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Pollution Prevention Opportunities in the Offshore Oil and Gas Sector - Final Report

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Pollution Prevention Opportunities in the Offshore Oil and Gas Sector
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Dillon Consulting Limited with BMT Cordah

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Executive Summary

Pollution prevention is quickly becoming the preferred approach to protecting and conserving the environment. Pollution prevention is defined in the *Canadian Environmental Protection Act* as "the use of processes, practices, materials, products, substances or energy that avoid or minimize the creation of pollutants and waste and reduce the overall risk to the environment or human health". This includes waste reduction through: process redesign or modification; substitution; in-process recycling; improved maintenance; and administrative/corporate culture modifications.

This document is a review of pollution prevention practices and opportunities for offshore oil and gas activities in Atlantic Canada. The purpose of the report is to provide guidance to operators in applying pollution prevention to projects. It focuses on pollution prevention opportunities for five priority aspects of offshore operations as identified by ESRF East Coast Waste/Discharges Technical Advisory Group (TAG): air emissions; drilling muds and cuttings; produced water; biocides and glycol.

The document identifies current practices already followed or designed into projects that are pollution prevention practice and future opportunities that may become technologically and economically feasible in the offshore environment in Atlantic Canada as the technologies develop.

The five focus topics are addressed separately for ease of reference but this approach is not consistent with the strategy of holistic application of pollution prevention. In making project decisions about management of drilling muds, for instance, energy consumption, air emissions, vessel requirements, potential environmental effects of discharges and health and safety risks all may have relevance to the type of drilling fluids used. As a result, examples and case studies that have implications across more than one of these topics are provided.

Pollution prevention is a re-thinking of the source of pollution, best applied at conception of an undertaking and during design, when it is possible to consider whether an activity or process is necessary to meet the objective of the undertaking and a process can be optimized or redesigned to reduce or eliminate the need for a toxic substance or reduce the amount of energy required. Examples of pollution prevention planning techniques include: "Green" design and reformulation, also known as Design for Environment (DfE) or Cleaner Production (CP); process improvements and equipment modifications; materials or chemical substitution; inventory control; corporate culture and employee training; on-site re-use; and preventive maintenance.

Costs and benefits in pollution prevention projects should be evaluated for a sufficiently long period to capture the long-term benefits offered by many projects. Pollution prevention projects may also offer significant savings in the areas of compliance, waste disposal and insurance. Therefore when evaluating pollution prevention opportunities costs such as environmental compliance costs and oversight or management costs should be taken into account along with capital costs and operating costs. As well consideration should be given to: improved public image; improved productivity; decreased environmental liability; improved environmental and health quality; potential market opportunity (e.g., marketable by-products); and access to capital.

The document provides a number pollution prevention opportunities for consideration including:

- Avoidance of well testing of initial exploration wells, which will reduce flaring.
- Changes in power generation or selection of power generation methods that have the potential to be more efficient such as substitution of diesel with natural gas or condensate.
- Use of ignition systems that operate in any weather conditions to eliminate the need for a pilot flare.
- The use of low NOx turbines, also referred to as Dry Low Emissions (DLE) turbines, however, there are trade-offs with the technology (e.g., increased fugitive and CO_2 emissions).
- Sequester CO_2 through re-injection.

- The use of jetting instead of drilling, if suitable unconsolidated overburden or soft rock is present to reduce use of drilling muds.
- Re-injection of muds and cuttings.

- The use of synthetic-based mud (SBM) or enhanced mineral oil-based mud (EMOBM) reduces the diameter of wells drilled and, consequently, the volume of muds used and cuttings produced. It also reduces drilling time and associated emissions.
- To reduce drilling muds, the concept of slim hole technology applies the design of drilling programs with the minimum diameter necessary to complete the well. Also expandable casings have been used experimentally to drill wells.

- Re-injection of produced water into source or depleted reservoir.
- Downhole separation of oil and water and gas and water. Separation is also possible at the seafloor. The produced water must then be re-injected.
- Hydrocycloning of produced water using condensate to separate hydrocarbons from produced water.

- Where practical, alternative biocides may be used to substitute less toxic substances for those currently used.
- Monitoring of chlorine levels to adjust chlorine additions.
- Installation of electrolytic systems using copper and aluminum or iron anodes to replace biocides and chlorine.

- Options for pollution prevention for monoethylene glycol (MEG) are limited, however, propriety systems are available.
- Emerging technologies include the use of anti-agglomerates and kinetic inhibitors to prevent hydrate formation.

Pollution prevention includes the holistic consideration of the design of a project. The use of project design workshops can be used to broadly evaluate development options in a non-judgmental, inclusive environment.

Résumé

La prévention de la pollution est rapidement en train de devenir l'approche préférée pour protéger et conserver l'environnement. Dans la *Loi canadienne sur la protection de l'environnement*, elle est définie comme « l'utilisation de processus, de pratiques, de matériaux, de produits ou de sources d'énergie qui évitent ou réduisent au minimum la création de polluants et de déchets et qui diminuent les risques pour la santé humaine ou l'environnement ». Cela comprend la réduction des déchets par la reconception ou la modification des processus; la substitution; le recyclage en cours de traitement; l'amélioration de l'entretien; et des changements dans la culture administrative/organisationnelle.

Le présent document est un examen des pratiques et des occasions de prévention de la pollution pour l'exploration pétrolière et gazière en mer dans le Canada atlantique. Il a pour but de guider les exploitants dans l'application de mesures de prévention de la pollution aux projets, et se concentre sur les possibilités de prévention de la pollution pour cinq aspects prioritaires des activités en mer identifiés par le Groupe consultatif technique (GCT) sur les déchets (rejets sur la côte Est du FEE : les émissions dans l'atmosphère, les boues et les déblais de forage, l'eau produite, les biocides et le glycol.

Le document fait état des pratiques de prévention de la pollution déjà appliquées ou incorporées à des projets, et des possibilités futures qui pourraient devenir technologiquement et économiquement faisables dans les zones extracôtières du Canada atlantique à mesure que les technologies se développeront.

Les cinq domaines prioritaires sont examinés séparément par souci de commodité, mais cette approche ne concorde pas avec la stratégie d'application globale des mesures de prévention de la pollution. Par exemple, dans le cadre des décisions de gestion des boues de forage dans un projet, la consommation d'énergie, les émissions dans l'atmosphère, les exigences concernant les navires, les effets potentiels sur l'environnement des rejets et les risques pour la santé et la sécurité sont tous des éléments qui peuvent dépendre du type de fluide de forage utilisé. C'est

pourquoi on fournit des exemples et des études de cas ayant des implications pour plusieurs de ces éléments.

La prévention de la pollution est un réexamen de la source de pollution qu'il est préférable d'effectuer au moment de la conception et durant l'élaboration d'une entreprise, quand il est possible d'examiner si une activité ou un procédé est nécessaire pour atteindre l'objectif de l'entreprise, et si un procédé peut être optimisé ou modifié pour réduire ou éliminer l'utilisation d'une substance toxique ou réduire la quantité d'énergie requise. Parmi les techniques de planification pour prévenir la pollution figurent les suivantes : la conception et la reformulation « vertes », également appelées conception écologique ou production moins polluante, l'amélioration des procédés et la modification de l'équipement, le recours à d'autres matériaux ou substances chimiques, le contrôle des stocks, la culture organisationnelle et la formation des employés, la réutilisation sur place, et l'entretien préventif.

Dans les projets de prévention de la pollution, les coûts et les avantages devraient être évalués sur une période suffisamment longue pour qu'on puisse saisir les avantages à long terme offerts par de nombreux projets. Ces projets peuvent également autoriser des économies importantes dans les domaines de la conformité, de l'élimination des déchets et de l'assurance. Par conséquent, au moment d'évaluer les possibilités de prévention de la pollution, il faudrait tenir compte de coûts comme les coûts de conformité environnementale et les coûts de surveillance ou de gestion, de même que des coûts d'immobilisation et d'exploitation. Il faudrait également prendre en considération l'amélioration de l'image publique, l'augmentation de la productivité, la réduction des responsabilités environnementales, l'amélioration de la qualité de l'environnement et de la santé, les possibilités de marchés (p. ex., produits commercialisables), et l'accès au capital.

Le document présente un certain nombre de possibilités de prévention de la pollution à examiner, dont :

- L'élimination des essais de puits d'exploration, ce qui réduira le torchage.
- Le changement de méthodes de production d'électricité ou le choix de méthodes qui peuvent être plus efficaces, comme de remplacer le combustible diesel par le gaz naturel ou un condensat.

