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RENEW

Renewable fuels for advanced powertrains

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Toxicity and safety properties of renewable fuels

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Table of contents

Introduction

In the RENEW project a variety of liquid and gaseous fuels produced from biomass has been examined. These fuels are produced by different processes, which are with the exception of the enzymatic production route for ethanol (ABENGOA, SP 4, WP 4.1), all based on a thermo chemical conversion of the biomass to syngas, followed by a synthesis step to produce the final fuel. For most of the processes a life cycle analysis has been made (ESU SP 5, WP 5.2) from which energy efficiency, emissions and environmental impacts for the different processes are available.
The most important criteria for an assessment as automotive fuel is the potential to reduce emissions and fuel consumption. As this potential depends also on engine technology and especially on the exhaust gas aftertreatment technology a differentiation between older technologies, which represent most of the current vehicle fleet, and modern state of the art vehicles is reasonable.
The fuels should provide the same good drivability behaviour than modern conventional fuel. This has to hold also for extreme climate like low and hot temperatures and high altitudes.
The fuels should be compatible with materials, typically used in engines and tank systems. They must not cause corrosion or abrasion.
One of the fuels, DME is not liquid at standard condition. Storage density of gaseous fuels is generally lower. This cause lower cruising ranges or lower payloads. Gaseous fuels need a dedicated distribution infrastructure. Blending with conventional liquid fuels is not possible.

The focus in the RENEW project for toxicity and safety has been to investigated the effects of four different fuels all produced from biomass. The fuels are the following

Dimethyl-Ether (DME), (CAS# 115-10-6)
Ethanol (EtOH), (CAS# 64-17-5)
Methanol (MeOH), (CAS# 67-56-1)
Fischer-Tropsch diesel (FT-diesel) (no CAS# available)

Environment and safety aspects of the fuels are important especially in case of accidents.
The toxicity, both for the environment and for humans, of the fuels is an important criterion at normal or accidental exposure. Both the acute toxicity and chronic toxicity has to be considered when introducing new fuels. Especially the long term effects as allergy and cancer are important to investigate.

Fuel descriptions

Dimethylether

DME Dimethylether (CH_3OCH_3) can be produced from a variety of feedstocks, including natural gas, heavy crude oil, coal, waste and biomass. DME is the simplest ether, consisting of two methyl groups bonded to a central oxygen atom. Because of the absence of carbon–carbon bonds, emissions of hydrocarbons (such as PAHs and benzene) are very unlikely.
DME was introduced in the earlier 1980's as an environmental friendly alternative to CFC gases (freons). It is also used as a safe aerosol propellant especially for household products and cosmetic items like hair-spray. [1, 2]
DME is a colorless gas at room temperature with an ethereal odor. It can be easily handled and stored as liquefied gas similar to LPG. DME has no corrosive effects on metals but it is an excellent solvent and can dissolve a number of elastomers.

Ethanol

Ethanol or ethyl alcohol (C_2H_5OH) is a clear colourless liquid. Ethanol is biodegradable has a low toxicity and causes little environmental pollution if spilt. Ethanol burns to produce carbon dioxide and water. Ethanol is a high octane fuel and has replaced lead as an octane enhancer in petrol. Ethanol fuel is mainly produced by the sugar fermentation process. The main sources of sugar required to produce ethanol come from fuel or energy crops.

Methanol

Methanol or methyl alcohol (CH_3OH) is often called wood alcohol because it was once produced chiefly as a by-product of the destructive distillation of wood. It is now produced synthetically by a multi-step process based on the direct combination of carbon monoxide gas and hydrogen in the presence of a catalyst.
Methanol is a colorless liquid that boils at 65° C. It forms explosive mixtures with air and burns with a nonluminous flame. It is a violent poison; many cases of blindness or death have been caused by drinking mixtures containing methanol.

Fischer-Tropsch diesel

Fischer-Tropsch diesel is a synthetic fuel that can be produced from natural gas (GTL). In the RENEW project the FT-diesel that have been investigated is based on thermo chemical conversion of biomass to syngas with a following synthesis to produce the final fuel (BTL). The FT-diesel is a colorless and odorless liquid and has a very low sulfur and aromatic content. Fischer-Tropsch fuels can use the existing fuel distribution infrastructure and require no engine modifications.

