11. MTBE in petrol as a substitute for lead

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11.1. Introduction

A core notion of sustainability is that of futurity, whereby development in the present should not compromise the ability of future generations to meet their needs. Although it may not be possible for us to predict exactly what the needs of the future will be, we can respond by developing procedures for making robust and flexible decisions.

The goal of this case study is to examine how foresight, embodied in the precautionary principle, can lead to robust and flexible decisions that meet the needs of the present, but that can be adapted to meet the changing needs of the future. Recently there has been much debate over the use of methyl tert-butyl ether (MTBE) in petrol. Concerns in particular over the potential for contamination of groundwater supplies have prompted regulative authorities in western nations to reassess the risks associated with the use of MTBE.

After presenting the background, this case study will examine whether, at the time of MTBE's introduction, it would have been possible for the petrochemical industry and regulatory agencies to foresee that MTBE's physical, chemical and microbiological properties might eventually be deemed to be undesirable characteristics. The analysis will then be pursued to illustrate how foresight, in the form of some essential precautionary questions, can be applied to arrive at robust and flexible decisions.

The editing of this contribution was finished on 10 May 2001. Undoubtedly, the debate on MTBE will continue after that date and some aspects of the paper may be quickly outdated, but it is hoped that the paper will be a valuable contribution to the debate on the precautionary principle.

11.2. Lead in petrol

The toxicity of lead has been known to man since ancient times. The Romans were aware of the fact that the lead they used to make their utensils was poisoning people. The field of occupational health formally established the toxicity of lead in the 1800s. Already in the early 1920s, at the very beginning of the automobile industry, the wisdom of using lead in petrol was questioned. The debate was reignited in the 1960s. There developed a widespread consensus that a long-term trend of rising airborne lead concentrations was undesirable and it was eventually decided by most western nations to phase out lead in petrol. The gradual phase-out of lead in petrol began in the late 1970s and by the mid-1990s, most western countries had phased out lead in petrol. As a substitute to lead, the petrochemicals industry chose MTBE.

11.3. The MTBE case

The choice of MTBE as an engine anti-knocking agent to replace lead was made on the basis of a variety of advantageous properties: it is a low-cost and easily produced chemical with favourable transfer and blending characteristics; it can be produced at the refinery; it blends easily without separation in petrol; and the blend can be transferred through existing pipelines (Squillace et al., 1996).

Commercial production of MTBE started in Europe in 1973 and in the United States in 1979 (DeWitt & Company Inc., 2000). Italy introduced MTBE into petrol in the late 1970s, followed by other European countries, mainly in the mid-1980s. Total worldwide annual production was about 21.4 million tonnes in 1999. Roughly 3.3 million tonnes of MTBE were produced in the European Union (EU) in 1999. Some 2.3 million tonnes were used domestically, 1.1 million tonnes were exported and 0.2 million tonnes were imported (DeWitt & Company Inc., 2000). In 1995 MTBE was the third most produced organic chemical in the United States, at approximately 8.0 million tonnes per year (Johnson et al., 2000). MTBE is therefore a very high production-volume chemical.'

In the United States, the use of MTBE greatly increased following the 1990 amendments to the Clean Air Act requiring petrol 'oxygenates', such as MTBE or ethanol, to be added to petrol to reduce atmospheric concentrations of carbon monoxide (CO) or ozone. In January 1995 a special blend of petrol (dubbed 'reformulated gasoline', RFG) containing more MTBE was introduced for use in metropolitan areas in the United States that had severe ozone pollution problems. The present average MTBE content in RFG in the United States is around 11 % (NSTC, 1997; ENDS Env. Daily, 2000). There is also a large volume of conventional petrol sold in the United States, with a 2–3 % MTBE content.

In the EU, the application of MTBE was regulated by a 1985 directive (85/536/EEC) on additives to petrol, by which no Member State can prevent the use of organic oxygenates at concentrations lower than regulated by the directives. For MTBE this is a maximum of 15 % by volume. In 1999 in the EU, the average was 2.1 %, calculated from the total consumption figures on motor petrol and MTBE consumption. Actual concentrations of MTBE in petrol are highly variable, from 0 to 15 %, depending on petrol grade, oil company and country (Finnish EPA, 2001).

In the following sections we will attempt to summarise the relevant background information. As the aim is to examine the potential use of the precautionary principle, particular attention will be focused on areas of uncertainty within current scientific knowledge.

11.4. The benefits of MTBE

The original purpose of adding MTBE to petrol was to prevent 'knocking'. In addition MTBE or other oxygenates allow more complete combustion, which in turn leads to a reduction of CO emissions and a reduced emission of precursors for ozone formation (Koshland *et al.*, 1998). MTBE also achieves some elevation in the octane rating that alternative components of fuel such as benzene (a class 1 carcinogen) and other aromatics provide.

The role of MTBE in reducing air emissions has however been questioned. In this respect, it is important to distinguish between the general effects of using RFG and those associated specifically with the presence of MTBE in RFG. During the 1990s the United States saw a significant decrease in CO, low-level ozone and nitrogen oxide (NO_x) pollution in major cities using RFG. But, although the use of RFG results in significant reductions in automotive pollutant emissions relative to conventional petrol, studies have shown that CO, NO_x and volatile organic compound (VOC) emissions are not significantly affected by including MTBE in petrol (NRC, 1996). In a more recent report investigators concluded that the use of oxygenates in RFG had a negligible impact on ambient ozone concentrations (NRC, 1999). It has also been reported that the benefits of MTBE are decreasing, because these mostly apply to older vehicles, which are progressively being replaced by vehicles with more effective emission controls (Keller *et al.*, 1998b).