- L'utilisation de systèmes d'allumage pouvant fonctionner dans toutes les conditions climatiques afin d'éliminer les veilleuses.
- L'utilisation de turbines à faibles émissions de NO_x, également appelées turbines à faibles émissions sèches; il y a toutefois un prix à payer pour cette technologie (p. ex. augmentation des émissions fugitives et des émissions de CO_2).
- La séquestration du CO_2 par réinjection.
- L'utilisation du fonçage au jet d'eau au lieu du forage dans les roches de recouvrement ou les roches tendres appropriées afin de réduire l'utilisation de boue de forage.
- La réinjection des boues et des déblais.
- L'utilisation de boues synthétiques ou de boues à base d'huile minérale réduit le diamètre des puits de forage et, par conséquent, le volume des boues utilisées et des déblais produits. Ce remplacement réduit également le temps de forage et les émissions connexes.
- Pour réduire les boues de forage, le filiforage permet de réaliser le forage d'un puits en n'utilisant que le diamètre minimum nécessaire. On a également utilisé expérimentalement des cuvelages extensibles pour le forage des puits.
- La réinjection de l'eau produite dans une source ou un réservoir épuisé.
- Séparation dans le puits du pétrole et de l'eau ainsi que du gaz et de l'eau. La séparation est également possible sur le plancher océanique. L'eau produite doit alors être réinjectée.
- L'hydrocyclonage de l'eau produite au moyen d'un condensat pour séparer les hydrocarbures de l'eau produite.
- Dans la mesure du possible, on peut utiliser des biocides moins toxiques pour remplacer ceux présentement utilisés.
- La surveillance de la concentration de chlore pour en régler les ajouts.
- L'installation de systèmes d'électrolyse utilisant des anodes de cuivre et d'aluminium ou de fer pour remplacer les biocides et le chlore.
- Les options de prévention de la pollution pour l'éthylèneglycol sont limitées, mais des systèmes brevetés sont disponibles.
- Les nouvelles technologies comprennent l'utilisation d'anti-agglomérats et d'inhibiteurs cinétiques pour empêcher la formation d'hydrates.

La prévention de la pollution implique la prise en considération de la conception du projet dans son ensemble. Les ateliers de conception de projets peuvent être utilisés pour évaluer les options de développement générales dans un environnement inclusif et sans préjugés.

Acknowledgements

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Table of Contents

Page

List of Figures:

List of Tables:

1.0 Introduction

Pollution prevention is quickly becoming the preferred approach to protecting and conserving the environment. Pollution prevention in the Canadian context includes waste reduction through: process redesign or modification; substitution; in-process recycling; improved maintenance; and administrative/corporate culture modifications. As the principles, techniques and benefits of pollution prevention become more broadly known and concepts such as whole-system engineering are embraced in the industrial and commercial fields, new opportunities will become apparent more and more pollution prevention initiatives will take place.

This document is a review of pollution prevention, as defined in Section 1.1, and pollution prevention practices and opportunities for offshore oil and gas activities in Atlantic Canada. The purpose of the report is to provide guidance to operators in applying pollution prevention to projects. Pollution prevention was incorporated within the Offshore Waste Treatment Guidelines (NEB *et al*., 2002) for the first time in the 2002 revisions. Operators need to provide pollution prevention plans with a drilling program authorization (DPA) or a production operations authorization (POA) when following the Offshore Waste Treatment Guidelines (OWTG).

One of the themes of this document is the identification of current practices already followed or designed into projects that are pollution prevention practice. There are also opportunities identified to replace current practices that may be good environmental management but are not pollution prevention. Future opportunities are also identified, which may become technologically and economically feasible in the offshore environment in Atlantic Canada as the technologies develop.

Revisions

This document is intended to be a living document that will be formally updated concurrent with the 5-year review cycle for the OWTG. In between the formal updates, the Boards (Canada-Nova Scotia Offshore Petroleum Board and Canada-Newfoundland Offshore Petroleum Board) should consider posting pollution prevention initiatives and updates to the document on the Boards' websites. An email notification alerting interested parties of recent postings will also help to disseminate new information.

1.1 Definition and Legal Context

Pollution prevention is the central theme of the 1999 *Canadian Environmental Protection Act*. The Act defines pollution prevention as "*the use of processes, practices, materials, products, substances or energy that avoid or minimize the creation of pollutants and waste and reduce the overall risk to the environment or human health*". The Act also refers to pollution prevention plans, allowing the Federal government to require the development and implementation of pollution prevention plans for specific toxic substances (for example, acrylonitrile and dichloromethane). Environment Canada through the National Office of Pollution Prevention and its regional equivalents provide advice on pollution prevention for government, business and individuals.

The Canadian definition of pollution prevention should take precedence in application to the offshore oil and gas sector in Atlantic Canada. Multi-national companies operating in the offshore oil and gas sector have developed corporate pollution prevention strategies based on definitions such as those of the US EPA or the international standard of ISO 14000 series. Therefore these definitions are presented here as context.

Following passage of the *Pollution Prevention Act* of 1990, the US Environmental Protection Agency developed a formal definition of pollution prevention and a strategy for making pollution prevention a central guiding mission. The US definition of pollution prevention means *source reduction* but also *other practices that reduce or eliminate the creation of pollutants through (1) increased efficiency in the use of raw materials, energy, water, or other resources or (2) protection of natural resources by conservation*. While this is similar to the Canadian definition, it does not provide an emphasis on reductions in the use of toxic substances.

ISO 14001:1996 specifies requirements for environmental management systems, to enable an organization to formulate a policy and objectives taking into account significant environmental impacts. ISO 14001 requires top management to define the organization's environmental policy ensuring, among others, that there is a commitment by top management to "prevention of pollution". Thus prevention of pollution becomes one of three pillars of the standard. The other two are compliance to regulations and continual improvement. ISO 14001's definition of prevention of pollution is similar to those given above being the "*use of processes, practices,* *materials or products that avoid, reduce or control pollution, which may include recycling, treatment, process changes, control mechanisms, efficient use of resources and material substitution*". This definition varies from the Canadian definition in several important factors. Recycling off-site, treatment or most control mechanisms are not included within pollution prevention in Canada.

In addition to Canadian Federal initiatives through the *Canadian Environmental Protection Act*, activities are taking place at the provincial level. For instance, in the *Alberta Leaders Environmental Approval Document Program* (which provides an alternative regulatory framework for dealing with industrial activities), one of the entry criteria is a pollution prevention or continuous improvement plan. The Province of Nova Scotia has a web site devoted to pollution prevention (NSDEL). Through this web site the Department of Environment and Labour provides free information and technical assistance to business, industry, government and the public on how to develop and implement programs to prevent pollution. Nova-Scotia has adopted the Canadian Council of Ministers of the Environment (CCME) definition of pollution prevention as: *"...the use of processes, practices, materials, products or energy that avoid or minimize the creation of pollutants and wastes, at the source."* The web site has a specific section dealing with pollution prevention in business and industry.

Additional web based information sources are provided with References in this document.

1.2 Structure and Use of This Document

This document focuses on pollution prevention opportunities for five priority aspects of offshore operations as identified by ESRF East Coast Waste/Discharges Technical Advisory Group (TAG): air emissions; drilling muds and cuttings; produced water; biocides and glycol. Produced water and glycol are relevant almost exclusively to production projects. Drilling muds and cuttings are only related to exploration and development projects. Biocides and air emissions are relevant to all projects.

For each of these topics there is a separate section that provides a summary description of the industry aspects relevant to the topic. Sources of wastes and the reasons these are a concern are identified. Current conditions and practices in Atlantic Canada are discussed in relation to alternative approaches. Where there are available or developing alternative practices or methods that may be applicable as pollution prevention, these are presented. There are pollution prevention practices now in use that were impractical or not applied until recently. These are identified and provide a context for the identification of new methods that are in development or are used elsewhere and may be suitable for use in the harsh conditions of Atlantic Canada in the future.

Addressing the five focus topics separately and in isolation of each other is not consistent with the strategy of the holistic application of pollution prevention. In making project decisions about management of drilling, for instance, the energy consumption, air emissions, vessel requirements, potential environmental effects of discharges and health and safety risks all may have relevance to the type of drilling fluids used. Therefore in addition to the separate presentation of the five focus topics, examples and case studies that have implications across more than one of these topics are provided separately. Some of these also highlight recent successes and expected future opportunities in pollution prevention.

Pollution prevention is not a static process. Continuous improvement is fundamental to pollution prevention practice. Many opportunities for continuous improvement are likely to become available to the offshore oil and gas industry through new technology. A number of these are highlighted in this document. For example, expandable tubing has recently been taken from a technical solution for localized drilling problems to an experimental method for cased well sections in deep water. This offers considerable pollution prevention benefits as well as cost savings. When the use of expandable tubing will be practical in Atlantic Canada is not known.

The intent is for this to be a living document that will be revised and updated with new pollution prevention information as experience and technical advances make new methods available. Rather than creating a guideline for pollution prevention, the intent is to develop a functional handbook with an outline of pollution prevention practices in general, examples of current practices and signposts for opportunities that may become available.

Inclusion of the information sources is both to provide the reference sources for examples of current practice in Atlantic Canada and to encourage operators, individually and in cooperation, to find effective and innovative pollution prevention solutions.

1.3 Pollution Prevention and the Offshore Waste Treatment Guidelines

The *Offshore Waste Treatment Guidelines* (NEB *et al.*, 2002) provide practices and standards for petroleum drilling and production projects for the treatment and disposal of wastes as well as sampling and analysis of waste streams to ensure compliance. Each application for a drilling program authorization (DPA) or a production operations authorization (POA) must demonstrate how the operator will meet the guidelines with compliance monitoring and waste management programs. Although specified concentrations of waste discharges are achievable using proven and practicable best available waste treatment technology, the assessment and development of new technologies are encouraged to reduce the amount of substances discharged.

Operators are expected to minimize the volumes of wastes produced and the quantity of substances of potential environmental concern contained in the wastes of potential environmental concern as well as to reduce the toxicity of substances used. Each DPA or POA should describe the operator's specific pollution prevention plans to reduce waste generation and discharge. The plans should include monitoring the progress of waste reduction plans and at least annual reporting.