Physical properties

Physical properties for the different fuels are presented in the table 1 below.[3]

Table 1 Physical properties of fuel

	DME	Ethanol	Methanol	FT-diesel
State at NTP	Gas	Liquid	Liquid	Liquid
Boiling point ^{o}C	-25	78	65	150-380
Vapour pressure 20 ^{o}C kPa	510	6.6	12.8	0.4
Flash point ^{o}C	-41	13	11	55-60
Flammability limits %	3.4-18	3.3-19	5.5-36	1-6
Min. ignition energy in air mJ	0.29	0.23	0.14	0.25
Flame temperature in air ^{o}C	2130	2030	1910	n.a.
Auto ignition temp ^{o}C	235 (350)	360	390	220-320

Toxicity and safety aspects

Introduction

Facts about the effects on health and the environment for the four the different fuels have been assessed. For each fuel has both acute and chronic effects been studied.[4, 5] The safety aspects (fire and explosion) have also been studied.[6]
The open literature has been searched for information about the effects of the different fuels. Reports from seminars and scientific conferences have also been studied. Contacts have also been taken with some of the producer of the alternative fuels.[7] The Swedish Rescue Services Agency has been consulted for the risks when handling the fuels at service stations.

Toxicity

Acute effects

DME

DME has low acute toxicity with a LC50 value in rats after inhalation of 164 000 ppm (16,4% DME in air). Dogs exposed to 20% DME have shown cardiac sensitization, but not after exposure to 10 %.
Human exposure to 10 % DME under controlled laboratory exposures has shown reversible CNS-effects. Exposure to higher concentrations has an anesthetic effect. High exposure can cause headache, dizziness and lost of consciousness.
Vapor can cause eye, nose and throat irritation. Skin contact with liquid DME can cause severe frostbite.

Ethanol

Ethanol has a quite low acute toxicity after inhalation, both for humans and animals. A LC50 value in rats 13 000 ppm (1,3 % EtOH in air) has been reported.
The vapor, even in low concentration, is irritating to the eyes and upper respiratory tract.
Splash contact of ethanol with eye causes immediate stinging and burning.
Exposure by inhalation is completely different from drinking ethanol. It is broadly accepted that exposure by inhalation, during a full day at 500 ppm (the Swedish occupational exposure limit) leads to the same alcohol level in the blood as 1/50th (!) of an alcoholic drink. Similar alcohol levels are made by the human body itself after drinking a glass of orange juice or eating a white bread sandwich.

Methanol
Methanol has a high acute toxicity especially for humans. Exposure to vapors can cause headache, dizziness, lost of consciousness and also visual disturbances. Methanol is oxidized to formic acid which is responsible for the effects on the optic neuropathy. Methanol can be absorbed through the skin and give the same symptoms as after inhalation of methanol vapor.
Ingestion of as little as 50 ml of methanol can be lethal or produce irreversible visual degeneration.
Methanol vapor is irritating to skin, eyes and to the upper respiratory tract.

FT-diesel
The toxicity of diesel fuel depends on the route of exposure, product viscosity, whether presented as aerosol or vapor and whether pulmonary aspiration has taken place. The relatively low volatility of diesel fuel seldom makes it hazardous as vapor. Diesel aerosol can affect the respiratory system.
Diesel fuels are moderately irritating to skin and eyes. Prolonged contact with the skin can cause non allergic eczemas.
Ingested diesel can be deadly if aspiration (the liquid is entering the airway system) occurs.

Chronic effects

DME
Mutagenicity: No mutagenic properties of DME have been showed in the studies that have been published in the literature.

Reproductive and developmental toxicity: Exposure to very high levels of DME (>40 000 ppm) has shown embryo and fetotoxic effects in rats. Exposure to 40 000 ppm did not show any teratogenic effects in exposed rats.
Cancer: There is no evidence that DME should be carcinogenic to humans. There is however no epidemiological studies published concerning DME exposure since there are no large populations exposed to DME vapors.

Sensitization: There are no studies that indicate that DME has allergic properties.

Ethanol
Mutagenicity: There is no evidence to suggest that ethanol has mutagenic potential. It should be noted that acetaldehyde, the main metabolite of ethanol, is mutagenic.

