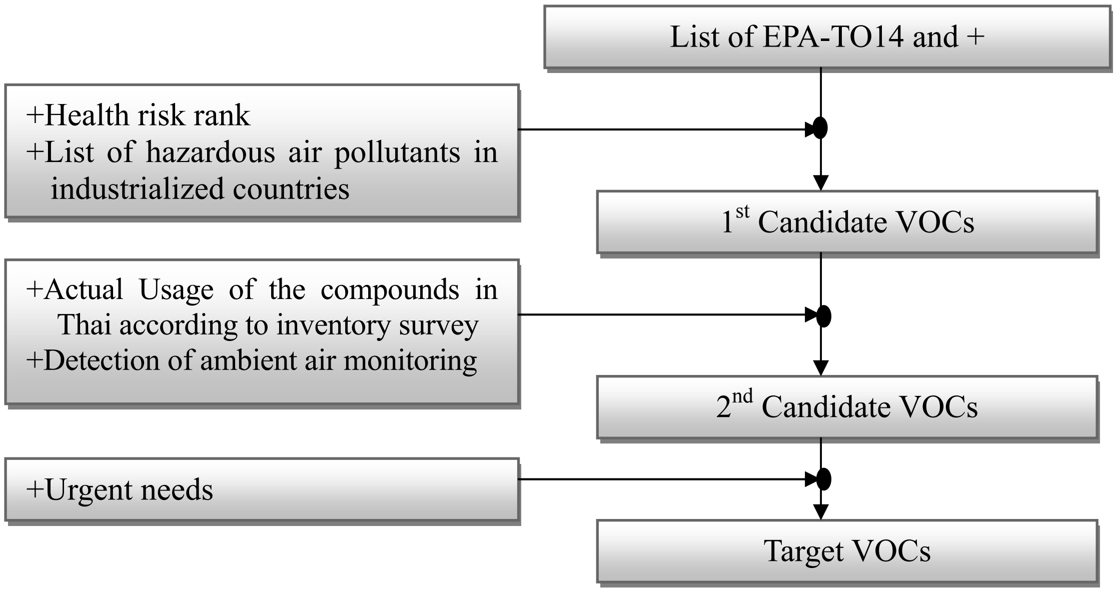


Figure 9 Flowchart of selecting target VOCs

4.2.2 Ambient air monitoring data and exposure assessment

As for possibility of exposure, if a chemical substance has high toxicity, it may well pose threat to human health and/or surrounding environment even if its release to the environment or detection in the environment is low. Likewise, a chemical may also pose threat to the human health and/or surrounding environment if it is released to the environment in large quantity or present in high concentration in the environment even if the chemical has low toxicity. With this concept, determination of the status of VOCs ambient concentration is needed. The status of VOCs in Thailand is determined by monitoring results, measured in several places both in the urban and in the industrial areas together with emission inventory data. These data are used to determine status and evaluate for exposure possibility of VOCs in the country. As for the ambient monitoring and analysis method the US. EPA Compendium Method TO-14A "Determination of VOCs in ambient air using specially prepared canisters with subsequent analysis by Gas Chromatography (GC) was adopted. The project evaluated the monitoring result to identify the priority VOCs in view of its abundance in the environment and the human health risk imposed by the concentration level found. Evaluation was summarized in the two dimensional plot for easy visualization of its priority. The plot was also examined from the inventory data if the abundant VOCs are clearly related to the potential source. Figure 10 shows the comparison of the monitoring frequencies with the existing concentration at 97 percentile of each compound.

X: Frequency of detection = Number of measurement above MQL / Total number of measurement x 100 (%)

** MQL = Method Quantitation Limit*

Y: Risk of exposure estimation = concentration at 97 percentile of monitoring result/reference risk

In this evaluation, the screening value of US. EPA region 6(US.EPA, 2007) is used as the reference risk. Screening value is calculated using following equation:

- Inhalation of Carcinogenic Contaminants

Screening Level ($\mu g/m^3$) = TR x AT x 365 d/yr x 1,000µg/mg /EF x InhFadj x SFo

when:
TR = target risk of 10^{-6}
AT = averaging time 70 years
EF = exposure frequency of 350 days
InhFadj = adjusted inhalation factor (m^3-yr) (kg-d) 11or InhFmadj for mutagens 3.9
SFo = Oral Cancer Slope Factor

- Inhalation of Noncarcinogenic Contaminants

Screening Level ($\mu g/m^3$) = THQ x BW x AT x 365 d/yr x 1000µg/mg / EF x ED x IRA x 1/RfDi

when:
THQ = target hazard quotient of 1
BW = body weight of adult 70 kg
AT = averaging time of resident 30 years
EF = exposure frequency of 350 days
ED = exposure duration of 30 years
IRA = inhalation rate of 20 m^3/day
RfDi = inhalation reference dose

However, the monitoring results are available only in 23 monitoring sites in Bangkok and Map Ta Phut area, therefore the situation of ambient VOCs may not represent the nationwide situation. It is worth to note that the evaluation of monitoring results and risk of exposure is limited. Additionally, other statistical data such as emission inventory, source of exposure, chemical properties etc., should be taken into consideration as support criteria.