Addressing the materials substitution approach to pollution prevention, operators are expected to evaluate chemicals that are used following the *Guidelines Respecting the Selection of Chemicals Intended to be Used in Conjunction with Offshore Drilling and Production Activities in Frontier Lands* (NEB *et al*., 1999). These guidelines suggest a management system to assist in the process of selecting the most environmentally appropriate chemical substances to use. However, regulatory acceptance of the discharge of substances selected through the guideline process is not automatic.

In sections of the OWTG that address specific waste streams there are objectives that are consistent with the pollution prevention approach, and operators are cautioned that meeting minimum standards for treatment and disposal of waste streams is not necessarily sufficient to meet the expectations of pollution prevention.

Air Emissions

Under air emissions, production operators are expected to provide as part of the DPA an estimate of annual emissions of greenhouse gases (GHG) with plans to control and reduce the emissions. Annual calculations of GHG should be submitted to the relevant offshore board in accordance with the *Global Climate Change Voluntary Challenge Guide* (CAPP, 2000). Volatile organic compounds (VOC) emissions should be determined and reported for each drilling or production installation. VOC reporting should be in accordance with existing best management practices for oil and gas operations in Canada.

Produced Water

Relative to produced water, production operators are expected to include in the DPA an examination of the feasibility of alternatives to marine discharge of produced water. During operations this is to be re-examined and reported every five years.

Drilling Muds

For drilling muds the OWTG recommend the minimization of the discharge of oil to the marine environment and the use of water based muds (WBM) or synthetic based muds (SBM). Oil based mud (OBM) use would only be approved by exception where WBM or SBM use is not technically feasible. Enhanced mineral oil-based muds (EMOBM, also called low-toxicity mineral oil [LTMO]) may be approved if the environmental performance is equivalent to or better than that of an SBM.

Whole SBM or EMOBM cannot be discharged to sea. The OWTG recommends that remaining muds of these types be: recovered and recycled; reinjected downhole; or transferred to shore for approved disposal. Although spent WBM can be marine discharged without treatment, operators are expected to reduce the need for bulk disposal of these muds.

For the use of SBM or EMOBM in development drilling, operators are expected to report on the technical feasibility of re-injection of drill cuttings. Where such re-injection is not technically or economically feasible, marine discharge of solids may be approved with retained oil on cuttings amounts achievable with best available technology.

Specific guidelines are provided in the OWTG (NEB *et al*., 2002). A tabular summary, which is attached as Appendix A, has also been compiled by Taylor (2002).

1.4 Pollution Prevention and Environmental Management Systems

An ISO 14001 compliant Environmental Management System is the ideal vehicle for promoting pollution prevention.

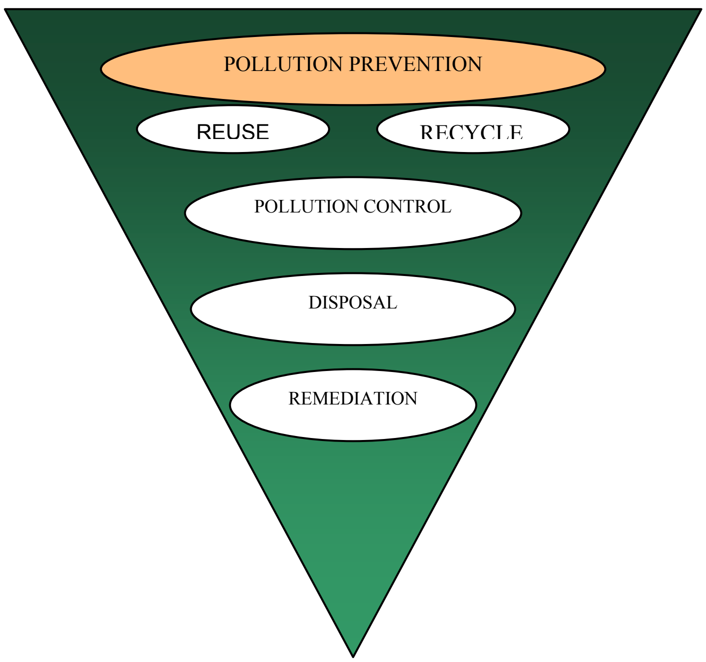
At the policy stage, the commitment by top management to compliance, pollution prevention and continual improvement ensures that pollution prevention activities are given a high visibility in the organization.

At the aspects identification stage, priorities will be assigned such that significant aspects are highlighted and actions taken to improve these aspects. Objectives and targets are set with a view to preventing pollution, and subsequently management programs ensure that adequate resources are assigned to carry out the projects. Monitoring, measurement and auditing confirm that the projects meet the objectives that were set.

1.5 Pollution Prevention Techniques

Pollution prevention is a re-thinking of the source of pollution, best applied at the conception of an undertaking, when it is possible to consider whether an activity or process is necessary to meet the objective of the undertaking and a process can be optimized or redesigned to reduce or eliminate the need for a toxic substance or reduce the amount of energy required. In its simplest form, pollution prevention is roughly synonymous with source reduction, reducing the generation and toxicity of wastes or contaminants at their sources, and thereby reducing releases to the environment that could pose hazards to the environment and public health. Strictly speaking, recycling outside of a process stream is not a form of prevention (although ISO 14001 specifically mentions recycling as a pollution prevention activity). The EPA in particular has held fast to a stricter interpretation because wastes that are recycled have not been prevented.

Figure 1-1 Environmental Protection Hierarchy (Environment Canada, 2001)



The protection of the environment can be thought of as a hierarchy of activities that are the exact reverse of the way things used to be done. The new hierarchy, as presented in Figure 1.1, is thus prevention as a first initiative (*i.e.*, the zero emission concept that is achieved from project conception through initial design), full life cycle optimization and operation, source reduction and on-site reuse, followed by recycling, control (*i.e.*, treatment and disposal) and finally remediation as the least desirable step. In the past, emissions were essentially uncontrolled and, when required, remediation activities were carried out. More recently, industries concentrated on end of the pipe treatment. Industries are now realizing that these are costly and unnecessary steps and are investing in zero emissions factories or as near as they can get to zero emissions by implementing pollution prevention thereby managing emissions/discharges further up in the process. This is pollution prevention at work. A useful conception of the new hierarchy is to re-think of waste as a product that has been paid for but cannot be sold.

Pollution prevention plans form the basis of the pollution prevention process. These plans are used to systematically identify all available options. Processes are analyzed in order to focus on the root causes of pollution thus allowing for the identification of the most suitable solution.

Many techniques can be used depending on the pollution source; some of these techniques include:

"Green" design and reformulation; also known as Design for Environment (DfE) or Cleaner Production (CP)
This is probably the most effective technique, because pollution can be "designed" out or a product reformulated to use less toxic chemicals. This also includes design using a whole-system approach or whole-system engineering that takes into account both capital costs and resulting operational costs/benefits.

Process improvements and equipment modifications
Existing processes can be redesigned to consume less energy, use less water, produce fewer rejects and wastes.

Materials substitution
Similar to product reformulation, materials substitution involves the use of materials or feedstock that are less polluting.

Inventory control
"Green" purchasing policies help achieve significant waste reduction. Reducing packaging, using returnable packaging and returning unused products to suppliers help to reduce pollution.

Corporate culture and employee training
Management commits to creating and supporting corporate initiatives to reduce waste through, for example, ISO 14001. Training helps to change wasteful habits and education promotes environmental awareness in employees, suppliers and clients.

On site re-use
Reusing water contaminated by a process into another less sensitive process, internally recycling scrap, filtering rather than replacing lubricants; re-using solvents for less rigorous needs before distilling solvents are all techniques that reduce wastes and pollution.

Preventive maintenance

Effective maintenance programs help reduce energy consumption, improve operating efficiencies and reduce the generation of rejects and wastes.

Costs and Benefits of Pollution Prevention

Pollution prevention can save money on the costs involved in an industrial process. Many pollution prevention opportunities actually cost little money, being more behavioral change projects than technical projects *e.g.*, training; others must be analyzed carefully to measure their profitability. Other opportunities may have initial capital or implementation costs but these costs may result in longer term saving, such as reduced energy costs that in time will offset the initial cost.

Project plans are usually evaluated on the basis of capital costs, and operating costs such as utilities and materials. Pollution prevention projects may also offer significant savings in the areas of compliance, waste disposal and insurance. Neglecting to account for these hidden costs and savings may lead to the rejection of a perfectly viable project.

The following financial variables should be considered:

Usual costs

Depreciable capital (Equipment, site preparation, installation)
Operating expenses (Direct labour, raw materials, supplies, utilities, maintenance)
Operating revenues including by-products

Compliance costs

Receiving area (spill response equipment, emergency plans)
Raw materials storage (storage facilities, secondary containment, reporting and reports)
Process area (emissions control equipment, safety equipment, waste collection equipment)
Solid and hazardous waste (personnel training and certification; disposal fees, storage areas, transportation fees)
Air and water emissions control (capital costs, operating expenses, discharge fees, permits)

Oversight costs
Purchasing (inventory control, product/vendor research, regulatory impact analysis)
Engineering (hazard analysis, sampling and testing)
Production (rework, disposal management, training, medical monitoring, inspection and audits)
Marketing (public relations)
Management (penalties and fines, legal fees, information systems, insurance)
Finance (credit costs, tied-up capital)

Apart from the beneficial effects to the bottom line, pollution prevention has many other benefits:

Improved public image
Consumers view more favorably businesses that adopt pollution prevention strategies.