Reproductive and developmental toxicity: Inhalation studies in rats with high exposure (10 000 – 20 000 ppm) has not showed increased frequencies of malformations. In humans, ethanol is a developmental toxin, and various effects have been associated with ethanol intake. Excessive consumption of alcoholic beverages during pregnancy is associated with the development of a syndrome of physical and mental manifestations in the offspring - the fetal alcohol syndrome; it may also cause defects in the central nervous system, heart, kidney and limbs.

Cancer: Epidemiological studies clearly indicate that drinking of alcoholic beverages is causally related to cancers of the oral cavity and pharynx.[8] There is sufficient evidence for the carcinogenicity of acetaldehyde, the major metabolite of ethanol, in experimental animals
In a recently published article in Environ Sci and Tech. there are indications that the changes to E85 in the United States could increase the cancer risk due to increased emission of acetaldehyde.[9] It could also increase the ozone-related mortality, hospitalization and asthma.[10]

Sensitization: There are no studies that indicate that ethanol has allergic properties.

Methanol
Mutagenicity: The majority of test, both in vitro and in vivo, for mutagenic/clastogenic effects have been negative.

Reproductive and developmental toxicity: No epidemiological studies in humans have demonstrated an increased incidence of fetal malformations or developmental impairment. Studies on rats have shown congenital malformation after exposure to high concentrations (10 000 ppm). No adverse effects were noted when exposed to 5000 ppm.[11]

Cancer: Inhalation studies in rats and mice have not given any evidence of a carcinogenic potential. There are no indication in epidemiological studies that methanol causes cancer.

Sensitization: There are no studies that indicate that methanol has allergic properties.

FT-diesel
Mutagenicity: Diesel blends have been showed to have a mutagenic effect in test system for mutagenicity (Ames assay). The activity is correlated to the polynuclear aromatics (PNA) content of the blends. FT-diesel has very low content of PNA and therefore should the mutagenetic activity be low. Test that confirms this should be carried out.

Reproductive and developmental toxicity: There are no evidences that FT-diesel has reproductive or developmental toxicity.

Cancer: Prolonged and repeated skin contact with diesel fuels (petroleum derived) may be associated with an increased risk of skin cancer. If this is true for FT-diesel is not showed yet. Since FT-diesel contains no aromatics the risk for cancer should be much lower than for common diesel.

Sensitization: There are no studies that indicate that FT-diesel has allergic properties. Dermal effects = dermatitis after prolonged exposure on skin is a non allergic reaction caused by the degreasing effect of diesel.

Conclusions of the toxicity

DME has the lowest acute toxicity and methanol the highest. DME, methanol and ethanol have anesthetic effects at high exposure levels. The relative low volatility of FT-diesel fuel seldom makes it hazardous as vapor.
All fuels can cause acute skin, eye and respiratory irritation. Ingested methanol is very poisoning and aspiration of FT-diesel fuel can be fatal.

The most concern for chronic effects is the risk for cancer. The mutagenic properties of some of the different fuels have been studied quite well but for DME and FT-diesel there is little or no information available. Petroleum derived diesel fuel have been showed to give a higher risk of skin cancer probably due to the content of PNA. FT-diesel has very low aromatic contents and the risk for skin cancer should be very low. Drinking of alcoholic beverages is related to cancer but there is no evidence that exposure to ethanol vapor at the exposure levels that are common in the working areas will give rise to cancer.

There are no indications that exposure to moderate levels of all the fuels is causing reproductive or developmental damages.

None of the different fuels are sensitizers but they are all degreasing agents that can cause dermatitis after prolonged skin exposure.

Need for further work

Since DME has only been used in small quantities until now long term studies of human exposure is missing. The possibility for DME to have a cancer or genetic effect should be further investigated. FT-diesel is also not studied as exhaustive as the other fuels and there is a need for more studies on the mutagenic and carcinogenic properties of this fuel.

Environmental effects

Emission to the air

From the fuel:

None of the fuels has a Global Warming Potential (GWP) with the lowest GWP of the studied fuels for DME.[12] Photochemical Ozone Creation Potentials (POCP) as Ethene-equivalents (Ethene = 1) is also low for the fuels, see below.

