THE IMPACT OF A "BAN" ON THE USE OF PCB IN CAPACITORS

SUMMARY

The PCB-impregnated capacitors produced in the U.S. annually have a major effect in reducing the electric current which must be generated to serve industrial and public needs for power. The annual saving may be viewed as equivalent to 44 large electric generators, each of the 1000 megawatt size, which do not need to be installed – an aggregation comparable to the nation's annual growth requirement.

The following consequences will result from a PCB effluent standard so strict as to have the effect of a ban:

- If the industry is forced to convert to a non-PCB impregnant, low dielectric-constant liquids, such as mineral oil, offer the best initial fallback position.
- Mineral oil would roughly double the pounds of capacitor grade dielectric paper and aluminum foil needed to produce present capacitor requirements. Current world-wide shortages of capacitor paper and foil would not support this.
- Materials availability would support about 50% of the current capacitor requirements using mineral oil.
- If adequate materials supplies were somehow attained, current capacitor manufacturing facilities could produce at best only 50% of capacitor unit requirements.
- Forced conversion to a non-PCB would result in capacitor shortages and major production cutbacks in the lighting, air conditioner, and power supply industries, and in their customer operations.
- Doubling the size of capacitors would present serious replacement problems where PCB capacitors had been used.
- Ballast and air conditioner manufacturers would have to redesign certain products to accept the larger capacitors.
- Power system stability would be adversely affected by a shortage of capacitors, and black-outs could be expected.
- New non-PCB's, such as G.E.'s Ecohol®, could subtantially reduce the magnitude of the materials problem. However, Ecohol® still represents an unknown risk in reliability and safety in the major consumer application areas. A mass conversion is not justified at this time.

0042850

TOWOLDMON0055248

I. INTRODUCTION

This is a forecast of the consequences of a PCB effluent standard which cannot be met by capacitor manufacturers, and consequently becomes an effective ban. It is submitted by the General Electric Company to assist in the determination of appropriate effluent standards relative to capacitor grade PCB.

II. BACKGROUND

In the U.S., an impregnated capacitor can be very simply described as:

- Aluminum foil (around 0.22 mil thick) which serves as the electrodes.
- Sheets of dielectric consisting of capacitor grade paper or combinations of this paper with plastic film. The dielectric is positioned between the aluminum electrodes as it is wound into rolls.
- An appropriate liquid impregnant.
- A sealed container for the capacitor roll and impregnant.

The choice of dielectric materials, the number of sheets, and their thicknesses are all the result of many years of research and testing for reliability and consumer use safety. About 90-95% of liquid impregnated capacitors contain PCB, and are critical components to the fluorescent and mercury vapor lighting, the electric motor and air conditioning industries, and power transmission by electric utilities. The dielectric paper and plastic films (primarily polypropylene), aluminum foil, and PCB have all been specially developed and controlled for capacitor use and are produced as "specialty" materials.

Capacitor grade PCB is Aroclor 1016, manufactured only by Monsanto. It is primarily trichlorobiphenyl. It differs from all previously used formulations in that practically all of the higher boiling homologs--which have given rise to reports of PCB in wild-life residues--have been removed. Introduced in 1971, it is now the only PCB used by the U.S. capacitor industry. Compared to other formulations,

- it has a higher degree of biodegradability;
- it has a lower degree of persistence in the environment.

TOWOLDMON0055249

III. CONSEQUENCES OF A "BAN" TO THE CAPACITOR INDUSTRY

This evaluation addresses itself to the situation wherein the capacitor industry is effectively banned from using PCB's.

A. Alternative Impregnants

Alternative impregnants are unproved in the U.S. capacitor industry. Mineral oil was the major impregnant before PCB's, and it appears to represent the best immediate fallback position. Even though mineral oil technology would put the industry back 30-40 years in progress, it still represents the best combination of known technology, materials availability, and reliability. For these reasons, mineral oil impregnant has been selected at this time as the basis of comparison with PCB's.