11.5. The impacts of MTBE

11.5.1. Persistency in groundwater

Concerns regarding the use of MTBE began to arise following studies indicating that MTBE moves at about the same speed as groundwater, making it a very mobile chemical (Barker *et al.*, 1990). These concerns became widespread following a report published by the US Geological Survey in 1996. Of VOCs analysed in samples of shallow ambient groundwater collected from eight urban areas during 1993–94, MTBE was the second most frequently detected chemical (Squillace *et al.*, 1996). Its solubility is in the order of 50 000 mg/l (milligrams per litre). A level of 10 % MTBE in petrol gives an equilibrium concentration in water of the order of 5 000 mg/l.

Persistency can be discussed in terms of physical, chemical or microbiological persistency. Uncertainties concerning the persistency of MTBE in soil and groundwater still remain. MTBE is rapidly photodegraded in the atmosphere. The available data in the sub-surface is limited, there being few well-documented reports concerning attenuation of MTBE in the field. Two studies have shown that biodegradation could not be detected in the groundwater under field conditions (Borden *et al.*, 1997; Schirmer and Barker, 1998). However, in subsequent laboratory studies, a very slow but measurable biodegradation was observed (Landmeyer *et al.*, 1998). Each of these three investigations occurred under aerobic conditions. The results of field investigations have shown that MTBE can be degraded anaerobically (Sufflita and Mormile, 1993; Mormile *et al.*, 1994; Yeh and Novak, 1994; Hurt *et al.*, 1999). But significant rates of MTBE degradation, either biologically (Eweis *et al.*, 1998a and b) or chemically have only been observed under laboratory conditions. Thus, because of its high solubility, mobility and persistency, MTBE poses a potential risk to groundwater.

11.5.2. Aesthetics

The aesthetic impact of MTBE contamination of groundwater is considerable. The potent terpene-like odour in water is detectable by people at very low concentrations. The odour threshold was determined to be 180 g/l (micrograms per litre) in Denmark (Larsen, 1997), but as low as 5 g/l in California (CAL-EPA, 1999). Based on current monitoring data, MTBE has been shown in some cases to be present in drinking water at concentrations exceeding taste and odour thresholds.

Relatively small amounts of MTBE may thus render large reserves of groundwater useless. When the taste and odour threshold in water is exceeded, contaminated drinking water is normally not used, requiring the utilisation of alternative supplies. When a large and important groundwater reservoir is contaminated the consequences can be remarkable, both in terms of cost and disruption.

Leaking underground storage tanks and spillage from overfilling the tanks are the main cause of groundwater contamination (Finnish EPA, 2001). The severity of the consequences may vary greatly between countries depending on, for example, the level of groundwater utilisation for drinking water and the condition of petrol station underground storage tanks. The number of pollution cases varies significantly from country to country in the EU. The EU risk reduction report (Finnish EPA, 2001) states that 'MTBE concentrations are currently not routinely monitored in groundwater. There is only limited data on MTBE concentration trends'. In a recent report to the European Commission (Arthur D. Little Limited, 2001) it is stated that 'little public information is available across Member States regarding monitoring of groundwater contamination by MTBE'. The report refers to unpublished data as a significant source of information, combined with data available from six Member States (Denmark, Finland, France, Germany, Sweden and the United Kingdom). It concludes that 'none of the findings indicated widespread or serious groundwater contamination by MTBE on the same scale as the USA'. However, according to the EU risk assessment study, the 'documented cases provide sufficient justification for concern that MTBE poses a risk for the aesthetic quality of drinking water from groundwater supplies'. The EU risk reduction report states: 'It is justified to conclude that MTBE is causing a risk for the aesthetic quality of drinking water.' (Finnish EPA, 2001)

11.5.3. Cancer

The classification of the carcinogenicity of MTBE is the focus of a continuing controversy (see Box 11.1.). The recent EU risk assessment concluded that MTBE was a borderline case for classification as a carcinogen (Finnish EPA, 2001). Nonetheless, the European Chemicals Bureau has decided that MTBE should not be classified as a carcinogen (Dixson-Decleve, 2001). For the purpose of this case study, it is noteworthy that the issue of carcinogenicity was not addressed until long after the marketing of MTBE as a high production-volume chemical: no comprehensive pre-marketing carcinogenicity testing was carried out. Even today, after in-depth investigations, uncertainties about the carcinogenicity of MTBE remain. The ongoing debate in the United States and the EU over the classification of MTBE illustrates the difficulty of dealing with uncertainty and borderline results.