Dimethylether 0,174

Methanol 0,131

Ethanol 0,386

FT-diesel 0.48

Since DME is a gas it evaporates to the air quickly and disperses in the atmosphere. EtOH and MeOH also vaporize quite quickly to the air. Diesel has a low vapor pressure and the contribution to the atmosphere from the fuel is low.[13]

When DME was introduced as a propellant there were questions if DME could form bis(chlormethyl)ether (BCME). BCME is a strong carcinogenic substance and could be formed through chlorination of dialkylethers. Several tests have showed that this doesn’t occur during normal atmospheric conditions. In cases where BCME had been added to aerosol formulation, the concentration of this compound decreased over time.

From the combustion of the fuels:
The main concern for the emissions to the air is the formation of secondary pollutants during the combustion of the fuels. Air pollution is a serious threat to human health. Exposure to ambient air pollution has been linked to a number of different health outcomes, from impaired pulmonary function to increased mortality in respiratory and cardiovascular diseases.

DME: The combustion of DME gives very low emissions of pollutants. The emission of particles is extremely low since the soot formation does not occur due to the absence of carbon to carbon bonds in the molecule. Emissions of ultra fine particles (UFP) from the lubricating oil are still possible and should be studied more deeply in the future. Emission of nitrogen oxides is also lower than for gasoline or diesel and therefore formation of ground level ozone is lower for DME.

Ethanol and Methanol: Combustion of alcohols also decrease the emission of particles compared to gasoline and diesel. The main concern is the formation of aldehydes (Formaldehyde from methanol and acetaldehyde from ethanol). Aldehydes are irritating for eyes and the respiratory tract. Formaldehyde is classified as a human carcinogen (IARC Group 1A) and acetaldehyde is classified as possible human carcinogen (IARC Group 2B). Aldehydes are active in the formation of ground level ozone.

FT-diesel: The emissions of particles during combustion of FT-diesel are lower than from conventional diesel fuel. The reason for this is the lower content of aromatic hydrocarbons in the fuel.

Emission to water and ground

DME

If released into water DME will volatilize quickly. DME exhibits low toxicity to aquatic life (LC50 Fish 96h: 1474 mg/l and EC50 Daphnia 48h: 2390 mg/l) and has a low bioconcentration potential (Log Pow: 0,10).[14]

Ethanol

If spilled into marine waterways, ethanol is toxic to marine life in high concentrations but quickly dilutes in open water, with no residue. The acute toxicity to aquatic life is very low (LC50 for Fish 96h: 13500 mg/l, EC50 Daphnia 48h: 5400 mg/l). The bioconcentration potential is also low (BCF: 0,66 Log Pow: -0,32). Although ethanol itself is readily biodegraded if it leaks into groundwater, its presence may retard the degradation of more toxic compounds, increasing the risk of groundwater contamination.[15]

Methanol

A major spill issue is contamination of drinking water supplies; however, methanol biodegrades fairly rapidly in open waters or even in shallow aquifers with high oxygen content. The infinite solubility in water will result in a fast dispersion. Tests for toxicity on fish and daphnia shows a low acute aquatic toxicity of methanol (LC50 Fish 96h: 15400 mg/l, EC50 Daphnia 48h: 24500 mg/l). Methanol also have a low bioconcentration potential (BCF: 1, Log Pow: -0,64).[16]

FT-diesel

FT-diesel is comparable in biodegradation and toxicity to petroleum diesel. It is classified as environmental dangerous with the labeling, toxic to aquatic organisms and may cause long-term adverse effects in the aquatic environment. There are however studies that indicates that FT-diesel is less environmental dangerous than petroleum diesel.

Conclusion on environmental aspects

Ethanol is relatively harmless in low concentrations, so it should not represent a danger to drinking water supplies. However, fuel ethanol may contain a strongly flavored denaturant to discourage people from drinking it, and this denaturant could pose a problem to drinking water supplies. Fuel methanol is dangerous in small concentrations, so a large methanol spill should represent a greater danger to drinking water supplies than the other fuels. There is no indication that DME release to water environment should pose a threat to the environment.
FT-diesel has the same environmental disadvantages as petroleum derived diesel.

All fuels have a lower impact on the air pollution but there is still concern of combustion emissions of aldehydes from the alcohols. The formation of ultrafine particles from the different fuels should also be further investigated.[17, 18]

There is still a lot of information missing on the environmental impact of the alternative fuels. Especially for DME and FT-diesel facts are missing since those fuels are not in the market yet.[19]

Safety

Fire

DME
DME burns with a slight visible flame, burns with less thermal radiation than either gasoline or diesel, and produces less smoke, which results in lower danger of harm than from gasoline and from diesel.