Improved productivity
Pollution prevention plans help organizations identify opportunities to decrease raw material usage, eliminate unnecessary operations, maximize throughput, reduce off-spec material, reduce waste and other inefficiencies and improve yields.

Decreased liability
Organizations that substitute toxic materials with safer alternatives reduce the liability and high costs associated with an unsafe environment.

Improved environmental and health quality
Pollution prevention projects will contribute to reducing the air, water and land pollution that results from waste generation, treatment and disposal and reduce worker health and safety risks.

Other Potential Benefits
Market expansion/retention, supply chain compliance, access to capital.

Costs and benefits in pollution prevention projects should be evaluated for a sufficiently long period to capture the long-term benefits offered by many projects. It is important to consider all costs and to evaluate the current cost of the project's components and their alternative costs. Each pollution prevention option considered may be evaluated using a variety of tools. The range of these includes conventional cost accounting, and full cost accounting. A description of these and their application is provided in the Pollution Prevention Planning Handbook (Environment Canada, 2001). The web site for the associated tutorial can be found at http://www.ec.gc.ca/NOPP/P2TUT/eg/indexe.html.

Environmental Protection Hierarchy

Environment Canada states that pollution prevention measures are the upper levels of an environmental protection hierarchy. Table 1-1 provides more detail than the basic hierarchy presented in Figure 1-1 as well as brief examples. Environmental protection activities are ordered from those closest to the root causes of pollution. Product or service changes are given the highest priority; reuse or recycling are given the lowest priority as pollution prevention activities if the recycling is on-site. Off-site recycling is considered a higher priority environmental protection activity, but is not considered as pollution prevention.

Table 1-1 The Environmental Protection Hierarchy (Environment Canada, 2003)

	ACTIVITY	EXAMPLE	
Closer to the root causes of pollution →	**Product or Service Changes**	Replace environmentally-harmful product/service with environmentally-responsible product/service	Pollution prevention as defined in Canadian policy and law
	Product or Service Improvements	Redesign or reformulate product/service to make more environmentally-responsible throughout life cycle e.g., extend product life, design for reuse.	
	Process or Technology Improvements	Redesign process or change technology, to make more efficient use of materials or to avoid/minimize generation of pollutants/waste	
	Input or Raw Material Changes	Minimize raw material use Minimize water use Minimize energy use Change purchasing practices/specifications to substitute environmentally-preferable materials (including less toxic substances)	
	Operating Improvements	Optimize operating efficiency, scheduling Improve maintenance procedures Change inventory/purchasing practices to reduce waste Improve housekeeping practices Avoid/minimize losses/leaks/spills	
	Reuse or Recycling (possibly preceded by control or containment*)	On-site reuse materials Close process loops Recycle materials on-site	
	Reuse or Recycling (possibly preceded by control or containment*)	Off-site reuse of waste/by-product materials Waste exchange Off-site recycling, reprocessing, material recovery, reclamation	Traditional pollution control and waste management
	Waste-to-Energy	Combustion of wastes/by-products for energy value, e.g., municipal waste incineration, landfill gas power generation	
	Treatment or Destruction (possibly preceded by control or containment*)	Biological treatment, including municipal sewage treatment Physical treatment Chemical treatment, e.g., neutralization, stabilization	
	Disposal (possibly preceded by control or containment*)	Secure disposal, storage, encapsulation Landfill	
	Reclamation or Mitigation	Site/soil remediation Ecosystem restoration Impact mitigation, increased health care requirements	

*e.g., precipitation, scrubbing, baghouses, cycloning, screening, settling, filtration, dewatering, berming, shrouding, sumps, on-site spill cleanup, etc.

An Ontario pollution prevention planning guidance document gives examples of process changes considered to be pollution prevention, because the changes reduce the amount of waste created during production, and provides a contrasting list of measures that are not pollution prevention, because they are applied after waste is created (Table 1-2).

Table 1-2 Environmental Management Measures that are and are Not Pollution Prevention (adapted from Box 1 and Box 2 of Ontario, 1993)

<table>
<tr><th>Pollution Prevention Process Changes</th><th>Measures that are Not Pollution Prevention</th></tr>
<tr><td>On-site Reuse – closed loop recycling reduces material use and waste production</td><td>Off-site Recycling – likely to be more residual waste than with on-site reuse; likely to be more releases to the environment during transportation and may be added exposure risks for workers</td></tr>
<tr><td>Input Material Changes – replacement of toxic process materials with less toxic ingredients; purchase additives without trace quantities of hazardous or toxic impurities</td><td>Waste Treatment – changes in form or composition of wastes to reduce or eliminate the amount, toxicity or disposal space requirements, e.g. incineration or stabilization</td></tr>
<tr><td>Technology Changes – redesign of equipment such as piping to reduce the volume of material contained; install hard piped vapour recovery; use more efficient motors</td><td>Concentrating Hazardous or Toxic Constituents to Reduce Volume – dewatering of sludge before disposal to reduce disposal volume</td></tr>
<tr><td rowspan="2">Best Management Practices – train operators; separate waste streams to avoid cross contamination; track shelf life and manage inventory to avoid unnecessary disposal; turn off equipment and lighting when not in use; spill and leak prevention</td><td>Diluting Constituents to Reduce Hazard or Toxicity – the absolute amounts entering the environment are not reduced</td></tr>
<tr><td>Transferring Hazardous or Toxic Constituents from One Environmental Medium to Another – collection of pollutants from one medium and discharging them in another, for instance activated carbon removal of solvents from water followed by air emission of the solvents by regenerating the filter medium</td></tr>
</table>

1.6 Pollution Prevention Planning

Pollution prevention is primarily implemented through rethinking a project from its inception. More effective protection of the environment is linked to lower production costs and increased efficiencies. Increased productivity may be achieved through more efficient materials and energy use. Pollution prevention may also reduce long-term liabilities from discharges or disposal of wastes; reduce the risk of accidental spills and discharges to the environment; and reduce occupational health and safety risks. This summary of pollution prevention planning is primarily drawn from the Pollution Prevention Planning Handbook (Environment Canada, 2001) and is closely akin to the ISO 14001 Standard and other environmental management system (EMS) approaches. The handbook works best in application to manufacturing, but is adaptable in principle to offshore oil and gas activities.

Effective pollution prevention requires systematic and effective planning, and incorporation of pollution prevention with broader organizational planning processes. A general outline of implementation is provided by the pollution prevention planning checklist in Table 1-3:

Table 1-3 Pollution Prevention Planning Checklist (Environment Canada, 2001)

1.	**Commitment and Policy**		
	a.	Obtain senior management commitment	
	b.	Prepare and communicate a written pollution prevention policy	
	c.	Assign an accountable manager	
	d.	Establish a pollution prevention planning team and commit adequate resources	
	e.	Integrate the pollution prevention planning process with existing management systems, including any EMS	
2.	**Baseline Review**		
	a.	Define the system boundaries (scope) of the plan	
	b.	Assess the existing situation (with good baseline information)	
		i.	Establish a process and material flow profile of relevant operations and processes
		ii.	Quantify inputs and outputs and mass balance
		iii.	Calculate total costs and benefits of current approaches
		iv.	Identify relevant legal requirements (international, federal, provincial, municipal)
		v.	Identify related company policies and targets
		vi.	Identify stakeholder concerns and market issues
		vii.	Identify business issues including the existing planning and management systems
3.	**Planning**		
	a.	Identify pollution prevention opportunities	
	b.	Establish objectives, targets and performance indicators	
	c.	Define and involve the affected community and employees	
	d.	Develop an action plan to meet objectives and targets	
		i.	Identify specific pollution prevention options, and their environmental, technical and cost aspects
		ii.	Evaluate and rank options based on environmental benefits, technical feasibility, costs and applicable strategic considerations
		iii.	Select preferred options and assign responsibilities, resources and timelines
4.	**Implementation**		
	a.	Implement the selected options	
	b.	Identify employee training needs and provide training	
	c.	Integrate with existing management systems	
	d.	Create support mechanisms (e.g., incentives, penalties, internal and external communications, reporting forms)	
5.	**Monitoring and Reporting**		
	a.	Monitor implementation of the plan and performance against objectives and targets	
	b.	Document the results, including costs, savings and other benefits	
	c.	Take corrective action if necessary	
	d.	Report to management and to the public	
6.	**Review, Evaluation and Improvement**		
	a.	Conduct regular reviews of implementation progress and performance results	
	b.	Identify changing internal and external circumstances	
	c.	Revise the objectives and targets, resource allocation and action plan as required	

Commitment and Policy

A written policy of preventive environmental management is needed to provide broad support and demonstrate the commitment of the company. Accountability supported by sufficient authority and resources should be provided to a senior manager. Pollution prevention may be fully integrated into an EMS, so that separate documentation may not be required.

Baseline Review

Detailed information is required to identify the most significant pollution prevention opportunities and information gaps. System boundaries should be defined, as where the boundary is set can influence the options considered. For instance, value engineering practices can be applied to identify pollution prevention opportunities; however, this tends to be focussed on construction only or capital costs only and not on operating costs. Setting pollution prevention boundaries so that all phases of a project can be considered holistically may justify higher construction costs, when net pollution prevention benefit (and net project cost savings) can be demonstrated.