There have been a number of very active programs to develop non-PCB impregnants, especially after the environmental problem was recognized. These programs are continuing in the industry, and it is expected that an improvement will be found which would be more acceptable than mineral oil. As an example, General Electric is using a phthalate ester as the base for its non-PCB Ecanol impregnant. Ecanol capacitors are being sold commercially where special situations require a non-PCB. This is the case where U.S. electrical equipment, such as computers, is to be shipped to Japan where PCB's are banned.

Ecanol has a higher dielectric constant (see next Section B for discussion of this property) than mineral oil, and consequently will require less additional materials and manufacturing capacity. However, limited availability of the phthalate ester, lack of appropriate manufacturing facilities, need for developing new efficient manufacturing processes, and particularly the unknown factors of reliability and safety in the broad consumer use areas such as lighting and air conditioners are some of the problems that prevent a near-term substitution.

Unless considerable time for the development and evaluation of alternative liquids is permitted, the most suitable immediate stratagem appears to be the use of mineral oil.

The virtues of PCB impregnant and the disadvantages of mineral oil have been discussed in detail in a number of recent documents. Among these documents are the report of the Interdepartmental Task Force on PCB's (COM-72-10419), a paper titled, "The Role of Polychlorinated Biphenyls in Electrical Equipment" presented by General Electric on February 4, 1972, and NEMA's Official Standards Proposal CP-P1-1973/TR-P6-1973, dated January 25, 1973.

All of these documents have pointed out that PCB-impregnated capacitors are significantly smaller, more reliable and safer than mineral oil impregnated capacitors and that use of mineral oil would return

TOWOLDMON0055250

capacitor technology to its pre-1932 level. The substitution of mineral oil for PCB impregnants would necessitate redesign of end equipment to utilize the larger capacitors, large increases in capacitor manufacturing facilities (both plant and equipment) and would result in increased use of basic materials which are presently in short supply.

The following is an attempt to quantify some of the consequences related to the use of mineral oil as an alternative impregnant.

B. Capacitor Manufacturing Capacity

Mineral oil impregnated capacitor sizes relative to PCB capacitors are shown in Table 1.

Table 1 - Relative Size Comparisons

Types*	AROCLOR 1016	Mineral Oil
Small Industrial	1.0	2-2.5
Power	1.0	2.5-3.2

*Small Industrial - Used in lighting, air conditioning, motors and electronics.

Power - Large capacitors used by electric utilities and by industry for induction furnaces and power factor correction.

The dielectric constant of a capacitor's dielectric system is the ratio of its ability to store electrostatic energy relative to air. The dielectric constant of PCB impregnant is 5.85 while that of mineral oil is 2.25. Use of the lower dielectric constant mineral oil in a paper dielectric system, assuming no change in the thickness of the paper dielectric, would result in a capacitor which is 60% larger than the PCB impregnated design. Additionally, however, use of mineral oil requires that the thickness of the paper dielectric be increased to reduce the operating stress on the system if equal life and reliability are to be attained. In the case of lower voltage industrial type capacitors, such as those used in fluorescent ballast and air conditioning applications, the dielectric thickness must be increased 10 to 25%. In power capacitors operating at higher voltages, the dielectric thickness must be increased 25 to 40%. The larger increase in the high voltage units is related to the fact that corona initiation and extinction voltages of mineral oil impregnated dielectric systems are lower than those of PCB impregnated systems.

The approximate doubling of physical size results in about half the throughput of capacitors in existing manufacturing equipment. The capacitor industry currently has little if any excess capacity to handle this, even if adequate capacitor materials supplies are assumed to be available.

TOWOLDMON0055251

CONSEQUENCE - THE CAPACITY AND OUTPUT OF THE CAPACITOR INDUSTRY WILL BE CUT APPROXIMATELY IN HALF.

C. Capacitor Materials Availability

The following Table 2 estimates the capacitor industry requirements for paper, foil, and impregnant based on the currently used AROCLOR 1016 and for mineral oil.

Table 2 - 1974 Capacitor Materials Requirements (lbs. in millions)

	AROCLOR 1016	Mineral Oil	% Change
Paper	26	52-65	100-150%
Al Foil	18	32-36	80-100%
Impregnant	26	35-42	35-60%

There is a worldwide shortage of capacitor grade paper and aluminum foil. The capacitor paper supply is expected to continue at its present level of availability. Mineral oil impregnation will require at least twice the amount of materials to produce the same capacitance as with PCB's. Using the most optimistic of the above numbers, the total capacitor industry's requirements of Kraft paper dielectric, all of it using imported pulp for its production, would increase by 2 to 2.5 times and its requirements for aluminum electrode foil would increase by 1.80 to 2 times.