11.5.4. Asthma

A similar debate is taking place regarding whether the use of MTBE in petrol has contributed to an increase in urban asthma. In an editorial published in the *Archives of Environmental Health* in February 2000 (Joseph, 2000), concerns were raised over epidemiological studies indicating an increase in the occurrences of asthma and other conditions of respiratory and/or inflammatory natures in the years following the introduction of MTBE to the cities of Philadelphia (Joseph, 1997) and New York (Crain *et al.*, 1994; Leighton *et al.*, 1999). The past five years have seen reports of alarmingly high rates (above 20 %) of asthma among children in several large cities on the east coast of the United States where MTBE was in use (Mangione *et al.*, 1997; McBride, 1996; Hathaway, 1999; Leighton *et al.*, 1999). It has been suggested that the increase in asthma is due to an unknown exhaust product of MTBE combustion entering the ambient air (Joseph, 1999; Leikauf *et al.*, 1995).

The University of California, Davis report states that it is plausible that combustion products of MTBE could exacerbate or even cause asthma, but that there have been no studies to date designed to address this issue. They conclude that 'there is little evidence at present either to implicate or exonerate MTBE as a cause or exacerbating factor in asthma' (Keller *et al.*, 1998b).

11.5.5. Other impacts

There are a few investigations indicating that MTBE may function as an endocrine disrupter (Williams *et al.*, 2000; Moser *et al.*, 1998; Day *et al.*, 1998). However, the mechanisms by which MTBE may disrupt endocrine systems remain unclear and further research is required. In this respect, the EU risk assessment concluded: 'Because the data is not considered to be sufficient, no NOAEL (no observed adverse effect level) is assigned.' (Finnish EPA, 2001)

Box 11.1. Carcinogenicity — complex science, borderline results and conflicting interests

Comprehensive investigations of carcinogenicity were initiated in the 1990s. Evidence from three animal bioassay studies demonstrated that chronic exposure to MTBE — either by inhalation or orally — causes cancers in animals. MTBE inhalation exposure caused an increased incidence of kidney and testicular tumours in male rats (Bird *et al.*, 1997; Chun *et al.*, 1992), and liver tumours were identified in mice (Burleigh-Flayer *et al.*, 1992). Oral administration of MTBE produced a statistically significant increased incidence of lymphomas and leukaemias in female rats and testicular tumours in male rats (Belpoggi *et al.*, 1995 and 1998).

Based on these results, it would seem that MTBE induces benign and malignant tumours at multiple sites, in multiple species, and via multiple routes of exposure. However, the results have been criticised on the grounds that the 'conduct and reporting in the carcinogenicity studies is inadequate, interpretation of the obtained results is difficult and a relation of the observed increases in tumour incidences to MTBE-administration is questionable. Moreover, rodent-specific mechanisms of action have been established for several of the tumours induced by MTBE, thus making the results inapplicable to man.' (Dekant, 2000)

According to the International Agency for Research on Cancer (IARC) of the World Health Organization (WHO), no analytical epidemiological studies have addressed a possible association of MTBE with human cancer. IARC concluded that because there is 'inadequate evidence in humans' for carcinogenicity, and only 'limited evidence' for experimental animals, 'MTBE is not classifiable as to its carcinogenicity to humans' (IARC, 1999). The US National Toxicology Program's (NTP's) Board of Scientific Counselors voted 6 to 5 not to list MTBE as being 'reasonably anticipated to be a human carcinogen' (BSC, 1998). The International Programme on Chemical Safety (IPCS), a joint programme of the International Labour Organisation, the United Nations Environment Programme and WHO, echoed the IARC's conclusion, recommending that in order to provide quantitative guidance on relevant limits of exposure and to estimate risk, the acquisition of additional data in several areas remains necessary (IPCS, 1999).

Other institutions and individual scientists have decided that the evidence provided by the animal bioassay studies is sufficient to conclude that MTBE is likely to cause cancer in humans and should therefore be labelled a probable human carcinogen (Mehlman, 2000). A review of the existing studies by the University of California (Keller *et al.*, 1998b), indicated that MTBE is a potential human carcinogen, although further studies would be needed to make a conclusive determination. The White House National Science and Technology Council concluded that 'there is sufficient evidence that MTBE is an animal carcinogen' and that 'the weight of evidence supports MTBE as having carcinogenic hazard potential for humans' (NSTC, 1997). The US Environmental Protection Agency (EPA) concluded that 'the weight of evidence indicates that MTBE is an animal carcinogen, and MTBE poses a carcinogenic potential to humans' (US EPA, 1997). The most recent in-depth review of the available carcinogenicity data was performed by the Finnish EPA in the context of the EU Risk Assessment on MTBE (Finnish EPA, 2001). In the draft risk assessment report, the conclusion on carcinogenicity states: 'There are indications of carcinogenicity in two species. However the treatment relation of the occurred tumours is equivocal in some studies (mouse adenoma) and the relevance of the mode of action is questionable in others (Leydig cell). Moreover, the tumours appear mostly at very high and systemically toxic doses, and MTBE is not genotoxic *in vitro* or *in vivo*. On the other hand, the human relevance of the testicular interstitial adenomas observed in rats on two separate rat strains cannot be neglected. In addition, some uncertainty remains as to the significance of the lymphatic tumours found, especially in the light of the limitations of the study and somewhat inadequate study quality reporting. The rapporteur considers MTBE as a borderline case between non-classification and Carcinogenicity Category 3.' (Finnish EPA, 2001)

The classification and labelling of MTBE for hazard was discussed by the Working Group on the Classification of Dangerous Substances at the European Chemicals Bureau in November 2000. A proposal to classify MTBE as a carcinogen in Category 3, with an R40 risk phrase was rejected (R40 states that a substance poses 'possible risk of irreversible effects') (Dixson-Decleve, 2001).