Within the boundaries identified, the review requires the completion of a detailed profile of all processes, including quantification of all inputs and outputs. This may require detailed life cycle analysis, which would include emissions, discharges and disposal of materials.

Other internal or external factors may also be considered. These include regulatory requirements, stakeholder issues and concerns, and internal policies and procedures.

Planning

Planning builds on the baseline review through iterations of objectives and targets from tentative to specific and detailed options. These should be identified to prevent on-site releases and off-site transfers for disposal and recycling. They should also prevent pollution associated with pollutants contained in products that are taken off-site.

Pollution prevention should be considered for the full life cycle. In manufacturing the full life cycle of a product would be considered; in offshore oil and gas the full life cycle of a project can be considered. Objectives and types of pollution prevention practices for the full life cycle of project are listed in Table 1-4.

Table 1-4 Possible Pollution Prevention Objectives and Practices (adapted from Table 2, p. 15, Environment Canada, 2001)

Project Stage	Possible Objectives	Possible Practices	Example Applications
Design	Reduce material intensity Extend product life Reduce pollutants from product use	Design and reformulation	Slim hole design Drilling fluid selection
Raw material acquisition and processing	Increase use of low-impact materials – renewable, low energy content, recycled and/or recyclable; Reduce materials – reduce weight, reduce storage volume, reduce transport volume, reduce number of different materials	Design and reformulation Materials and feedstock substitution Purchasing techniques and inventory management	Drilling fluid additive selection and substitution with less toxic chemicals; optimize re-use of drilling fluids; inventory management to minimize waste materials
Exploration and development	Increase clean operations – low and clean energy use, water conservation, low waste, few and clean inputs	Equipment modifications and process changes Operating efficiencies and training On-site reuse and recycling	Expandable casings; Reuse WBM
Production	Increase clean operations – low and clean energy use, water conservation, low waste, few and clean inputs	Equipment modifications and process changes Operating efficiencies and training On-site reuse and recycling	Downhole separation of produced water; re-injection of produced water; CO_2 re-injection; H_2S re-injection; collection and recycling of glycol and waste oil; formation oil/water separation using polymers
Use, reuse and maintenance	Minimize user impact – low energy use, clean energy use, low water use, low material use and waste generation, low emissions Optimize initial life – adaptable and upgradable, reliable and durable, easily maintained and repaired	Product design and reformulation Materials and feedstock substitution	Improve efficiency of motors
Disposal	Optimize end-of-life – ensure that products are reused, remanufactured, recycled or safely disposed	Product design and reformulation Materials and feedstock substitution	SBM use to avoid shipping cuttings to shore; use muds that can be renewed and reused

Options may be evaluated based on technical feasibility, environmental effectiveness, cost effectiveness and business considerations relevant to the particular corporate organization.

Technical feasibility may include considerations of availability and proven performance; risk of non-performance; maintenance requirements; compatibility with existing space, technical systems and support systems; health and safety implications; labour skills and training requirements; effect on operational flexibility; and shutdown requirements for implementation.

Environmental effectiveness should consider the magnitude of both benefits and possible adverse impacts. A benefit in one medium may have potential adverse effects in another. Reductions in air emissions may be offset by increases in hazardous waste or effluents.

Financial considerations include the difference between the costs of current processes and the proposed options. Full cost accounting may demonstrate a reduction in overall costs.

Business considerations may provide priorities for evaluation criteria, which may be factors of legal considerations, regulatory trends, social and cultural issues, corporate image and opportunities for partnerships.

Action plans should be developed for each option selected. These plans should include specific targets to meet, tasks required, responsible parties, affected parties, resource requirements, a schedule and indicators for monitoring. Training requirements may be included. Both internal and external parties (such as suppliers) should be engaged in both plan development and implementation.

Further information on developing pollution prevention plans is available through Environment Canada's Pollution Prevention website: http://www.atl.ec.gc.ca/epb/pollprev/loapic.html.

Implementation

For implementation, various employees will have responsibility for components of the plan but one manager should oversee implementation. All employees should be aware of the plan and some may require relevant training, such as in new equipment operation or waste reduction procedures.

Monitoring and Reporting

Monitoring should include plans for status evaluations, including costs and savings as well as progress towards objectives and targets. Monitoring methods, staff responsibility and monitoring frequency should be part of the monitoring plans. Where possible, performance indicators and milestones should be identified.

An outcome of regular monitoring would be detection of variance from objectives and targets to allow early correction. Records of the monitoring and any corrective actions should be retained for review. Progress reports are important to maintain momentum and evaluate progress. Public reporting may be part of the plan to provide benefits in enhanced image and improved community and government relations.

Evaluation and Improvement

Pollution prevention plans should be continuously re-evaluated and improved. Regular review of achievements and the appropriateness of objectives and targets should be made in the context of internal and external considerations. Changes in technology, finances or other considerations may make new options feasible. The review may identify the need for reallocation of resources; plan revisions; or objective and target changes.

2.0 Pollution Prevention Priority Topics

The following priority topics are addressed: air emissions, drilling fluids and cuttings, produced water, biocides and glycol. In addition a single section identifies various other pollution prevention opportunities relevant to the industry. Under each topic the background is presented with a description of emission and waste sources and the related processes, as well as the issues of concern relevant to pollution prevention. Current practices in Atlantic Canada and elsewhere are outlined. These practices are then discussed in the context of pollution prevention practices that are available, may become available or may not be suitable for offshore use in Atlantic Canada. Practices may be unsuitable under current operating or project risk conditions, may be applicable for development but not for exploration or may be technically undeveloped, but have some promise for future application. Again, it is noted that pollution prevention should be applied holistically, so that pollution prevention plans should encompass and consider all waste and emission sources and all phases and aspects of a project. Comparing options in drilling fluid selection may incorporate effects on net energy consumption and consequent air emissions, as well as potential marine effects and health and safety risks. This interrelationship of outcomes between waste and emissions sources is addressed in Section 3 with case studies.

2.1 Air Emissions

2.1.1 Background

Air emissions include flaring and venting, fugitive emissions and combustion emissions. Flaring is the combustion of natural gas and light condensates as waste or byproducts. When the quantities cannot economically, feasibly or safely be collected for sale the practice has been to burn them as waste. When produced gases do not contain sufficient hydrocarbons to maintain combustion, they may be freely vented to the atmosphere. The non-hydrocarbon gases are predominantly CO_2 and others such as H_2S. Also during well testing hydrocarbons may be flared, since the quantities do not make collection, transportation and processing/sale of the hydrocarbons practical.

Fugitive emissions are those that escape to the atmosphere from standard operations or maintenance procedures. Sources of fugitive hydrocarbons include losses during coupling disconnection, leakage out of equipment and losses of the volatile gas volume in liquid storage systems. Losses of unburned hydrocarbons that would otherwise be flared may also be considered venting or fugitive losses.

Combustion air emissions are those derived from the engines and power systems used to operate drilling and production systems. Subsidiary equipment such as cranes, compressors, pumps and hydrocyclones are necessarily or may be separate emissions sources from the main power system. Commonly, engines and motors are diesel fuel driven, but other fuels including natural gas may also be used.

Sources of air emissions from offshore oil and gas activities in Atlantic Canada are characterized in another ESRF document, *Standardizing the Reporting of Emissions to Ambient Air From Atlantic Canadian Offshore Petroleum Activities* (Dillon and Cordah, 2003).

The OWTG require operators to provide in a DPA an estimate of the annual greenhouse gas emissions from offshore installations and the plans to control and reduce such emissions (NEB *et al.*, 2002, s. 2.2).

Operators of drilling or production facilities should provide an annual calculation of greenhouse gas emissions as well as a determination of the type and significance of volatile organic compound (VOC) emissions. VOC emission rates are to be related to existing Canadian oil and gas industry best management practices.

Concerns

Emissions of concern are both atmospheric losses of vented or incomplete combustion products and emissions from complete combustion. The isolated locations of offshore activities generally make air emissions primarily a concern at the global level, or at most a regional level. Emissions from incomplete combustion can however impinge locally on the marine environment, if hydrocarbons settle to the sea surface. The emissions of greenhouse gases, CO_2 and methane are of global concern. Methane emissions from venting, fugitive losses and incomplete combustion are contributions to greenhouse gases that have a 21 times greater effect than the equivalent carbon dioxide resulting from complete combustion (Houghton *et al*, 1995). Therefore, flaring is preferable to venting, when there is no alternative. Combustion efficiency is important to limit the loss of hydrocarbons the atmosphere.

A significant source of flaring emissions can be flaring of methane and light hydrocarbons that are produced with oil. In the offshore, where there is no available method for collection and marketing of natural gas produced with oil the past practice has been to flare the gas.

2.1.2 Current Practice

Atlantic Canada Practices

The Hibernia project has ceased its previous operating practice of flaring natural gas and is now compressing and reinjecting natural gas both for production enhancement and as storage for potential production and sales in the future. Technologies for the shipping of liquified natural gas and compressed natural gas may become economical. From 90 to 95% of produced natural gas is now re-injected and 3 to 4% is used for power production. The power generation systems are dual fuel turbines, so that when there is sufficient produced gas the use of diesel fuel is displaced. Some flaring still occurs when the re-injection compressors are not operating, but there has been a yearly decline in the flaring (Hibernia web site; D. Burley, pers. comm.).