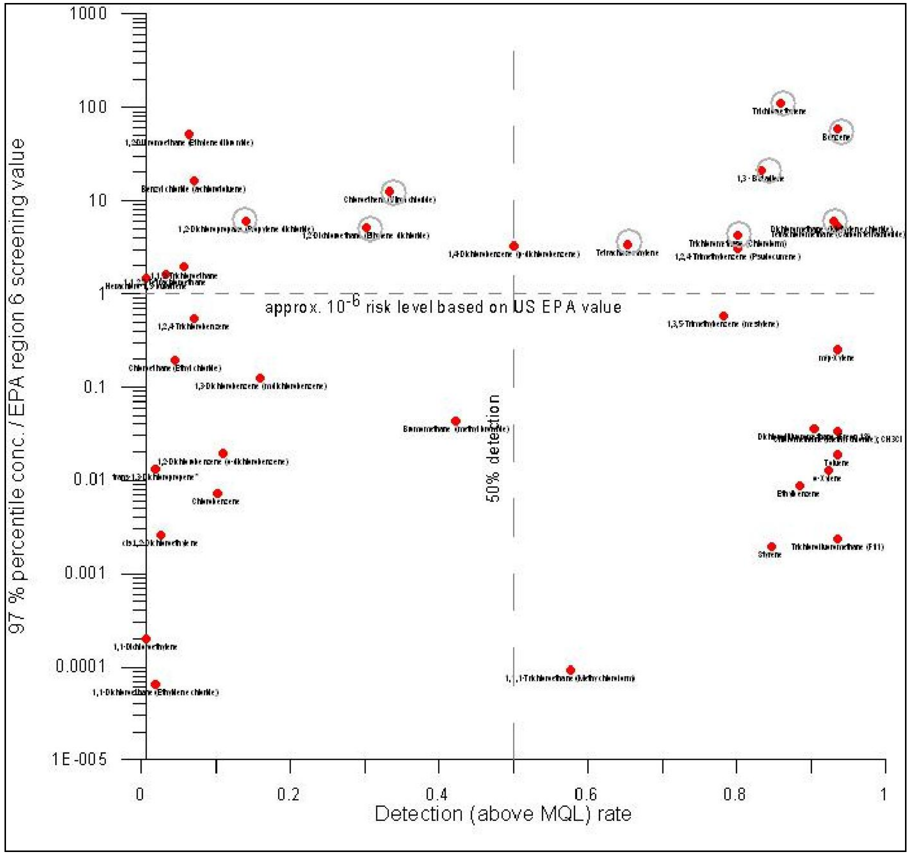


Figure 10a Bangkok monitoring result above MQL (September 2006 -August 2007)

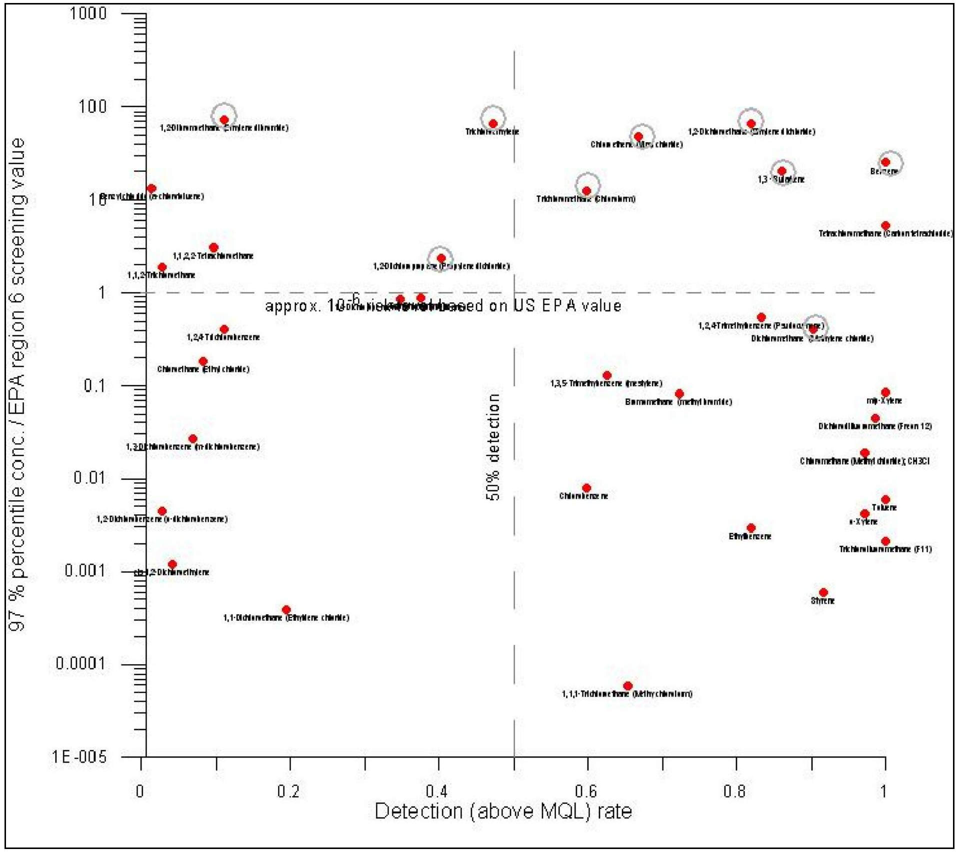


Figure 10b Map Ta Phut monitoring result above MQL (September 2006-August 2007)

Figure 10 Criteria of target VOCs according to its monitoring frequency and risk assessment

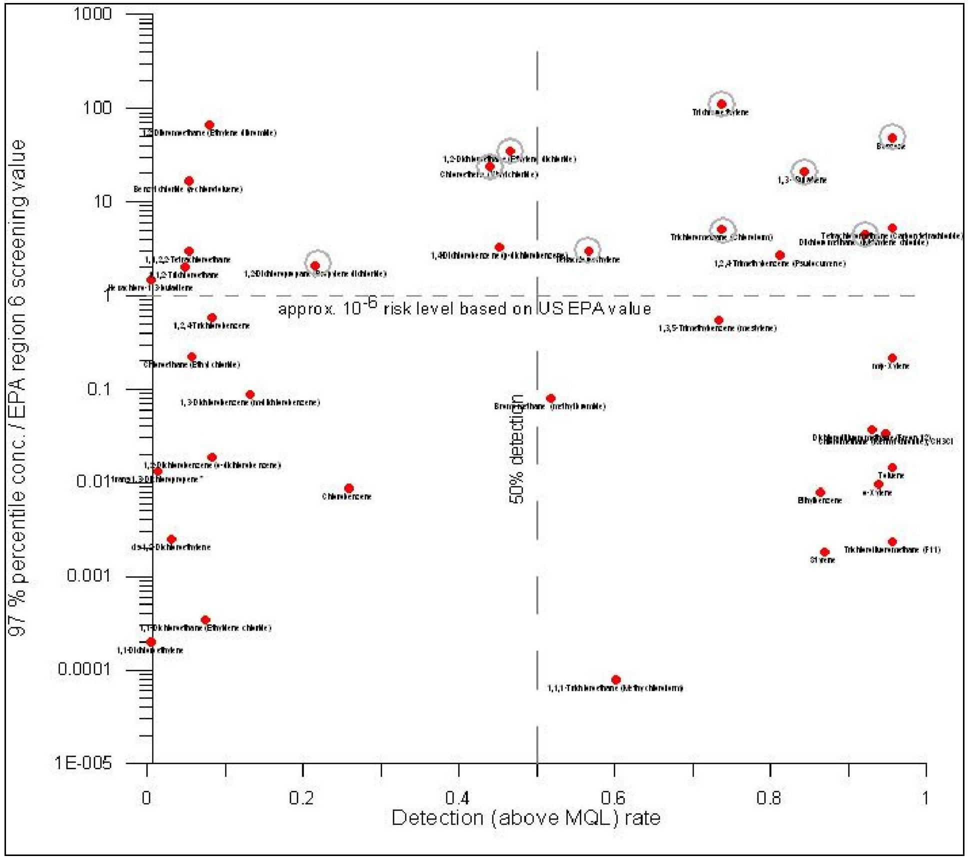


Figure 10c Bangkok and Map Ta Phut monitoring result above AQL (August 2006 – January2007)