Ethanol
Ethanol burns with a visible flame and a heat release rate only one-fifth that of gasoline. Ordinary aqueous-film-forming foams (AFFF) are not effective with alcohols and there is a need for more complex firefighting foams.

Methanol
Methanol burns with a near-invisible flame, creating the danger that firefighters or others might inadvertently move into a fire. The heat release is in the same order as for ethanol a fifth of that for gasoline. As for ethanol, methanol fires must be fight with special firefighting foams.

FT-diesel
Diesel fires have higher thermal radiation than fires from the other studied alternative fuels and near the same as for gasoline. The fire generates a great deal of black smoke.

Explosion

DME
DME has wide explosion limits, 3.4–19.0% in air, presenting a substantial explosion hazard in such situations as a spill in a residential garage. For large spills or tanker fires, this explosion danger dictates significantly higher evacuation/isolation distances than gasoline — 0.8 km (versus 0,3 km) for a large spill, 1.6 km (versus 0.8 km) for a tanker fire

Ethers are known to form peroxides that are very explosive. Literature provides no indication that peroxides are formed spontaneously from DME. During very special conditions with irradiation with UV-light, presence of ethanol and availability of air, peroxides in small amounts can be produced. Those conditions are far from practice.[20]

Ethanol
Ethanol should be considered less susceptible than gasoline to explosion. Unlike gasoline, which has vapor that is too rich, ethanol's vapor tends to be in the combustible range inside storage tanks. Evacuation/isolation distances is the same as for gasoline — 0,3 km for a large spill, and 0.8 km for a tanker fire.

Methanol
Also methanol has vapor that is in the combustible range inside storage tanks and poses the same risk as ethanol. The same evacuation/isolation distances as for gasoline and ethanol.

FT-diesel
Diesel has a very low explosion danger. The vapor is to lean to ignite with a spark. Although fuel explosions are rare, they are much damaging. Evacuation/isolation distances is the same as for gasoline — 0,3 km for a large spill, and 0.8 km for a tanker fire.

Handling

DME
Although DME is heavier than air and thus has a tendency to flow along the ground and settle in low-lying areas, its relative density is much lower than that of gasoline vapor, 1.5 compared to 3.4–4.0 (and gasoline persists for long periods whereas DME does not). Thus, DME disperses much more quickly than gasoline, presenting a risk for only a comparatively short time after a spill.
A DME release becomes a gas essentially instantly, unlike gasoline, which vaporizes slowly. Thus, a DME release generates a much larger (flammable) gas cloud than release of an equal quantity of gasoline.
One drawback for DME is the risk for static electricity and measures against static discharges must be taken.

Ethanol
Like gasoline vapor is ethanol vapor heavier than air and are slow to disperse in calm air. There is also a potential danger for misuse because it is drinking alcohol.

Methanol
The high level of toxicity and the probability for misuse makes methanol has raised strong concerns about the general population if it is widely used as a fuel.

FT-diesel
Diesel fuel is generally considered to be the safest petroleum fuel, as well as the safest highway vehicle fuel among the full range of alternatives to gasoline,

Conclusion on safety aspects

DME, ethanol and methanol have less thermal radiation compared to gasoline and diesel. The invisible flame from a methanol fire and the slight visible flame from a DME fire is hazard for firefighters. Since DME is a gas there is a higher risk for explosion. The alcohols have a much wider flammability limit and vapors are in the combustible range inside storage tanks. For the alcohols there is also high risk for misuse which can be fatal in the case of methanol

Need for further work

There are more to investigate especially the risk at service stations and the safe handling of the fuels. Also firefighting properties of the fuels must be evaluated. The risk for static electricity especially when handling DME must be evaluated further.

Summary and conclusions

The results for the different fuels are summarized in the toxicity/safety risk matrix below. For comparison with regular fuels have also the properties for Gasoline, Diesel and LPG been include in the matrix (figure 1).

	Toxicity		**Environmental**		**Safety**		
	Acute	Chronic	Air	Water/Ground	Fire	Explosion	Handling
DME	Low	(Low)?	Low	Low	Medium	High	Medium-high
EtOH	Medium	Low	Low	Medium	Medium	Medium	Medium-high
MeOH	High	Low	Medium	Medium-high	Medium-high	Medium	High
FT-diesel	Medium	Medium-high	Medium	Medium	High	Low	Low
Gasoline	Medium	Medium-high	Medium-high	Medium	High	High	Medium
Diesel	Medium	Medium-high	High	Medium	High	Low	Low
LPG	Low	Low	Low	Low	Medium	High	Medium

Figure 1: Fuel matrix with classification of fuels.