Total industry requirements in 1974 for paper dielectric in PCB impregnated capacitors is estimated at 26 million pounds. Based on recent experience, this requirement is the limit that suppliers of this type of paper can produce with existing equipment. Adding facilities to more than double the present domestic output of paper is a task that could not be completed in less than 4 to 5 years and the total investment required by the paper manufacturers is estimated to exceed $200 million. It is questionable that the paper industry would make this investment, facing the probability that future impregnant and design developments would negate its need.

Aluminum foil is also in short supply. Some investment in foil-rolling equipment is already under way at General Electric to alleviate the shortage, but an adequate continuing supply of reroll aluminum stock from which the thin gauges of aluminum electrode material are made cannot presently be assured.

The supply of dielectric-grade mineral oil required to replace PCB impregnants is also unassured. Doubling the size of capacitors would

TOWOLDMON0055252

approximately double the volume of impregnant required. The sole manufacturer of dielectric-grade mineral oil has recently announced that its manufacture is being discontinued. The feasibility of supplying the capacitor industry on a timely basis with 35 million pounds annually, starting from a production rate of zero, is doubtful to say the least.

CONSEQUENCE - THE CAPACITOR INDUSTRY WOULD BE ABLE TO SUPPLY ONLY ABOUT 50% OF THE CURRENT CAPACITOR DEMAND BECAUSE OF MATERIAL SHORTAGES.

D. Costs

U.S. impregnated capacitor sales for 1974 are shown in Table 3.

Table 3 - Estimated 1974 Total Impregnated Capacitor Sales

	$ Millions
Small Industrial	100
Power	55

About 90-95% of these are PCB impregnated capacitors. It is estimated that the cost of capacitors would increase by at least 100% in going to mineral oil. It is likely that there would be an added inflationary force with demand far exceeding supply.

CONSEQUENCE - COST OF CAPACITORS WOULD AT LEAST DOUBLE. AT CURRENT PCB CAPACITOR SALES LEVELS, THIS WOULD ADD ABOUT $145 MILLION IN CAPACITOR COSTS TO EQUIPMENT MANUFACTURERS. TO THIS WOULD BE ADDED AT LEAST ANOTHER $200 MILLION IN COSTS AT THE END-CONSUMER LEVEL.

E. Reliability and Warranty

The life expectancy of capacitors exceeds 10 years for lighting applications and more than 20 years in electric utility power transmission applications. Although capacitors are considered long-lived products, there is an ever present danger of short life and early failure. This can be caused by a number of factors such as poor process control, materials quality, mis-application, and new product introduction with inadequate knowledge and experience of reliability.

The General Electric Company warrants its capacitors for one year, and has extended this warranty where capacitor failures have been excessive and due to shortcomings in capacitor quality. The major reliability and warranty problems lie in the small industrial type capacitors

TOWOLDMON0055253

such as used for lighting, motors, and power supplies. The capacitor industry produces in the order of 100 million capacitors per year. The majority of these units sell in the price range of 50¢ to $4. The service cost for replacing a failed capacitor is $20 to $25. The in-warranty failure rate of General Electric capacitors during the first year is well under 0.5%. We believe that this reliability is typical of the capacitor industry in general. This performance has been attained after many years of developing the PCB capacitor, and establishing expected norms for failure rates and service life.

The capacitor industry historically is very careful in introducing product and process changes because small changes in failure rate, which are extremely difficult to determine without years of service experience and statistics, could result in excessive complaint and replacement costs. For example, Table 4 shows the replacement cost if the failure rate during the warranty period increased by different levels.

Table 4 - Replacement Costs for Early Failures

% of Annually Installed Capacitors Failing, over Existing Rate

Increase in Percentage Points	Millions Replaced	Cost at $25/Service Call
1.0	1.0	$25 million
2.0	2.0	$50 "
3.0	3.0	$75 "

In order to avoid the consequences of such warranty costs, the capacitor industry would design any new non-PCB products on the conservative side. However, there would still be a substantial risk associated with a mass changeover to a new impregnant, especially in the end-consumer product area, with essentially no experience on reliability and safety.