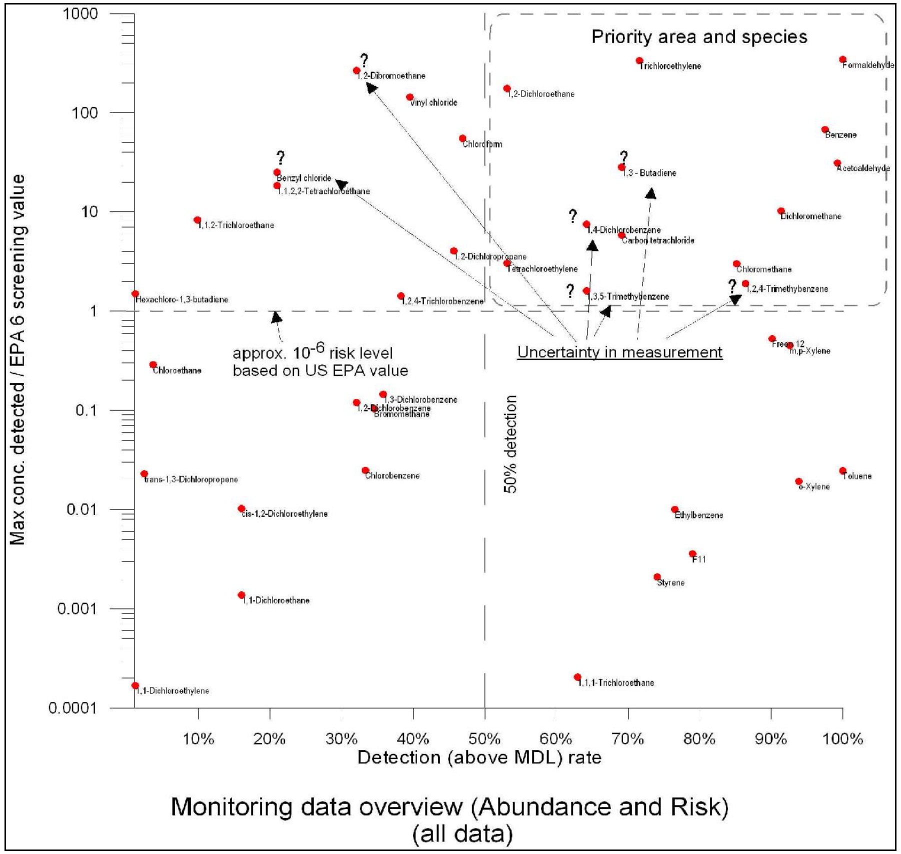


Figure 10d Bangkok and Map Ta Phut monitoring result (August 2006-January2007)

Figure 10 Criteria of target VOCs according to its monitoring frequency and risk assessment (cont'd)

4.2.3 Comparison of international ambient air quality standards

At present, ambient air quality standards for VOCs were set up by several agencies. List of the international standard are complied and are classified according to their averaging time as presented in Table 9.

The project tentatively selected, from technical point of view only, 5 VOCs to be proposed as priority for setting the ambient standard namely benzene, vinyl chloride, 1,2-dichloroethane, trichloroethylene, dichloromethane. Then initial selection was reviewed by the more comprehensive point of view, and list of priority VOCs was expanded to 9 species, but based on the same plot prepared for priority visualization. As a result 1,3-butadiene, tetrachloroethylene, chloroform and 1,2-dichloropropane are added to the set of environmental quality standards.

Toxicological data, especially unit risk from cancer, was reviewed as the basis of setting numerical standard value for priority VOCs. Such data were mostly from WHO and US.EPA. Unit risk value provides easy computation of the ambient concentration value at the specified risk level, i.e. at 10^{-5} or 10^{-6}. Considering health impact by long term exposure of VOCs, it is proper to set an environmental standard as an annual average value.

Table 9 Internationally available of ambient VOCs guideline

Compounds	Guideline Values ($\mu g/m^3$)											
	WHO Guideline for Air Quality (2000)		**New Zealand**	**Canada**	**Japan**	**California**	**Rhode Island Air Toxic Guideline**			**Arizona**		
	Average ambient air concentration	Guideline Value (GV) or Tolerable concentration (TC)	Guideline value	Ambient air quality criteria [Ontario]	(annual)	Ambient air quality standard	(Acceptable ambient level) ($\mu g/m^3$)			Ambient air quality guidelines ($\mu g/m^3$)		
							1 hour	24 hour	annual	1 hour	24 hour	annual
Acetaldehyde	5	2000 (TC) (24 hour.) 50 [TC] 1 year	30 (annual)	500 (24 hour)					0.5	2300	1400	0.5
Acrolein	15						0.1	0.02		6.7	2	
Acetone	0.5 - 125	n.p.		48000 (24hr)			60000	30000		20000	14000	
Benzene	5 - 20	No safe level	10 (annual)		3		200	10	0.1	630	51	0.14
Carbon Disulfide	10 - 1500	100 (GV) (24 hour) 20 (GV) (30 min)		330 [24hr]			6000		700	91	24	
Carbonyl Sulfide							200		30	120	40	
Chloroform							140		0.2	60	16	0.043
Ethylbenzene	1 - 100	22000 (GV) (1 year)		1000 (24 hour)				1000		4500	3500	
Formaldehyde	0.001 - 0.020	100 (GV) (30 min)	15 (annual)	65 (24 hour)			50	40	0.08	20	12	0.08
Hydrogen Sulfide	0.15	150 (GV) (24 hour) 7 (GV) (30 min)				42 (1 hour)	40		10	180	110	
Methyl tert-Butyl Ether (MTBE)				7000 [24hr]			7000	3000				
Methylene Chloride							2000	1000	2			
Stylene	1 - 20	260 (GV) (1 week) 7 (GV) (30 min)		400 [24hr]			20000	1000	100	3500*	1700*	
Tetrachloroethene [PERC]										11000	770	2.1
Tetrachloroethylene	1 - 5	250 (GV) (24 hour) 8000 (GV) (30 min)			200		1000		0.2			
Toluene	5 - 150	260 (GV) (1 week) 1000 (GV) (30 min)		2000 (24 hour)			4000	400	300	4700	3000	
Trichloroethylene	1 - 10						10000	500	0.5			
Vinyl Chloride	0.1 - 10			1 (24hr) 0.2(annual)	10	26(24hr)	1000	100	0.2	17	4.4	0.012
Xylene	1 - 100	4800 (GV) (24 hour) 870 (GV) (1 year)		2300 [24hr]			4000	3000	100	5500	3500	