From the matrix (figure 1) it can be concluded that there are both advantage and disadvantage for all fuels that have been investigated. For DME the advantages are the low toxicity both for humans and the environment. The drawback for DME is the Safety considerations. Ethanol is a more safety fuel with a low toxicity. Methanol has a high acute toxicity which also influences the safe handling of the fuel. For FT-diesel there is as for diesel fuel a high safety risk when there is a fire. The toxicity and environmental impact is comparable with regular diesel.

References

[1] Ministry of the Environment of the Netherlands (VROM): Dimethylether. A report on examination concerning the safety and environmental aspects of its use as propellant. 1985.

[2] Robust Summaries & Test Plans: Dimethyl Ether. The high production volume (HPV) Challenge Program. EPA U.S. 2002.

[3] Material Safety Data Sheets (MSDS) for the different substances from chemical suppliers:
- Akzo Nobel
- Air Liquid
- Du Pont
- Svensk Etanol kemi AB
- Topsoe Technologies

[4] Documentation of Threshold Limit Values for DME (1994), EtOH (1990), MeOH (1985): National Institute for Working Health, Solna Sweden.

[5] Documentation of Threshold Limit Values for EtOH (2001) MeOH (2001) and Diesel Fuel (2002): American Conference of Governmental Industrial Hygienists (ACGIH) U:S

[6] Steven E. Plotkin: Assessment of PNGV Fuels Infrastructure: Report from Center for Transportation Research, Energy Systems Division, Argonne National Laboratory. 2000.

[7] Ekbom T, Lindblom M, Berglin N and Ahlvik P: Technical and Commercial Feasibility Study of Black Liquor Gasification with Methanol/DME Production as Motor Fuels for Automotive Uses (BLGMF). December 2003 Contract No. 4.1030/Z/01-087/2001.

[8] IARC Monogr Eval Carcinog Risks Hum. 1988;Vol 44:381-401.

[9] Jacobson M: Effects of Ethanol (E85) versus Gasoline Vehicles on Cancer and Mortality in the United States: Environ. Sci. Technol. 2007 Jun 1;41(11):4150-7.

[10] Hampton T: Ethanol-Fueled Vehicles Could Pose Health Risk JAMA.2007; 297: 2068.

[11] NTP-CERHR Expert Panel Report on the Reproductive and Developmental toxicity of Methanol. CERHR NTP, U.S Department of Health and Human Services 2002.

[12] Derwent R.G. et al., (1998). Photochemical Ozone Creation Potentials for Organic Compounds in Northwest Europe Calculated with a Master Chemical Mechanism. Atmospheric Environment, Vol. 32, No. 14/15, pp.2429-2441, Elsevier Science Ltd., Great Britain.

[13] Tom Beer et al: Comparison of transport fuels, Final Report (EV45A/2/F3C). CSIRO Atmospheric Research 2001.

[14] IUCLID Dataset for DME European Chemicals Bureau, European Commission 2000.

[15] IUCLID Dataset for EtOH: European Chemicals Bureau, European Commission 2000.

[16] IUCLID Dataset for MeOH: European Chemicals Bureau, European Commission 2000.

[17] Brunerkreef Bert and Leendert van Bree (2005): Air pollution and the risks to human health- intgrated report. AIRNET-Integrative report 2005.

[18] Emerging Technologies for Diesel and Diesel-like Engines: Chart 1 Potential Emissions of Health Concern. Health Effects Institute (HEI) U.S. 2003.

[19] Verbeek R and Van der Weide J: Global Assessment of DME: Comparison with Other Fuels. SAE-Technical Paper Series 971607.

[20] M Naito, C Radcliffe, Y Wada, T Hoshino, X Liu, M Arai and M Tamura : A comparative study on the autoxidation of dimethyl ether (DME) comparison with diethyl ether (DEE) and diisopropyl ether (DIPE) Journal of Loss Prevention in the Process Industries Volume 18, Issues 4-6, 2005, Pp 469-473