The probable basis for this decision is that it is generally accepted that there is a threshold concentration below which no effects can be observed for carcinogenic substances that are not mutagenic. For MTBE, several *in vitro* mutagenicity assays with metabolic activation are positive, while *in vivo* studies are negative. It is believed that the positive responses occur when cells *in vitro* are exposed extracellularly to the MTBE metabolite formaldehyde, and that formaldehyde will not exert this effect when it is generated intracellularly, in the intact organism. For this reason, MTBE is regarded as non-mutagenic (Finnish EPA, 2001).

Thus the level of concern for MTBE is not as high as it would be for a mutagenic carcinogen where, in theory, effects can be expected at all doses, right down to infinitely small concentrations. For non-mutagenic carcinogens, the effect is often connected to some other damage to the target organ, for instance the kidney or liver. The high regeneration and growth of cells that then takes place in connection with tissue regeneration in the damaged organ can be accompanied by an increased tumour production. For the primary damage on the target organ, there will be a threshold value. This threshold value is the no observed adverse effect level (NOAEL). By remaining below the threshold value, damage to the organs is prevented, as is the formation of tumours (stergaard, 2001). Thus, the risk of carcinogenicity posed by such substances is considered manageable.

11.5.6. MTBE in drinking water

In late 1995, the authorities in the city of Santa Monica in California detected MTBE in a well that supplied the city with drinking water. By June the following year the problem had escalated and the city authorities were forced to shut down some of the potable water supply groundwater wells. A review of known and suspected petroleum spill sites identified about 10 potential sources of contamination within 1 kilometre of the well field (Johnson *et al.*, 2000). As a result of the MTBE contamination the city lost 71 % of its local water supply. About half its total water consumption must now be bought from outside sources at a cost of USD 3.5 million a year (Rodriguez, 1997). Some MTBE plumes have originated from very small spills. For example, a spill resulting from a single automobile accident in Standish, ME, led to MTBE transport through more than 0.7 kilometres of fractured rock and the contamination of more than 20 domestic wells (Johnson *et al.*, 2000; Hunter *et al.*, 1999). By now there are many documented cases of MTBE pollution of groundwater in the United States, the number is increasing and where pollution occurs the consequences can be serious. Assuming treatment by granular activated carbon, the cost of purifying MTBE contaminated drinking water sources could be enormous, due to the extremely low concentration limits for MTBE in drinking water (in the order of 5 to 30 g/l). The cost of dealing with underground storage tank and pipeline leaks and spills could be of the order of tens to hundreds of millions of dollars per year in California alone (Keller *et al.*, 1998a). This however could change in light of yet unpublished results from work indicating that MTBE could potentially be biologically degraded in ordinary waterworks using sand filtration (Arvin, 2001).

11.6. Responses

In Denmark, a report on MTBE was published in 1998 (Miljø og Energiministeriet, 1998). The introduction acknowledges: 'In 1990 The Danish EPA received information from Professor Erik Arvin, Institute for Environmental Science and Engineering, Technical University of Denmark, that there might be a problem in relation to groundwater, because of the mobility and apparent persistency in groundwater.' The Danish EPA did not consider that to be a problem at the time, because leakage from tanks was considered a minor problem, and 'because problems with gasoline components were rarely found in groundwater at the time'. In 1998, the Danish EPA introduced a tentative limit for drinking water at 30 g/l.

In California, the first US state to suffer the consequences of MTBE, the California Legislature created a task force within the University of California. The task force evaluated the available evidence, produced an assessment of health and environmental impacts and made several recommendations to the Governor and the Legislature, including the phase-out of MTBE (Keller *et al.*, 1998b). As a result, a Governor's Executive Order in March 1999 recommended developing 'a timetable by July 1, 1999 for removal of MTBE from petrol at the earliest possible date, but no later than December 31, 2002' (Davis, 1999). The University of California study also concluded that: 'A lesson to be learned from the MTBE story is that addition of any chemical compound to the environment in quantities that constitute a significant fraction of the total content of gasoline may have unexpected environmental consequences. Therefore, we recommend a full environmental assessment of any alternative to MTBE.' The intention here is to emphasise that any alternative to MTBE should undergo a full assessment prior to its introduction. This measure is in particular due to the 'potential adverse health effects associated with incomplete combustion products of ethanol'. The report also observed that: 'The current structure of state agencies which focus on specific media (land, air, water), leads to fragmented and incomplete environmental impact assessments.'

A 'Blue Ribbon Panel' was established by the US EPA in 1998 'in response to the growing concerns from State and local officials and the public' (Blue Ribbon Panel, 1999). The report of September 1999 concluded *inter alia*: 'The Panel agreed broadly that, in order to minimise current and future threats to drinking water, the use of MTBE should be reduced substantially. Several members believed that the use of MTBE should be phased out completely.' One lesson, the panel concluded, is that: 'In order to prevent future such incidents... EPA should conduct a full, multi-media assessment (of effects on air, soil, and water) of any major new additive to gasoline prior to introduction.' In March 2000, the US EPA announced that steps would be taken to 'significantly reduce or eliminate' MTBE as a petrol additive, as a 'possible carcinogen' and in order 'to protect America's drinking water supplies' (ENDS Env. Daily, 2000).