In conclusion, priority VOCs as well as toxicological data was then presented to the policy makers. The National Environment Board of Thailand notified the ambient standard of 9 VOCs in September 2007. The annual average values of designated VOCs are shown in Table 10.

Table 10 Ambient VOCs annual standard

VOCs	Ambient annual average (µg/m^3)
Benzene	1.7
Vinyl Chloride	10
1,2-Dichloroethane	0.4
Trichloroethylene	23
Dichloromethane	22
1,2-Dichloropropane	4
Tetrachloroethylene	200
Chloroform	0.43
1,3-Butadiene	0.33

5 Establishment of Stationary Source Emission Standard and Control Measures

5.1 Definition of emission standard

Emission standards : when the government set emission/effluent standards concerning air and water, it fully considered scientific factors in order to examine the applicability of pollution control technologies. Emission standards are set and revised to provide the targets for attaining environmental standards.

Section 55 of NEQA prescribes an emission standard as: “emission or effluent standards for the control of wastewater discharge, polluted air emissions, or discharge of other wastes or pollutants from point sources into the environment, in order to meet the environmental quality standards set by virtue of the NEQA for the conservation of national environmental quality.

5.2 Particular sources of VOCs to be controlled

Point source emits VOCs related to environmental quality standards, was specified to apply emission standards, and its scale applied also was determined in consideration of actual situation of utilization of VOCs. Potential emission source of individual VOCs has been classified. The emission from industrial source was analyzed in order to quantify the contribution of their emission for the proper controlling and regulation.

5.3 Principle of setting up emission standards of VOCs

Approach of setting up the emission standards of VOCs are as follows:

- Identification of particular facility related to selected VOCs.
- Current situation of its emission from those facilities
- Examination of technical and economic feasibility on measures for emission reduction
- Predictions of concentration of VOCs in a surrounding area due to VOCs' emission by applying a diffusion simulation model
- Emission limits: mass emission rate, process weight limit, concentration, design standard
- Monitoring and analysis method for industrial emission standards and control measures
- Monitoring and report criteria

The VOCs project examined the emission standards of VOCs based on following five view points.

- Monitoring data;
- Emission estimation;
- Source sampling & analysis;
- Air diffusion modeling;
- Other country standard, Best Available Technology(BAT)

5.4 Example of establishment of VOCs emission standards: vinyl chloride monomer (VCM) and 1,2-dichloroethane (EDC)

(1) Characteristic of VCM and EDC

The following table shows characteristic of VCM and EDC. The boiling points of VCM and EDC are -13.8^{o}C and 83.5^{o}C, respectively. VCM is gaseous under normal condition that is 25^{o}C and 1 atm. On the contrary, EDC is liquid under normal condition. Both VCM and EDC are explosive.

Table 11 Characteristic of VCM and EDC

VOCs	Vinyl Chloride Monomer (VCM)	1,2-dichloroethane (EDC)
Molecular formula	C_2H_3Cl	$C_2H_4Cl_2$
Molar mass	62.498g/mol	98.96g/mol
Appearance	Colorless gas	Colorless gas
Density and phase	0.91 g/cm^3, liquid	1.253g/cm^3 , liquid
Melting point	-154 ^{o}C	-35 ^{o}C
Boiling point	-13.8 ^{o}C	83.5 ^{o}C
Explosive range	0.6~33.0%	6.2~16.9%

(2) Health risk of VCM and EDC

In 1974, cancer incidents were reported among workers who had been employed by the PVC industry in the U.S., and VCM were reported to be responsible. As a result of an epidemiological survey, a very rare type of cancer (angiosarcoma) was identified in workers who had been exposed to high concentrations of VCM for an extended period of time.

For reference, the IARC, which is a branch of the WHO, classified VCM as substance belonging to Group 1 (Carcinogenic to humans) in June, 2001. It also classified EDC as substance belonging to Group 2B (Possible carcinogenic to humans) in 1999.

(3) Ambient monitoring

- EDC Monitoring

Ambient air quality standard of EDC is 0.4 μg/m^3. According to the ambient monitoring in Bangkok and Map Ta Phut from September 2006 to August 2007, annual average of three monitoring sites in Map Ta Phut outreached the ambient standard. The monitoring sites are No19 Map Ta Phut Health Centre, No21 Map Ta Phut New Town Station and No 24 Banplong Community. EDC is primarily used in the production of VCM; 99% of total demand in Canada, 90% in Japan, and 88% of total production in U.S. are used for this purposed (IARC, 1999). Therefore, it suggests that EDC is emitting from facilities related to VCM manufacturing process in Map Ta Phut.

- VCM Monitoring

Ambient air quality standard of VCM is 10 μg/m^3. According to the ambient monitoring in Bangkok and Map Ta Phut from September 2006 to August 2007, monthly monitoring data which went beyond the ambient standard is only one. It was data in December of 2006. Regarding annual average data, no monitoring sites came to outreach the ambient standard. Three monitoring sites, one in Bangkok and two in Map Ta Phut, went beyond 1 μg/m^3. It is believed that VCM is emitting from facilities related to PVC manufacturing process. However, reason why VCM concentrations were relatively high at special monitoring sites in Bangkok was not clear in this moment. It might come from mobile sources or there is an unknown emission source.