The EnCana Deep Panuke project has been designed to prevent the discharge of both H_2S and associated CO_2 by re-injection to an underground formation. Offshore processing would strip acidic gases hydrogen sulphide and carbon dioxide from the natural gas to meet sales gas specifications. Natural gas liquids and water would also be separated. Since the ratio of condensates to natural gas is low, the condensate would be used as fuel for the power needs of the production and processing facilities. Seawater scrubbing of these gases was considered in the initial project design, and rejected in favour of re-injection. Seawater scrubbing would almost eliminate H_2S air emissions, but not CO_2, and would transfer sulphur to the ocean. The re-injection formation would be selected to prevent accidental seepage of the gases, so that they remain effectively sequestered. Some flaring of acid gas would be required during maintenance or if equipment malfunctions in the injection system, which may be as much as 5% of the time. The flaring is required for safety to burn off toxic H_2S. Flaring will be minimized by optimizing shutdown times for injection compressor maintenance when production levels are low (EnCana, 2002).

Current Practice Elsewhere

Flaring represents around 30% of the UK offshore industry's CO_2 emissions (5.5 m tonnes CO_2). During 2001, the industry participated in the voluntary Flare Consents Pilot Scheme. Eleven companies participated in 2001 involving 63 offshore fields, representing some 45% of UK offshore production. The companies involved agreed to targets averaging 10% below approved levels. The scheme led to successes in reducing GHG emissions. Actual flare volumes released in 2001 (across the industry) were 12.5% less than 2000. The scheme continued to run in 2002. Other projects were initiated by non-participants in the pilot study and these were successful in reducing flaring by a similar amount.

2.1.3 Pollution Prevention Opportunities

Avoid Production of Air Emissions

There are few opportunities to completely avoid air emissions. One is the avoidance of well testing of initial exploration wells, which requires flaring. Testing of discovery wells, as opposed to delineation wells, is not necessary from a reservoir potential standpoint. As a result, some companies will not test and flare on the first discovery well.

It has been common practice to flare during well testing; however, the amount of flaring has been reduced recently by limiting the amount of testing, which also reduces the accuracy of information used to make efficient production decisions. Emission-free sampling and well testing systems have been designed to both eliminate flaring and improve the quality of data collected. Halliburton has developed one of these systems (Fosså, 2001), which is a tubing-conveyed, cased-hole system for liquid reservoirs. The process uses a down-hole apparatus to test formation pressures and test and sample fluids. Both bulk and small volume samples can be collected. The system meets all the industry "must have" functions that were anticipated, but does not meet some of the "desirable but not essential" functions. It is not capable of multi-phase measurement, limits testing or testing without a rig. In addition to meeting the desired functions, the process improves well-site safety, eliminates flaring (although not all emissions can be eliminated) and reduces overall well test cost, since a smaller test crew is required. Durability and reliability are provided by the modification of existing components.

Reduce the Amount of Air Emissions

Process and technology improvements and operating improvements can very substantially reduce air emissions. Both the Hibernia and Deep Panuke projects provide examples that reduce direct air emissions to the level of about 5% of the uncontrolled emissions. Both the natural gas and acid gas re-injection have associated air emissions from compression requirements.

Both projects also illustrate changes in power generation or selection of power generation methods that have the potential to be more efficient. Fuel substitution of diesel with natural gas or condensate in this manner is a waste to energy use, which would not be considered as pollution prevention. However, this fuel substitution is good pollution prevention practice since power must be used for injection and natural gas and condensate are cleaner burning and more efficient fuels than diesel. In the past natural gas and condensate have been treated as waste products.

Where conventional diesel engines continue to be used, engine and fuel efficiency can be improved. Noble Drilling installed commercially available diesel fuel injectors and used engine – injector-timing retardation on all diesel engine power systems on three rigs. Testing showed fuel consumption decreased 2% and NOx emissions decreased 30 %, for an expected average savings of $5,000 a year for each engine. With confirmation from permanent monitoring of sulphur, NOx and CO_2 emissions on four engines of an operating rig, the company may install these emission improvement devices on all 32 of its drilling rigs in its fleet with the same locomotive-type diesel engines (Boudreaux, 2002).

Technology is available to reduce operational flaring. Ignition systems that operate in any weather conditions eliminate the need for a pilot flare (Miles, 2001; see ABB, 2003 for instance). Continuous flare gas flows can also be recovered. One system provides a rupture disk and ignition system, so that gases can be diverted to a flare when a specific pressure level is reached, but continuous lower gas levels can be recovered and used (ABB, 2003).

Inert blanket gases are commonly used over liquid storage vessels such as those for product storage on an FPSO. This blanket gas can accumulate significant amounts of VOCs, which are subsequently emitted to the atmosphere as the vessel fills and the blanket gas is displaced. An alternative method is the use of a hydrocarbon blanket gas, which eliminates oxygen, but can be recovered and re-used as the vessel fills (ABB, 2003).

Under the Integrated Pollution Prevention and Control (IPPC) Directive in the EU, it is necessary to demonstrate that Best Available Techniques are used for certain activities. In the case of turbines used for power generation or compression, the benchmark for new installations is the use of low NOx turbines, also referred to as Dry Low Emissions (DLE) turbines. Operators are expected to use this technology unless there are very good reasons to do otherwise. While this technology represents BAT for NOx emissions, the technology has the following trade-offs:

- Due to the increased number of fuel injection points on a DLE Machine, there may be a higher potential for fugitive releases;
- DLE machines are generally less thermally efficient than the non DLE Machine, which increases carbon dioxide emissions; and
- More complex equipment and control systems increase the likelihood of breakdown and hence greater venting emissions.

Clean burner technology can be applied to control combustion of flared gas or hydrocarbon fluids. Proprietary 'super-green burners' maximize the efficiency of the burning process by ensuring the appropriate airflow to the burner. Use of the technology minimizes hydrocarbon dropout to sea.

A case study is presented for the sequestration of CO_2 in Section 3.8.

2.2 Drilling Fluids and Drill Cuttings

2.2.1 Background

Drill cuttings are the mineral particles produced by the drill bit from the native bedrock. Cuttings are removed from the borehole by dense drilling fluid formulations or muds. Drilling fluids are also used to lubricate the drill stem in the borehole, stabilize the borehole, and may be used to hydraulically turn the drill bit. For the top hole sections of a well, where there is no casing installed, sweeps of WBM are used to clean cuttings away from the bit and the muds and cuttings are discharged to the seabed. Once casing is installed in a well, drilling muds and cuttings are returned to the drilling unit through the riser. Cuttings are removed from the muds and the muds are re-used if they are suitable.

There are several methods of managing the waste cuttings and muds. The cuttings disposal methods used can vary with the type of mud used, the location of the well and regulatory requirements. Cuttings from WBM are generally discharged to sea from the drilling unit. Cuttings separated from muds with synthetic oil (SBM) as a lubricant may also be discharged to sea in some jurisdictions. The general alternatives to discharge to sea are shipping to shore or re-injection into bedrock through an existing or purpose drilled well. Re-injection requires access to a bedrock formation that will accept and retain injected cuttings. The former common practice of using diesel fuel in oil based muds (OBM) has been generally discontinued and is not discussed further. However, EMOBM[1] uses similar oils, which have been purified to remove most of the polycyclic aromatic compounds (PAH) and to reduce toxicity, are used when cuttings are not discharged to sea. Once shipped to shore oily cuttings may be treated, re-used or managed on land.

Except for the uncased well sections, muds are usually re-used after cuttings have been separated from them. WBM is commonly discharged to sea when it can no longer be used, which is often after a single use. SBM and LTMO that is no longer suitable for use may be re-injected or shipped to shore. Some muds may be reconditioned at shore-based facilities for reuse on another well.

Other Mud Components and Additives

There are a variety of additives used in drilling fluids to modify their properties and enhance their performance. In addition to the major components of bentonite clay and barite, categories of

[1] EMOBM is defined in s. 2.4 of the OWTG as containing highly-purified petroleum distillate that has a PAH content less than 10 mg/kg.

additives that may be used include scale inhibitors, viscosifiers, corrosion inhibitors, wetting agents and dispersants.

Beyond the initial selection decision between WBM or SMB/EMOBM use, the application of pollution prevention to the formulation of drilling fluids is supported by the Offshore Chemical Selection Guidelines (OCSG) (NEB *et al*., 1999). The OCSG provide criteria for the selection of chemicals for use in offshore drilling and production that are to be discharged to the environment. Considerations include CEPA listed substances, substances known to cause tainting in fish tissues, and hazard rating. Tainting and an early acceptability criteria are based on substance evaluations by the Oslo and Paris Commissions (OSPAR) sources. Substances passing these criteria are rated for hazard by the UK Offshore Chemical Notification Scheme (OCNS), which classifies chemicals using test protocols approved by the OSPAR under the requirements of the Harmonised Offshore Chemical Notification Format (HOCNF). The OCNS assigns hazard ratings from the most hazardous category of A to the least hazardous category of E. Toxicity testing, discharge quantities and chemical specific hazard analysis may be required to determine the suitability of a substance rated in group A or B. With each step of the review, substitution of substances by less hazardous alternatives is reinforced.