11.7. Present trends

The future in the United States is likely to see a shift towards other oxygenates such as ethanol, as well as equivalent non-oxygenated petrols, which meet the strict emission requirements (Keller *et al.*, 1998b; CEC, 1998). In Europe, the comparatively low use of MTBE has meant that concerns and possible problems associated with MTBE have developed later than in the United States (Morgenroth and Arvin, 1999). The EU regulations introduced on fuel quality covering both petrol and diesel in 1998 (98/70/EEC) call for compounds such as benzene (class 1 carcinogen) and overall aromatics to be reduced in steps by the years 2000 and 2005. This could result in an increase in the use of MTBE in Europe. In August 2000 the Danish EPA placed MTBE on its list of undesirable substances and announced that it planned to introduce economic instruments to discourage the use of MTBE. The recent EU risk assessment of MTBE concluded that because of the risk that MTBE poses to groundwater reservoirs, risk reduction measures are justified (Finnish EPA, 2001). A report to the European Commission on risk reduction for underground storage tanks was released on 19 April 2001 (Arthur D. Little Limited, 2001) as a supplement to the risk reduction report written in connection with the risk assessment (Finnish EPA, 2001). The reports stress the difference between the US and EU situations. The anticipation is that 'MTBE octane requirements will settle out in the 1–4 percent volume range, depending on the available octane, and will still be well below the 10–15 percent currently used in reformulated gasoline in the USA'. Many EU countries have recently adopted regulatory measures against leakage from underground storage tanks to ensure that the risk of groundwater contamination 'remains low in the future'. The report points at the risks posed by existing underground storage tanks not complying with the new regulations in the interim period until full enforcement. The regulations are anticipated to have taken full effect by 2005. The report emphasises the need for 'strong enforcement of the underground storage tank specifications' and suggest 'penalties to prove an effective deterrent'.

Accordingly, it seems that the position in the EU tends to be that oxygenates such as MTBE should have their place to improve combustion and help reduce emissions of CO and organic compounds. The increased risk associated with leaking underground storage tanks is seen as a technical problem that can be managed by risk reduction. However, studies in the United States have shown that even sophisticated, double-walled underground storage tanks with detectors may leak undetected due to improper installation (Couch and Young, 1998). This explains the push for 'strong enforcement' and follow-up monitoring of groundwater in the report to the European Commission (Arthur D. Little Limited, 2001).

11.8. Discussion in relation to the precautionary principle

Our analysis will first take a historical perspective in order to highlight the questions that could have been asked at the time of the introduction of MTBE in the early 1980s. The objective here is to illustrate the potential of applying foresight as part of the precautionary principle.

As early as 1954, studies were published indicating the very low biodegradability of the ether family (Mills and Stack, 1954). By 1960, the resistance of ethers to biological degradation had become textbook knowledge (Sawyer, 1960). On this basis we consider it reasonable to believe that at the time of the introduction of MTBE, competent chemists and microbiologists could have anticipated that MTBE might be persistent in groundwater. Documentation for this argument has however not been found. It appears that the first warnings against persistency of MTBE in groundwater, based on the first experimental facts (although only at the laboratory scale), were published in 1990 (Barker *et al.*, 1990; Jensen and Arvin, 1990). However, the regulatory agencies did not react to these first warnings. It was not until the full-scale results emerged in 1996 that the regulatory system was alerted to the seriousness of the problem. That delay is documented in the United States and Denmark.

On the other hand, it is reasonable to believe that there were no indications of any obvious harmful effects associated with MTBE at the time it was chosen to replace lead in petrol. Accordingly, the fundamental issue is not whether a persistent *and* harmful chemical poses an unacceptable risk. The fundamental issue is whether or not the prevailing knowledge was adequate at the time to foresee that persistency in itself might eventually be considered problematic.

11.8.1. The historical perspective

Widespread concern over the persistency of chemicals first arose following the publication of the landmark book *Silent spring* (Carson, 1962). In her book, Carson described the disastrous effects of large-scale applications of pesticides on insects, birds and ecosystems. At the time, the debate was closely connected to what was known as the 'dirty dozen' of pesticides, now referred to as persistent organic pollutants, or POPs. In connection to this debate, research on biodegradability and mobility, as well as other characteristics of pesticides, has been ongoing since the early 1960s.

A similar debate emerged in Europe in the early 1960s, following incidences of foaming in rivers caused by the use of non-biodegradable detergents. The soap and detergent industry became actively involved in efforts to develop criteria and methodology for testing the persistency/degradability of detergents (ASDA, 1965; Swisher, 1987) as did the Organisation for Economic Co-operation and Development (OECD, 1970).

It would therefore appear that industry and regulators would have had reason to suspect that persistency could entail complications when present in combination with detrimental properties. The experience with pesticides and detergents provided scientific evidence that in combination with certain other chemical properties, persistency could cause lasting undesirable effects, such as persistent toxicity or foaming rivers.

Based on this, we may further ask if at the time of the introduction of MTBE there were any indications that society was formulating and implementing responses to address the issue of chemical persistency combined with other negative characteristics.