(4) Emission standard establishment

The VOCs Project had conducted detailed inventory survey in 2007. The purpose of the survey was to identify the emission sources and estimate the amount of emissions in the specific area where EDC, VCM and PVC producers located. Then, the result of detailed survey, the meteorological data and VOCs ambient monitoring data were undergone to the diffusion model to establish the emission standards. The emission standards in other countries and the best available technology were also taken into the consideration. Then, strategy for drafting air quality emission standard was developed as present in Table 12.

Table 12 Strategy for drafting emission standards

Emissions	Strategy
Plant	● Total control, process weight limit ● Many emission sources, various characteristics of the emission
Tank Farm	● Design and structure control ● Internal floating roof tank or End of pipe technology equipment required
Fugitive	● Check periodically ● Prevent fugitive emissions
Total	● Relationship between ambient standard and emission standard should be examined

(5) The draft of VCM and EDC emission standards

As the pilot standards, the team decided to set the emission standards to control the emission from relevant plant. The factory that has to follow the emission standards had defied as the following.

- Definition of factories to be regulated

Facilities to be regulated are defined as follows.
(a) This definition applies to plants which produce:

- EDC by reaction of oxygen and hydrogen chloride with ethylene,
- VCM by any process, and/or
- One or more polymers containing any fraction of polymerized vinyl chloride monomer.

(b) This definition applies to facility which store

- EDC
- VCM

(c) This definition does not apply to equipment used in research and development.

- Original draft of emission standards

Originally the expert presented the emission standards of process weight limit at VCM plant, Polyvinyl Chloride (PVC) resin plant and paste PVC plant as in Table 13.

Table 13 Original emission standards of EDC and VCM

	EDC	VCM
VCM Plant	● Process weight limit 20 g/t-EDC	● Process weight limit 100 g/t-VCM
PVC Resin Plant	—	● Process weight limit 100 g/t-PVC Resin
Paste PVC Plant	—	● Process weight limit 2,000 g/t-Paste PVC
Tank Farm	● Internal Floating Roof Tank or ● EOP Technology equipment required	

- Revised draft of emission standards

PCD insisted that idea of process weight limit is not familiar in Thailand. In addition to process weight limit, they thought concentration limit should be necessary. Then PCD and the expert revised the standard as in Table 14. PCD is making hearing with three factories and IEAT based on these revised emission standards.

Table 14 Revised emission standards of EDC and VCM

	EDC	VCM
VCM Plant	● Concentration limit Emission of all vent should be lower than 5 mg/Nm^3 (in case of combustion process : concentration should corrected to 7% O_2) ● Process weight limit 20 g/t-EDC	● Concentration limit Emission of all vent should be lower than 5 mg/Nm^3 (in case of combustion process : concentration should corrected to 7% O_2) ● Process weight limit 100 g/t-VCM
PVC Resin Plant	—	● Concentration limit Emission of all vent should be lower than 26 mg/Nm^3 (in case of combustion process : concentration should corrected to 7% O_2) ● Process weight limit 100 g/t-PVC Resin
Paste PVC Plant	—	● Concentration limit Emission of all vent should be lower than 26 mg/Nm^3 (in case of combustion process : concentration should corrected to 7% O_2) ● Process weight limit 2,000 g/t-Paste PVC
Tank farm	● Internal floating roof tank or ● End Of Pipe (EOP) technology equipment required(in case of EOP technology equipment, concentration of exhaust gas from the equipment should be lower than 36 mg/m^3)	

- Sampling and analysis
  - Sampling and analysis procedures of EDC and VCM is stated in 3.2

- Registration and reporting

The defied factories should report registration of facilities and analysis and/or amount of emissions to competent authority four times per year.

Required reporting items are as follows.

- Registration of facilities
- Emissions calculation
- Abnormal condition of the process and emission control equipment

5.5 Example of establishment of VOCs control measure: benzene emission from gas stations, gasoline storage tanks and transportations

Gas stations, gasoline storage tanks and transportations in Bangkok are also contribution for benzene emission in ambient air. High concentrations of benzene emission can caused of ozone forming and any health effects. Therefore, appropriate control strategy need to be implemented in order to control and manage benzene emission. From the 2nd phase emission inventory study shown in Figure 11, 15.9 % of benzene emission emitted from those 3 of sources: gas stations, gasoline storage tanks and transportations. The benzene emission loading was evaluate from gas stations, gasoline storage tanks and transportations in Thailand using fuel consumption and number of those facilities.

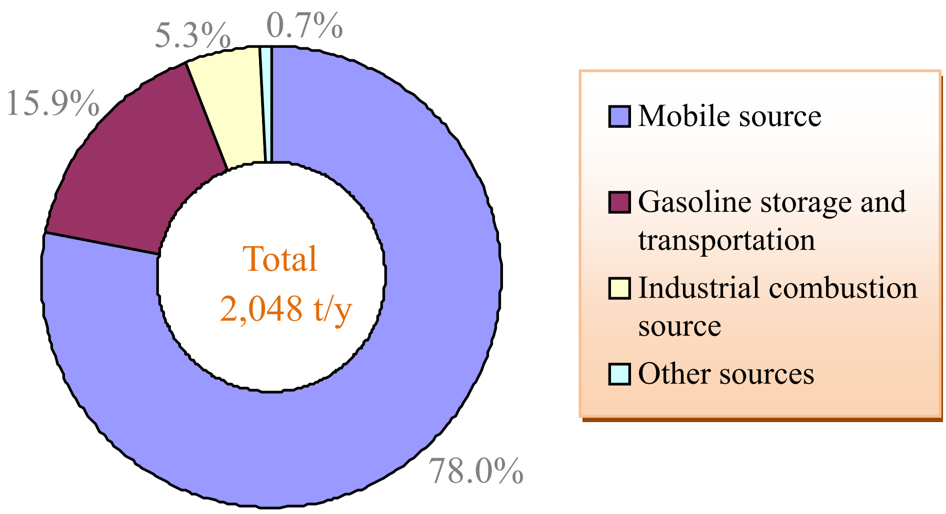


Figure 11 Emission inventory of benzene in Thailand in 2006

Gas stations have the function of receiving petroleum products transported from oil depots etc., storing them and delivering them to end users by means of filling operation. In other words, they are gas stations.