CONSEQUENCE - IF THE FAILURE RATE OF THE 100 MILLION CAPACITORS PRODUCED IN ONE YEAR WERE TO INCREASE BY 1 TO 3 PERCENTAGE POINTS, THE REPLACEMENT COSTS AT $25 PER SERVICE CALL WOULD RUN FROM $25 to $75 MILLION. THIS IS THE MAGNITUDE OF THE CAPACITOR INDUSTRY'S EXPOSURE IN GOING TO A NEW, UNTRIED IMPREGNANT ON A MASS BASIS.

IV. CONSEQUENCES OF A "BAN" TO CAPACITOR USERS

This section estimates the effect of a PCB ban on customers and users of capacitors.

TOWOLDMON0055254

CRITICAL COMPONENT AVAILABILITY

Capacitors are a critical and necessary component in end-user equipment, particularly in small industrial applications. Without the capacitor, the end product would not operate as designed. The capacitor shortage resulting from a "ban" on PCB capacitors would force a reduction by at least half from the normal production rate in the plants of capacitor users.

CONSEQUENCE - INCREASED LAYOFF AND UNEMPLOYMENT AS MANUFACTURERS ADJUST TO THE SHORTAGE.

ELECTRIC POWER SYSTEM SAVINGS

The magnitude of the energy levels under discussion can be assessed from the following:

- The U.S. capacitor industry produces the equivalent of 55 million kilovar per year.
- A kilovar is equivalent to at least 1 kilowatt of generating capacity (some estimates place this ratio of kilowatt/kilovar at up to 1.4).

About 20% of the capacitors are for replacement purposes, and the remaining 80% are for new service. Thus, 44 million kilovars are installed on new systems. Without these capacitors, the steam turbines and fuel requirements would be relatively unaffected, but generators would be larger to handle more current, and certain components of transmission and distribution systems (e.g., step-down transformers) would have to be larger to prevent burn-out. The additional generating capacity for 44 million kilovolt-amperes, priced incrementally, would amount to about $300 million; the additional transmission and distribution equipment would amount to about $700 million.

CONSEQUENCE - REDUCED AVAILABILITY OF CAPACITORS WOULD ADD FURTHER SUBSTANTIAL BURDEN TO THE ENERGY SUPPLY SITUATION.

POWER SYSTEM STABILITY

The preceding discussion indicates that electrical energy requirements could theoretically be met by using fewer capacitors and building oversize generation, transmission and distribution components (at a severe economic penalty). Such a system would be operating at low power factor -- or, in other words, the system would be carrying a large component of useless reactive volt-amperes in addition to the in-phase component that represents

TOWOLDMON0055255

energy delivery. Systems studies have shown (see Economics of Kilovar Supply by Campbell, Ros, and Tice, General Electric Company, June 20, 1972) that low power factor severely limits the capability of a power pool to import power from its neighbors during a loss-of-generation emergency.

CONSEQUENCE - CAPACITOR SHORTAGES WOULD MAKE LARGE POWER SYSTEMS SUBJECT TO CASCADING OUTAGES, OR "BLACK-OUTS."

SIZE AND REPLACEMENT

As pointed out earlier, the size and cost of mineral oil impregnated capacitors would be at least twice that of PCB capacitors. The lighting industry has designed their ballasts for the small size PCB capacitors. Approximately 20% of ballast capacitors are used in the replacement market. Many room air conditioners have no space for a larger capacitor if a replacement is required. The capacitor industry has continually moved to reduce the size of capacitors. Equipment manufacturers have taken advantage of these size reductions, and have no room for size increases. In certain cases, size limitations in the replacement market would force the scrapping of good light fixtures and air conditioners.

CONSEQUENCE - UNAVAILABILITY OF SMALL SIZE CAPACITORS WOULD FORCE THE EARLY OBSOLESCENCE OF GOOD, FUNCTIONAL EQUIPMENT.

General Electric Company
November 19, 1973

0042858

TOWOLDMON0055256