In 1978/79, an OECD working group on test methods for degradation and accumulation was formed to pioneer the development of the specific detergent methods into more general methods for measuring persistency (OECD, 1981). At these workshops, representatives from governments, industry and academia discussed the technical details of the already accepted concept of persistency. As well as the OECD, a number of governmental, industrial and non-governmental organisations were active in developing standard test methods for biodegradability during the 1970s and the early 1980s (US EPA, 1979; ECETOC, 1982; ISO, 1984).

Persistency appeared early in the development of EU environmental legislation as an undesirable property of a chemical (European Commission, 1967 and 1984). According to the sixth amendment (European Commission, 1979) to the EC classification and labelling directive for new substances (European Commission, 1967) adopted in September 1979, all new substances intended to be manufactured or marketed in the EU must be notified to the competent authority in one of the Member States. This pre-marketing notification must be accompanied by a set of data on the identity, use and properties of the substance. The size of the data set is dependent on the foreseen production-volume of the substance involved. Together with toxicity, bioaccumulative potential and suspected carcinogenicity, persistency could trigger a classification as 'particularly dangerous to the environment'.

However, MTBE was not legally bound to these 'new substance' regulations, which only applied to chemical substances that were not marketed within the EU in the 10 years prior to 18 September 1981. Because MTBE had been marketed prior to this date, it was classified as an 'existing substance' in the EU. Regulations for the evaluation and control of existing substances were adopted in 1993 (European Commission, 1993). The Finnish Environmental Institute is currently conducting the risk assessment of MTBE required under this regulation. Draft versions of the risk assessment, already referred to, became available by the end of 2000. The final version is expected during 2001.

The large amount of effort dedicated to developing test methods for persistency indicates that at the time society did in fact deem it important to identify persistency in a chemical. The subsequent incorporation into law of persistency as being an undesirable characteristic of a chemical further indicates that society was indeed prepared to implement responses to address the impact of chemical persistency in combination with other negative characteristics.

At the time it could have been expected that the projected high production-volume of MTBE would have given rise to concern. These concerns could have prompted further investigations, although there was no requirement at the time. Such investigations would have revealed the persistency of MTBE to decision-makers.

Had industry and regulators taken account of the persistency of MTBE, it is reasonable to assume that they could have considered the following question: does MTBE exhibit any other characteristic which, when combined with persistency, requires a response by society due to the risks involved?

As has been mentioned previously, the taste and odour problems associated with MTBE have been known for a long time. These were, however, overlooked during the screening of MTBE. It seems that the possibility that MTBE could pose a threat to groundwater reservoirs was never considered. Furthermore, the carcinogenicity of MTBE did not start to be investigated in detail until the 1990s and the classification of MTBE with regard to carcinogenicity remained uncertain long after the introduction of the chemical as a high production-volume chemical. There is no doubt that the introduction of a high production chemical displaying a combination of persistency, taste and odour characteristics, potential carcinogenicity and other adverse effects could have sparked concern in the early 1980s. Studies should therefore have been done at that time.

The choice of MTBE as a long-term replacement to lead in petrol was not grounded in precaution, as the possible threats associated with the choice were not adequately characterised. By applying foresight, it could have been possible for the petrochemicals industry and regulative authorities to identify that the persistency of MTBE could eventually become problematic.

11.8.2. The modern-day perspective

Of all the negative features of MTBE, persistency is unique in that it implies irreversibility. A persistent chemical remains present in the environment long after its use has been discontinued, thus dramatically increasing the risk associated with a false diagnosis of known detrimental effects, and with other detrimental effects of which science is still unaware. Indeed, the release of persistent chemicals into the environment begs the following questions: should a response be implemented on the sole basis of persistency, and should persistency motivate systematic, comprehensive and thorough investigations of perceivable negative effects?

These questions are still pending today, but the high production volume and the high solubility of MTBE should definitely give rise to concern. The list of known negative features of chemicals, other than persistency, is still expanding. Only now, for example, are we beginning to investigate the mechanisms that induce endocrine disruption. Should new information become available associating any new negative effect to a persistent chemical, the financial and technological resources required for remediation are likely to be out of reach once this chemical is spread throughout the environment.

In this case the interpretation of the precautionary principle is that the risk of being wrong and the potential consequences should always be considered. In the case of persistent chemicals, that risk is significantly greater than with other chemicals due to *irreversibility*. Lack of full scientific understanding of cause-effect relationships cannot be used as an excuse to postpone action. Moreover, scientific uncertainty and ignorance warrant precautionary measures.

11.8.3. Alternatives

The precautionary approach invokes the principle of substitution, seeking out safer alternatives to potentially harmful activities. There is no doubt that MTBE is a reasonably better option than lead. However, because we have reason to believe that there could be irreversible detrimental effects associated with the use of MTBE, we also have to investigate substitution as an alternative to risk reduction. There are alternatives to MTBE and it is likely that more could be discovered if sufficient research were conducted in this direction. Thus, the important follow-up question in the implementation of the precautionary approach is: what is the status of the alternatives to MTBE? The most recent account is presented in the EU report on risk reduction drafted in connection with the risk assessment (Finnish EPA, 2001)

The most commonly considered alternatives to MTBE include other oxygenates, improved engine technology and altered petrol composition (Morgenroth and Arvin, 1999; CEC, 1998).