In general, there are two ways for gas stations to receive petroleum products from tank lorries to the underground tanks of gas stations. One is the remote access method and the other is the direct access method.

(1) In the remote access method, all of the inlet ports for petroleum products are located at one site for efficient use of the available land on the premises. This method is increasingly used for new gas stations.

(2) The direct access method can be frequently seen at older gas stations and the inlet ports for petroleum product are located immediately above the underground tanks.

Underground tanks are used to store such fuel oil as gasoline, kerosene and gas oil, etc. Compared to outdoor tank storage stations, their scale is much smaller. The storage capacity of each tank at gasoline stations is generally 10 kilolitres or less. An underground tank has a vent pipe and the vapour above the liquid level in the tank is emitted through this vent pipe as the liquid level rises with the reception of a petroleum product. As in the case of gas stations, an underground tank is seldom empty when receiving a petroleum product because of its constant use to deliver such a product. For this reason, vapour-liquid equilibrium is believed to exist inside the tank under normal conditions of use and vapour of which the concentration is near the saturation concentration is emitted at the time of receiving supply. The breathing loss at underground tanks resulting from the emission of a stored substance via the vent pipe due to the repeated expansion and contraction of the vapour zone can mostly be ignored because these tanks are seldom affected by changes of the temperature and solar radiation which cause the said expansion and contraction.

The filling of an automobile with gasoline or gas oil at a gas station is conducted by inserting the nozzle attached to the pump into the fuel port. The standard filling speed is approximately 40 litres/min for gasoline and 90 litres/min for gas oil. Filling operation is generally completed in a short period of time and hydrocarbon emission occurs due to a rise of the fuel level inside the fuel tank of the automobile and bubbling of the fuel oil during filling operation.

Control strategy to control VOCs emission

(1) Proposed Emission Standards

Design Standards for bulk tank and gas Station
Bulk Tank; Equip Vapor Recovery Unit (VRU) I-A which efficiency is 85% or more
Gas Station; Equip VRU I-B which efficiency is 85% or more and/or VRU II which efficiency is 95% or more

(2) Gasoline Vapour Recovery System (VRU Installation)

Stage I: Bulk terminals, tank trucks and service stations

1-Stage VR Units are very simple; these VR Units have only two motors. The single-stage sliding vane compressor has a motor and the absorber fuel supply pump has a motor. In cases where rack supply pumps operate at pressures over 65 psig and this flow source can be used, a flow control valve then replaces the absorber pump. A 300 cfm system has nameplate 70 hp. Since the Units run only when processing vapor, operation and maintenance costs are dramatically lower than carbon and/or refrigeration units in operation.

Stage II: Service stations

2-Stage units are more complicated than the 1-Stage unit, but still much simpler than carbon and refrigeration units. These units have again typically only two motors and various pressure and flow control valves. The two-stage sliding vane compressor has a first- and second-stage compressor with a common motor and the absorber fuel supply pump has the second motor. A 300 cfm system has 120 nameplate hp. Maintenance costs are dramatically lower than any carbon or refrigeration unit in operation as the systems only run when they are processing vapor.

(3) Inspection Program and Record Keeping

Inspection Program; Verify efficiency of VRU once every 2 months
Record Keeping; Volume of fuel filling a refueling
Efficiency of VRU

6 Establishment of Mobile Source Emission Guideline and Control Measures

In addition to the NAAQS , Ministry of Natural Resources and Environment by the PCD also regulates VOCs ambient standards for 9 species which are benzene, 1,3-butadiene, chloroform, dichloromethane, 1,2-dichloroethane, 1,2-dichloropropane, tetrachloroethylene, trichloroethylene and vinyl chloride. Most of VOCs originate from human-made sources, including on-road mobile sources, non-road mobile sources (e.g. airplanes), area sources (e.g. dry cleaners) and stationary sources (e.g. factories or refineries). For VOCs emitted from mobile source in Bangkok, benzene and 1,3-butadiene have been concerned and monitored mainly.

The VOCs emissions inventory for Bangkok was complied for several current and future scenarios. The inventory is based on recent vehicle activity and fleet studies conducted in 2007. Projections of vehicle growth and fleet changes in Bangkok were assumed based on anticipated population growth. Base emission rates as emission factors were used from the experiments in the PCD Automotive Emission Laboratory. Although the current emission factors used to calculate the emission inventory based on current situation of vehicle activity and fleet studies. Technology distribution and vehicle driving patterns have been concerned.

6.1 Mobile source emission guideline and control measures

As resulted in the 2nd phase VOCs emission inventory study shown in Figure 12 and Figure 13, benzene and 1,3-butadiene are 2 mainly VOCs emitted from mobile source which contribute for 77 % and 68.4 % respectively.

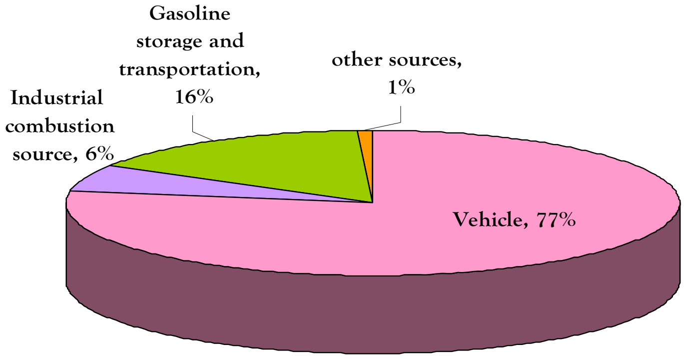


Figure 12 Emission of benzene in Bangkok

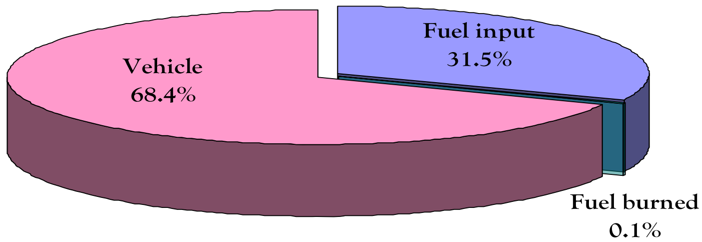


Figure 13 Emission of 1,3-butadiene in Bangkok

To control emission of total VOCs from mobile source, appropriate control strategies have been proposed as following:

(1) New vehicle emission standard

Thai government revised the regulations regarding motor vehicle pollution which contain more stringent standards for the new vehicles. After January 1, 2012 all new gasoline vehicles and light duty diesel vehicles are required to comply with EURO 4 standard. These vehicles shall be designed to operate on low sulfur content fuel or with sulfur content less than 50 ppm in fuel.