Chemical selection for use on the UK offshore now goes beyond the criteria specified in the OCSG. Since May 2002, in the UK chemical selection is to be administered under the Offshore Chemical Regulations 2002 (OCR 2002). Offshore chemicals are to be ranked according to their calculated Hazard Quotients (HQ) - ratio of Predicted Environmental Concentration (PEC) to Predicted No Effect Concentration (PNEC). The CHARM "hazard assessment" module is used as the primary tool for ranking. This is carried out by a multidisciplinary CEFAS team (the Centre for Environment, Fisheries and Aquaculture Science [CEFAS] is an Executive Agency of the UK Department for Environment, Food and Rural Affairs). The HOCNF can be filled in to suit the CHARM model.

Inorganic chemicals and some organic chemicals have functions for which the CHARM model has no algorithms. These will continue to be ranked using the existing OCNS hazard groups. A complete description of the OCNS assessment process can be found in the CEFAS guidelines to the non-CHARMable chemical assessment process (CEFAS).

The Offshore Waste Treatment Guidelines (NEB *et al.*, 2002) allow drillers to apply for approval to discharge SBM cuttings with 6.9% retained oil on cuttings as wet weight, although the use of WBM is preferred. To reach these levels additional treatment of cuttings beyond the conventional cutting from mud separation equipment (shale shakers) is required such as hydrocyclone cuttings dryers. WBM cuttings and whole WBM may be discharged to sea, but whole OBM cannot be discharged to sea under any circumstances, including SBM and EMOBM. Unused SBM and EMOBM may be recovered and recycled, reinjected or shipped to shore for disposal.

Concerns

Concerns about the discharge of drilling fluids and cuttings relate to the fate of particulate material in the marine environment as well as the potential toxicity of fluid components. Deposits on the seafloor may smother benthic organisms and high concentrations of suspended solids can affect marine organisms. Tainting of commercial species, most notably scallops, is also a potential effect from oil on cuttings. SBM and EMOBM oils on cuttings deposits will decompose, but this may cause oxygen depression and resulting smothering of benthic organisms.

2.2.2 Current Practice

Off Nova Scotia and Newfoundland, operators apply each of the practices outlined above. Where discharge to sea is allowed or land disposal is readily available, costs are likely to discourage re-injection.

Atlantic Canada practice is consistent with the US. The EPA published regulations to establish technology-based effluent guidelines and standards for discharge of SBM cuttings beyond 3 miles offshore. These regulations apply to the Gulf of Mexico and Alaska with the exception of coastal Cook Inlet. The EPA rule recognizes the use of SBM use as a pollution prevention method when cuttings are discharged to sea when base fluids and cuttings discharge criteria are met. Retained oil on cuttings limits are set at 6.9% wet weight. Base fluids are regulated for toxicity, biodegradation, PAH and metals content.

In the North Sea, the UK and Norway have set a retained oil on cuttings discharge maximum of 1 %. Since technology is not available to reach this level this is an effective ban on the discharge of cuttings with retained oil. Oily cuttings are re-injected or shipped to shore.
Muds and cuttings that are shipped to shore may be disposed of in a landfill or treated and disposed of or used in various ways. Drilling muds are also reprocessed onshore for re-use in drilling.

For more information on the current management and handling of drilling wastes, the reader is referred to: *Offshore Drilling Waste Management Review*, February 2001 by the Canadian Association of Petroleum Producers and http://www.cnsopb.ns.ca/Generalinfo/exploringoilgas.html.

2.2.3 Pollution Prevention Opportunities

Avoidance of Muds and Cuttings as Wastes

The use of muds and production of cuttings is essential to exploration and development drilling. In some locations the first top hole section can be developed by jetting instead of drilling, if suitable unconsolidated overburden or soft rock is present. This avoids the use of any drilling fluids for that section, and simply displaces the native material onto the seabed.

Re-injection is effectively an avoidance process, because injected muds or cuttings are sequestered within bedrock and are neither discharged to the marine environment nor shipped to land for disposal. Re-injection requires an available well and suitable bedrock formation, which are not usually available during exploration or early in development. An exploration project that used re-injection is described in the case examples (Cook Inlet, Section 3.3).

Reduce the Amounts of Materials Used and Waste Disposal

Methods that reduce the amount of muds used and the amount of cuttings produced fit this category. The use of SBM or EMOBM reduces the diameter of well drilled and consequently the volume of muds used and cuttings produced. Oil based muds provide better lubrication, better borehole stability, less loss of fluids to bedrock and reduced reaction with shale. In using SBM or EMOBM, not only can be borehole diameter be reduced, but less mud is wasted and fewer cuttings produced relative to the well diameter than with the use of WBM. The use of SBM or

EMOBM also allows faster drill penetration rates, which serves to reduce drilling time and the associated energy use and associated emissions. The concept of slim hole technology applies the design of drilling programs with the minimum diameter necessary to complete the well. A risk of this approach is 'running out of diameter' if more decreases in casing diameter are required than expected.

The practice of drilling multiple wells from a single location, using directional control of drilling, offers similar financial economy and associated reductions in the environmental footprint of drilling.

If well diameter can be reduced sufficiently, it is possible that the riser diameter may also be reduced. This would allow the use of smaller drilling units, again reducing the energy requirements and air emissions as well as reducing costs.

Recently, expandable casings have been experimentally used to drill wells. Conventional well diameters and casing diameters decrease as a well is drilled deeper. Casings have to be small enough to be 'nested' so that new casing can be run through the inside of previously cased well sections. Expandable casing has been used to produce onshore wells with a constant diameter from top to bottom. Experimental application of this technique is proceeding in offshore applications (see Case Studies, Section 3.2).

Control Disposal

Many options are available for the onshore re-use, treatment or disposal of cuttings. Although re-use and recycling off site is not generally considered as pollution prevention, a benign use of the waste material in place of some other raw material use, *i.e.* to replace quarried granular material in a product or process, is good environmental management.

A recent project by Mott MacDonald and BMT Cordah, funded by Shell and BP, looked at existing and innovative methods for the recycling of cuttings. Although the details of this report are confidential, the Executive Summary has been released into the public domain and provides an overview of recycling methods in the UK and general practices in cuttings re-use and disposal worldwide.

In this project, a total of 95 potential recycling opportunities were originally identified. Screening against environmental and commercial evaluation criteria indicated that the following ten specific recycling options were considered appropriate for further consideration:

- Use in estuarine restoration
- Use in cement manufacture
- Use in land reclamation and landscaping
- Use in road pavements, bitumen and asphalt
- Use as fuel and pulverised fuel ash
- Use as pipeline bedding and sub-base
- Use in roof tiles
- Use in pipeline coating
- Use in concrete block and ready-mix
- Use in path construction

The following table summarises a number of worldwide activities relating to the recycling and disposal of drill cuttings. This indicates the types of recycling and disposal routes that have been tried. Not all have been successful, and in many cases further data has been difficult to obtain. Note that no further details of these activities are available.

Table 2-1 Worldwide Activities Relating to Drill Cuttings Disposal

Activity	Location
Incineration (ash to landfill)	Norway
Bioremediation and Land Farming	Norway
Landfill	Norway
Landfarming	France
Cement	Austria
Cement	Azerbaijan
Desorption to Landfill and Quarry Roads	Canada
Supercritical Extraction to Land Farming	USA
Roof Tiles, Statoil	Norway
Chloride Free Bioremediation to Land Farming	Canada
Concrete	Alaska, USA
Landfill Liners	USA
Land Farming	USA
Replacement of Chlorides in muds with Formates (not a recycling solution, but a relevant issue)	Alberta, USA
Incineration and Land Farming	Venezuela

Activity	Location
Land Farming	Brazil
Spreading on Roads	Argentina
Rotary Kiln to Bricks	Colombia
Incineration	Nigeria
Landfill (very little OBM)	Australia
Chloride Free BioRemediation to Landfarming	New Zealand
Chloride Replacement with Nitrates, Landfarming	Canada
Landfill	Adriatic Sea
Land Farming	Sharjah, UAE
Land Farming	Egypt
Land Farming	Indonesia
Land Farming	Colombia

Other Issues/Limitations

Health and safety may also be a consideration in comparing drill cuttings disposal options. Onboard treatment of cuttings for discharge to sea, whether of WBM or SBM cuttings, may present less health and safety risks. The multiple lifts and associated handling required for the skips used to store and ship waste cuttings to shore would have some safety risks, both for movements on the rig deck and on and off-loading to supply vessels and ultimately trucks. Although custody may be legally transferred to the receiving disposal facility, some operators may consider on-land disposal as a long-term liability. Discharge to sea might also be considered a long-term liability. In comparing additional cuttings treatment using additional treatment equipment with shipping cuttings to shore, available deck space may be an important decision.

Bedrock drilled in the Gulf of Mexico produces cuttings that are generally coarser than in the offshore in Atlantic Canada. Lower oil on cuttings retention levels are achievable in the Gulf of Mexico with current technology. Nova Scotia, Newfoundland and Labrador and North Sea bedrock produces finer cuttings so that adhered oil is higher and more difficult to remove to meet discharge criteria.

Re-injection might be economically feasible if development and operating costs could be shared between several operators. However, corporate considerations of liability issues may make this less attractive. For such a solution the added cost and energy requirements of getting wastes to a central re-injection well should be considered. Cuttings may need to be slurrified for shipping and injection, which adds to costs and increases emissions.