Other oxygen-containing compounds include ethanol, ETBE (ethyl tert-butyl ether), TAME (tert-amyl methyl ether), and DIPE (di-isopropyl ether). However, other oxygenates could also have adverse impacts on the environment. For example, the area of agricultural land required to grow the plant matter for the production of biological ethanol would be significant and the ecological impact of the fertilisers and pesticides required to produce this crop need to be considered. Moreover, ethanol production requires considerable amounts of energy and this option may not lower greenhouse gas emissions significantly when the entire production cycle is considered. Other ethers could have health effects similar to those of MTBE which, as we have noted, are not fully understood.

Another alternative is the introduction of vehicles with improved engine technology, such as gasoline direct injection (GDI). At part load, GDI does not require as high an octane rating as conventional engines. At full load however the differences are not as important. With the reduction of the aromatics in petrol being called for in Europe, the addition of oxygenates would remain necessary even with improved engine technology.

Another widely considered alternative could be to improve the composition of the petrol. An increase in the octane rating of the petrol could be achieved by changing the structure of the 'branch alkanes' in petrol. This option may however be opposed by the petrochemicals industry, as it would imply process changes at the refinery, entailing major investment costs.

The use of MTBE as a petrol additive to reduce emissions of pollutants from motor vehicles is indicative of a deeper issue of which MTBE is only the symptom. As countries like India and China pursue the process of industrialisation, it is clear that future generations cannot afford to operate a mass transit system resulting in the emission of VOCs, CO, carbon dioxide, NO_x and other pollutants. Although the above mentioned alternatives could improve the current situation, it is not likely that the benefits they provide will be significant enough to meet the needs of future generations. Thus, the precautionary principle would now beckon us to invest seriously in the development of alternatives entirely different from the ones considered above.

In this respect, some European governments have been advocating a response directed at the very driving forces that lead to environmental degradation. In essence, they are questioning the basic need for a mass transit system. For example, the position of the current government in Denmark is that with advances in communication technologies, personal vehicles are increasingly becoming a 'want' versus a 'need'. They have therefore enacted various economic policies that aim to discourage citizens from driving personal vehicles.

Another point of view is that society will always have a need for a means of rapid transportation, but that a radical shift in engine technology can eliminate the pressures exerted on the environment by personal transport. One example of such a technological intervention is the hydrogen fuel cell. The emission by-products of this system are limited to oxygen and water. Pilot projects using hydrogen-based fuel cell buses have been set up, for example, in Chicago and Vancouver.

A feature of all these options is that none of them has been investigated to the point where they could be implemented on a wide scale in the short term. As we are currently realising the problems associated with the use of MTBE, foresight would beckon us to actively research and develop alternatives to this option.

11.8.4. Cost-benefit analysis

A cost-benefit analysis should ideally incorporate all costs and all benefits — or a reasonable approximation thereof. In the face of ignorance, a cost-benefit analysis is of only limited value to decision-makers and cannot, of itself, form the sole basis for a policy decision. Nevertheless, a systematic and comprehensive assessment of all the options can serve as an important tool for their relative assessment, even under situations of partial ignorance.

A cost-benefit analysis on the use of MTBE in California was conducted in 1998 (Keller *et al.*, 1998a). The analysis examined the human health benefits derived from controlling air pollution, and then analysed the costs associated with the use of MTBE across the following categories:

- human health costs due to an increase in cancer cases caused by air pollution from MTBE and its combustion by-products (aldehydes);
- costs of averting human health damages through water treatment or by using alternative water supplies;
- direct costs paid by the consumers in the form of increased petrol prices as well as decreased petrol efficiency due to the oxygenates;
- monitoring costs;
- recreational costs;
- ecosystem damage.

The analysis compared the costs and benefits of using MTBE, of using ethanol, and of the use of non-oxygenated petrol with either toluene or iso-octane. Conventional petrol sold prior to the introduction of RFG was used as a baseline comparison.

The air quality benefits associated with the three options were essentially the same, as all formulations achieve approximately the same reduction in CO and ozone precursors emissions. The air quality benefits of the three options were estimated to be relatively minor, between USD 14 million and USD 78 million per year.

The water treatment costs associated with MTBE made it the most expensive option, when all costs were considered. Based on an estimate of the number of groundwater supplies and surface water reservoirs currently contaminated with MTBE, the estimated aggregate cost of water treatment in California was found to be between USD 340 million and USD 1 480 million per year. These costs were based on the premise that contaminated water would be treated to a concentration below 5 g/l using granular activated carbon. As described earlier, there may be cheaper methods. For non-oxygenated petrol and ethanol blends, the differential cost of remediation and/or water treatment relative to conventional petrol would be small. Other important costs associated with the use of MTBE included the direct price paid by consumers for oxygenated petrol (USD 435 million to USD 1 055 million per year), and the potential loss of recreational boating activities in order to prevent this source of MTBE contamination of surface water reservoirs (USD 160 million to USD 200 million per year). The report concluded that non-oxygenated petrol achieves air quality objectives at the least cost, followed by ethanol-based petrol formulations.