In addition, the vehicles which emit the emission less than regulation enforced or low emission vehicles including eco-car will be promoted by using economic tools such as tax incentive and subsidy.

(2) In-use vehicle emission standard

A mandatory periodic emission inspection program is planned nationwide. The test method of vehicles inspection will be revised from measuring at idle test to loaded test methods (IM/240) or remote sensing. The loaded test emission method is designed to represent actual emission from each vehicle. The in-use vehicle performance test included retrofitting catalytic converter for poor performance vehicles. The first inspection should be shortening than 7 years. The incentive measure to reduce import tax and subsidy for new vehicles is promoted.

For effective emissions control measure of the in-use vehicles, fulfillment of roadside inspection should be established. The inspection of vehicle is important to control the VOCs emission of vehicles. Because the vehicles are VOCs emission source which can be repaired the inspection of vehicles will force owners of the vehicles to maintain the engines which will control the VOCs pollution (PCD, 1996).

(3) Fuel quality standard

After January 1, 2012, the quality of gasoline and diesel fuel is required to comply with EURO 4 standard. The maximum sulfur content of gasoline and diesel fuel is limited to 50 ppm.

(4) Traffic control

The traffic management should be complying in order to improve traffic flow rate. Increasing and improving the mass transit system, road network and traffic signal control system will reduce emissions from vehicle accordingly.

6.2 Principle of setting up mobile source control measures

Selecting priority VOCs needs a broad view. Measures for VOCs have two distinctive aspects; measures for HAPs and measures for Suspended Particular Matters (SPM) and photochemical oxidants. The focus of measures may change during mid- and long-term policy development. Furthermore, depending on the type of VOCs, measure and its approach may differ from the other type of VOCs, and effectiveness of the measures needs careful review. Hence, there are four criteria for selecting the priority VOCs;

• Viewpoint on health risk (such as carcinogenicity of specific VOCs)
• Viewpoint on precursors to SPM and photochemical oxidants
• Viewpoint on environmental concentration and amount released
• Viewpoint on effectiveness of the measures (economical efficiency and their benefits)

To success on VOCs emission control and management focusing on mobile source, a well cooperation among relevant organizations should be concerned. Therefore, a steering committee should be setting up responsible for the establishment of VOCs guideline and encouraging for public participation as well. The relevant organizations are Ministry of Industry, Ministry of Energy, Ministry of Transportation and Ministry of Natural Resources and Environment.

7 Policy Framework Management

7.1 Prime keys

Recently, VOCs are considered to be one of the important emerging pollution issues in Thailand. From the monitoring network of VOCs, some VOCs have been observed both in the urban area and in the industrialized area. Several organic compounds are included in the VOCs group; therefore, prioritizing of VOCs is necessary for preparing appropriate control strategies and implementation plans. Some VOCs are known to cause heath risk to the public. Therefore, VOC emission source reduction is important. Strategic planning for source control is necessary to reduce emission. Systematic monitoring network is important to assess the air quality status as well as the outcome of control strategies.

In 2007, Thailand's NAAQS for VOCs has been promulgated and consisted of 9 VOCs. Consequently, VOCs management firstly takes notice on these 9 compounds. To identify specific VOC problem in any area, systematic ambient air monitoring network is necessary to provide input information to evaluate the situation. In addition to the monitoring system for the regulated 9 VOCs, the other VOCs should also include in the routine monitoring to provide the information of the tendency of health risk situation, to reassess the situation and to amend the VOC national standards (if necessary). Expansion of VOCs monitoring network to cover more potential area is needed. Strengthening the capacity of both personnel and organization in relevant aspects such as sampling and data analysis, data interpretation and situation assessment should be carried out. Data dissemination and public education to enhance public knowledge are required for a better understanding. For emission source control, source identification is the key factor to support control strategy. Source inventory should be investigated particularly in a specific area which has been observed VOCs in the environment or in a high potential area of VOCs emission. Emission standards and source control are the other key measures to control VOCs emission.

The target areas for VOCs management consist of urban areas such as Bangkok and major cities, and industrialized area including Industrial Complex in Map Ta Phut.

The principal goal of VOCs management is to achieve NAAQS for VOCs. Comparable to general air quality management, the objectives of VOCs management are to maintain air quality in the attainment area and to carry out necessary measures for VOCs emission reduction in non attainment area to minimize the health risk posed by VOCs.

The specific objectives of VOCs management plan should include:-

1) To strengthen the capability of the existing VOCs monitoring system;
2) To examine the local source of VOCs particularly in the potential polluted areas;
3) To determine possible source control strategies;
4) To develop or modify environmental and emission standards as necessary;
5) To promote research and development in emission control and alternative technologies; as well as health risk assessment study; and
6) To provide public knowledge and data dissemination as appropriate.

7.2 Strategies of VOCs management

The strategies of VOCs management should include:-

1) Capacity building for sampling, monitoring and analysis of VOCs;
2) Emission inventory of specific VOCs (local source inventory in target areas);
3) Develop or modify environmental standards and screening level based on present information;
4) Develop or modify emission standards and source control measures of the specific VOCs including fugitive emission control;
5) Support cleaner technology for VOCs minimization, substitution and process modification;
6) Technology transfer for achievable control technology and alternative technology;
7) Research and study of health risk posed by VOCs in target areas; and
8) Public education, participation and involvement.

7.3 Challenge

At present, VOCs management has facing several challenges. Sampling and analysis is still limited to some laboratories mainly in the government agencies or academic institutes and some private laboratories. Since there are many compounds in VOC group, analysis is complicated in some cases. Sampling and analytical techniques are challenges. To determine VOCs as a total VOCs or speciated VOCs are needed to be chosen depending on the study objective. Emission control might be needed data of both total and speciated VOCs, if available. On contrary, air quality status assessment which intends to evaluate the potential health impacts should be examined based on specific VOCs monitoring report.

VOC' s understanding is still unclear in some aspects especially in health risk. Public is generally viewed VOCs as severe hazard to the community even though not all VOCs are considered to pose health risk as a carcinogenic, mutagenic agent or others. Many common VOCs are already used by the public in daily life such as solvent and cleaning solution, but people might not aware of such cases. Public perception is important. Information and monitoring data including rationalization is needed to be simplified for easy understanding. Development of public awareness as well as data dissemination protocol should be enhanced to support the relevant issue.

Collaboration among stakeholders including government, industrial, and public sector to tackle VOCs management is also challenged. Each stakeholder group has its own interest. Some are common and some are not. Their involvements to present and discuss their views and concerns related to VOCs management should be encouraged. Each group might have different ways to express the interest for making decisions or actions. Examples of stakeholders are neighborhood resident, property owners, community organizations, business owners/operators, or special interest groups.

8 Conclusion and Recommendation

8.1 Conclusion

The determination of significant VOCs which are not yet designated environmental standards or screening levels should be taken into consideration regarding the necessity and current VOCs situation in Thailand. Information of emission source inventory and standards is necessary to support source control strategies. In order to assess the potential impact of VOCs on human health, more researches are needed. Data related to public health should be collected systematically. A study on risk assessment should be promoted by the Government initiatives. Relationship between health impact, health risk and air quality particularly ambient air VOCs level should be studied and assessed. Research and development of counter-measure technologies are also necessary as well. Existing technologies should be examined for appropriated application to Thailand. Priority of control activities has to be defined to provide the most beneficial outcome to reduce VOCs emission which will result in minimizing health risk of people and efficient use of limited resource and budget allocation.

8.2 Recommendation

Further studies should be considered the following items:

8.2.1 Voluntary control of VOCs by point Sources

In general, there are many point sources releasing VOCs at a facility, and it is difficult to control all emission points by regulation of emission standards. It is also likely that many VOCs not set as environmental standards but still are considerable by environmental concern. Therefore, owner who owns a facility that is not controlled by the regulation but emits prescribed VOCs to the environment should be obliged to reduce its emission with the perspective of voluntary control as launch by the idea of Corporate Social Responsibility (CSR). It is desirable that technical guidelines, which develop to guide the target industry to reduce emission of those VOCs, will be set in cooperation with them.

Voluntary control, however, often receives the criticism about its practicability. Voluntary control would not be successful to reduce emission load without any regal-binding. Therefore, its activities should take a legal binding by develop a rule of report duty about emission of prescribed VOCs and provide an authorized technical guideline in order to emission reduction. Self monitoring and periodically report to the regulatory body is the subsequently activity which might be extended from the voluntary control program.

It would be expected that the industrial associations would take a set of technical guideline and implement an action plan to emission reduction by each industrial associations. Taking a responsible care by chemical industries is anticipated.

8.2.2 Future direction for enhancing VOCs control

Revision of environmental standards and addition of other VOCs

The designated standard should be revised according to update information on health impact and current situation of individual VOCs compounds. Standards can also set up for specific area where appropriated.

For those VOCs substances with potential health risk that are not designated for regulation at present, effort should be made in consideration the necessity of setting up specific regulation for them taking into account the situation of the country.

Development of environmental monitoring network

In order to evaluate the status of VOCs in the country, environmental monitoring network for VOCs should be set up. Monitoring sites should cover different types of land use such as community, industrial and roadside area. Design of monitoring network should be set up in order to evaluate the spatial and temporal variation of VOCs in the country. In addition to the regulated VOCs, carbonyl compounds and PAH monitoring network are also suggested.

Control of total VOCs

Effort should be made also for the controlling of total VOCs in order to cope with the problem related to photochemical oxidant.

Research and study of alternative control strategies

Control techniques such as alternative fuel to reduce emission should be encouraged to study. Control strategies or recommendation of best practice of specific VOCs control should be reviewed and syndicated.

Development of VOCs voluntary reduction management policy

The VOCs voluntary reduction management policy should be prepared in order to establish the mutual understanding among concerned agencies/organizations.

Criteria of the policy should be set up for the evaluation purpose as follows:

- Clear objectives and measurable results
- Define roles and responsibilities

The government should provide support to participating firms to aid in achieving targets and timelines.

- Provision for consultation
- Public reporting
- Incentives and consequences

The government should support firms in developing pollution prevention plans, environmental management system, and help companies meet objectives of the agreement.

- Verification of result

Partners will develop a spot verification protocol for program results.

- Regulatory backstop

The government can use risk management tools to address VOCs regulation for substances which are not addressed in the voluntary environmental performance agreement.

- Continual improvement

Initiation of PRTR

In order to promote the collaboration among stakeholder in VOCs controlling, the pollutant release and transfer registration (PRTR) should be developed.

Establishment of PRTR System

PRTR is commonly practice to manage a release inventory of chemical substances related to environmental concern in OECD member courtiers. A PRTR system is usually calls for forms to report periodically on their releases and transfers of a variety of substances of interest. This information is made publicly accessible bearing in mind legitimate needs for business confidentiality. The results provide comparative quantitative information among reporters and have stimulated investors and other affected and interested parties to asks question of firms whose performance is significantly below normal for their sector and to demand improvement.

A PRTR thus provides a powerful incentive for reporters to cut releases and transfers. It is believed that PRTR have had a stronger impact than many regulatory programs even though a PRTR set no improvement goals mandatory.

PRTR is strongly required by neighbor's right to know what kinds of chemical substances factories utilize. Global industries, which use hazardous chemical substances, tend to recognize social duty with informing its use to neighbor.

Countries that have initiated PRTR system have got two remarkable effects. The first is that it enables to make a precise inventory of chemical substances release. The second is that it brings pressure on facilities to reduce amount of release substances into environment.

Global industries located in Thailand already recognize PRTR and are ready to commence it. Therefore it is desirable that PRTR should be regulated in the near future.

In conclusion, one of the important lessons PCD has learned in dealing with VOCs is that no single level of government and no organization can work alone. Partnership is necessary to cope with the environmental challenges for the success of policy planning as well as its implementation. Therefore, it is important for the government to confirm the necessity of the countermeasures. When it comes to health and the environment, Thai people expect all levels of Government to act. People have the right to expect clean air and that there will be adequate monitoring systems, adequate regulations and that the laws and regulations will be enforced.

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Annex

Development of Environmental and Emission Standards of Volatile Organic Compounds in the Kingdom of Thailand

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