Given the ignorance surrounding our understanding of the health effects of MTBE, a cost-benefit analysis will always be provisional. It is possible that many potential costs still remain unknown to us. For example, if new information became available establishing a clear link between the use of MTBE and an increase in asthma occurrences, the health costs associated with the option of MTBE would increase significantly. On the other hand, if new information showed that MTBE could be degraded in municipal waterworks, the costs associated with MTBE could decrease significantly.

But on the basis of what is currently known with reasonable certainty, water treatment costs make MTBE a very expensive option. Furthermore, if we assume a worst-case scenario for the health effects of using MTBE, the cost of correction of damage would increase even further, far outweighing the cost of prevention. It is widely agreed that in the pursuit of the precautionary principle, the cost of any precautionary measures taken should be proportionate to the benefits that can be achieved by them. The potentially very high costs associated with MTBE would therefore justify a proportionately costly response.

It remains unclear who should be held responsible for the costs incurred as a result of the use of MTBE. Our analysis suggests that both industry and society (represented by regulators) were short-sighted in their decision to replace lead in petrol with MTBE. Because of this, it is difficult to single out who will bear the cost for the response. Who is the polluter, who should pay? Until now, the majority of the costs associated with the use of MTBE have been borne by society in the form of risk reduction, water treatment or alternative water supply costs, costs to industry carried over to consumers and human health costs. The consequences of any decision relating to our mass transit system will be far reaching. Because of this, foresight would now beckon society to select those alternatives to MTBE that are based on best environmental practices, even if these alternatives are more costly in the short term. The alternatives selected must be the best for the needs of the present day and for the needs of the future.

11.9. Conclusion

By applying foresight at the time of the introduction of MTBE, it could have been possible to predict that the persistency of MTBE would eventually be deemed problematic by society. The persistency, mobility and high production volume of MTBE should have prompted systematic, comprehensive investigations into perceivable adverse characteristics of the substance. This could have identified taste and odour problems and suspicions of carcinogenicity of MTBE at an earlier stage, and could have acquitted the chemical or confirmed suspicions.

The risk to groundwater due to persistency and the strong odour and taste of MTBE was ignored for a long time but has now been recognised. The classification of MTBE with regards to its carcinogenicity remains uncertain, long after its introduction as a high production-volume chemical. A state of near ignorance characterises our knowledge of the possible endocrine disrupting and asthma inducing effects of MTBE. Additional research is still recommended in these areas.

Because of its persistency in groundwater, the use of MTBE poses an ongoing, everlasting risk of having irreversible adverse effects. These adverse effects could come in the form of known effects such as taste and odour in contaminated drinking water, as well as in the form of presently unknown adverse effects.

The key question of principle is: does persistency alone, without indication of other adverse effects, give reason to apply the precautionary principle? It seems reasonable to conclude that systematic, comprehensive and thorough investigations into all known possible adverse effects should be exercised before any release of large volumes of a persistent chemical into the environment. These investigations should be reopened and pursued as new categories of adverse effects are discovered. It also seems reasonable to answer that, because persistent chemicals expose us and future generations to a variety of possible negative effects of which we are still ignorant, alternatives to the use of persistent chemicals should be sought out whenever possible. There are now a considerable number of examples of persistent chemicals (including chlorofluorocarbons, polychlorinated biphenyls and tributyltin) that caused unwelcome 'surprises' with serious consequences.

Foresight beckons us to investigate alternative decisions thoroughly and to reconsider these alternatives when we realise the limitations of the current decisions. Best environmental practices, like risk reduction, should be pursued. Due to the possibility of risk reduction being insufficient, research and development into alternatives should be actively encouraged in order to render them feasible as soon as possible. Such thorough investigations ensure that decisions are robust and flexible so that they may be adapted to unforeseen circumstances in the future. Thus, foresight, embodied in the precautionary principle, is the guarantor of futurity within the concept of sustainability.

MTBE: early warnings and actions Table 11.1.

1954	First scientific paper demonstrates low biodegradability of the ether family in water
1960	Information about taste and odour in water and low biodegradability available in textbook
1990	First indications of the potential for groundwater pollution with MTBE at laboratory scale
1990	Significant increase in use of MTBE in the United States due to amendments to the Clean Air Act
1990	Comprehensive investigations of carcinogenicity initiated in the 1990s
1995	MTBE detected in wells that supplied drinking water in Santa Monica, California. These had to be closed and the city lost 71 % of its local water supply
1996	Concerns become widespread following a US Geological Survey report
1997	Field studies demonstrate that MTBE is highly soluble, mobile and persistent and therefore a potential risk to groundwater
1998	A Danish EPA report acknowledges that the government was informed in 1990 that MTBE might give rise to groundwater problems and presents an action plan for MTBE remediation and risk reduction
1999	California recommends removal of MTBE from petrol as soon as possible, but not later than end 2002
2000	Indications that MTBE might be linked to asthma in some US cities
2000	Indications that MTBE might be an endocrine disrupter
2000	US EPA announces that steps will be taken to significantly reduce or eliminate MTBE as a petrol additive
2000	Danish EPA places MTBE on its list of undesirable substances
2001	EU reports on analysis of risks and risk reduction related to MTBE. European Chemicals Bureau decides that MTBE should not be classified as a carcinogen
2001	The debate goes on

Source: EEA

11.10. References

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