2.2.4 Future Pollution Prevention Opportunities

With ongoing technological changes and the continued approval of the practice of discharging treated SBM cuttings in most US offshore drilling areas and in Atlantic Canada, continuous improvements are possible or likely in several respects. Overall cuttings volumes per well may be reduced as technology improves for slim hole wells and subsequently constant diameter wells. The percentage of synthetic oil retained on cuttings may decline as best available technology improves for cuttings treatment. There has been a stated benefit in response to the regulatory acceptance of the discharge of SBM cuttings to sea. More research and development effort has been dedicated to synthetic oils now that their use has been enabled. This is likely to eliminate toxicity and maximize decomposition rates, since rapid decomposition is the selected strategy for environmental protection in the EPA decision. The continued improvements in SBM will have the additional benefit of reducing the environmental effects if spills of SBM or drilling fluid components occur.

Conversely, while there are some benefits to the use of WBM in cased well sections, shale control remains difficult with WBM. Where SBM cuttings cannot be discharged but WBM cuttings and muds may be discharged, there is some market benefit in improving the performance of WBM. Generally difficult drilling, such as directionally drilled and extended reach wells, require the use of SBM or EMOBM muds for their higher lubricity and also shale inhibition. A large diameter extended reach well was planned and drilled with WBM in the North Sea Central Graben. Such wells have historically been drilled with mineral oil or ester based drilling fluids. WBM was used because of the high cost of the required shipping of SBM cuttings to shore and the risk of shutdown in bad weather if cuttings boxes could not be off-loaded to supply vessels. The well was planned to determine shale inhibition requirements and required mud weights, which resulted in a well trajectory design change to a lower angle through problem shale formations. The size of cuttings was also carefully controlled. The well was successfully drilled with no significant hole instability problems (Stawaisz *et al*., 2003). This illustrates a successful pollution prevention practice through design and substitution.

2.3 Produced Water

2.3.1 Background

Produced water is an unavoidable waste of the oil and gas production processes. Produced water occurs naturally in subsurface formations and must be separated from the extracted oil or gas. For some production, seawater may be injected into the formation to maintain pressure and replace the petroleum products removed and this injected water may be recovered with petroleum products as produced water. Produced water quantities generally grow as a reservoir is depleted. In the offshore, produced water is usually discharged to the sea.

Guidelines for produced water discharge limit the concentration of oil in water discharged in Atlantic Canada. Concentrations must not exceed 30 mg/L (as a 30-day weighted average) and the 24-hour arithmetic average must not exceed 60 mg/L. These limits apply to facilities permitted after August 2002. Installations producing prior to that date can discharge up to 40 mg/L (as a 30-day weighted average) until December 31, 2007. Produced water discharges must be analysed for a suite of 18 metals plus N and P twice a year. The sea urchin fertilization aquatic toxicity test and at least two other bioassay tests must be completed annually for water that is also given the chemical analysis. (C-NSOPB *et al*., 2002)

These targets are consistent with the new OSPAR target of 30 mg/L, which is expected to contribute to achieving a 15% reduction in tonnes of oil in water discharges between 2000 and 2006. This target is a challenge for older platforms and depleted reservoirs with large proportions of produced water.

Concerns

While much of the produced water is similar to seawater, if more concentrated, produced water also includes hydrocarbons, heavy metals and naturally occurring radioactive materials. These contaminants of concern occur in varying concentrations that differ strongly between oil and gas sources, differ generally between basin areas and can differ significantly within the same reservoir. Management of produced water may require the use of additives such as anti-scaling or anti-corrosion chemicals, which are discharged also.

2.3.2 Current Practices

Current practice in Atlantic Canada and elsewhere is to discharge produced water to the sea after treatment to reduce hydrocarbon levels. In most settings this results in the rapid dilution of the produced water over short distances to concentration levels of most constituents to background levels or to non-detectable. While it can be shown that toxic conditions for some organisms can be reached in the discharge plume, these conditions are short term. Studies of the potential for bioaccumulation and biomagnification have generally shown these processes to occur. Some bioaccumulation has been measured in organisms attached to production facilities; however, the levels reached were neither harmful to the organisms or a risk to consumers or predators. Studies of the fate of produced water constituents have found elevated levels of some components in sediments in the vicinity of the discharge, but these could also be attributable to other sources, such as muds and cuttings. For these reasons it is considered appropriate under most regulatory regimes and in most marine settings to discharge produced water following hydrocarbon removal.

The Sable project uses treatment of produced water to meet guidelines for discharge to the sea. EnCana's Deep Panuke project will use a similar method. However, the EnCana project proposes to treat produced water using hydrocyclones to remove oil to meet the guidelines (C-NSOPB *et al*., 2002) with a voluntary project target of 25 mg/L. The hydrocyclone is expected to reduce produced water oil concentrations to the 30 to 50 mg/L range. Further oil removal will be achieved using an organophyllic clay treatment process. The clay will itself be a waste product requiring onshore disposal. Produced water will also be treated in a stripper to remove H_2S down to a 1 to 2 ppm concentration. The discharge stream of treated produced water (after it is treated to meet guidelines) will be mixed with cooling water to at least an 85 to 1 dilution prior to discharge. (EnCana, 2002 and G. Hurley, pers. comm.)

2.3.3 Pollution Prevention Opportunities

There are three general approaches to P2 that can be considered for the management of produced water. In the order of preference for pollution prevention these are:

Avoid the Production of Produced Water as a Waste

Avoidance of the discharge of produced water into the marine environment is possible through re-injection of the water into underground formations. The receiving formation may be the hydrocarbon source reservoir, a depleted reservoir or an aquifer.

Re-injection is not currently practiced or considered practical for production facilities in Atlantic Canada.

Although petroleum products and produced water cannot strictly be separated within the reservoir, it is possible to separate petroleum products from water close to the point of extraction rather than at the sea surface. Technologies exist for downhole separation of oil and water and gas and water. Separation is also possible at the seafloor. The produced water must then be re-injected.

Constraints to re-injection are: availability of an injection well and suitable formation. Environmental costs to consider are: energy required and associated air emissions. Potential economic benefits: maintenance of reservoir pressures.

In addition to reduced or eliminated discharges, the advantages of downhole or seafloor separation are reduced pumping and related emissions and energy costs. Re-injection may require the development of dedicated wells, with associated mud and cuttings management, air emissions and energy consumption. [e.g. for practical downhole re-injection, the Sable project would need a dedicated well at each production well; the operator of Deep Panuke might be able to re-inject to the depleted CoPan reservoir.] Re-injection also may require the use of treatment or additives to the water to prevent the development of sour conditions in the formation, which would have considerable cost and environmental consequences if treatment failed.

Reduce the Amount of Produced Water or Associated Discharges

There is no known method of reducing the total volume of produced water except by downhole separation. It would be possible to change the timing of produced water generation by controlling production rates. It should be noted that most down-hole produced water separation technologies are a reduction rather than an avoidance method as they do not eliminate produced water disposal requirements. Some proportion of water is still produced that must be treated on the production platform, which retains all the requirements to operate a treatment system onboard and discharge of waste water to the sea.

Control the Waste Management Processes Related to Produced Water

Since treatment is not a P2 strategy, and the total amount of produced water from the reservoir is effectively a fixed amount, P2 control strategies for waste management of produced water are those that reduce the discharge of toxic substances or use of energy. Reduced or less toxic additives are addressed under biocides in Section 2.4. Aspects of energy use reduction are addressed in air emissions, Section 2.1, may be relevant to produced water management. Selection of chemical additives for treatment or management of produced water must follow the *Guidelines Respecting the Selection of Chemicals Intended to be Used in Conjunction with Offshore Drilling and Production Activities in Frontier Lands* (C-NSOPB *et al*., 1999).

Downhole and Subsea Water Separation and Injection

Downhole oil/water separation (DOWS) and gas/water separation (DGWS) is recent technology that has not been applied in Atlantic Canada. Subsea separation systems are also in development.

DOWS has the potential to increase well profitability through the combination of increased production rates, lower produced water management costs, and extension of the production life or recoverable reserves. Some DGWS processes are designed to eliminate surface generation and handling of produced water (PTAC, 2000).

The Troll C subsea water separation and injection system has been successfully piloted and operated in the operation of Norwegian productions wells in 350 m of water (Horn and Soelvik, 2002). Details of this system and its application are provided as a case study in Section 3.7.

Most experience with downhole produced water management has been in onshore production wells. High variability in success and early failure of many systems make the technology still high risk (PTTC, 2000). Currently high risk technology is unlikely to be adopted in the frontier production of Atlantic Canada. With the high cost of operating production facilities offshore, the use of risky technology would require unacceptable shutdowns or 100 % backup with conventional produced water separation systems in case of the failure of a separation system.

When reliable systems are proven, the technology is likely to be adopted for the financial as wells as environmental benefits that are offered.

Hydrocyclone Process

An emerging technology for treating produced water from oil fields is being tested at Statoil's Statfjord B platform. Statoil will be conducting a long term test of the CTour technology which uses natural gas condensate to remove hydrocarbons from produced water. In this process, the produced water is injected with condensate which acts as a solvent which separates from the water together with other hydrocarbons when the mixture is hydrocycloned. The separated hydrocarbons and condensate are cycled back into the production stream.

Initial findings of research into the CTour process showed improved removal of hydrocarbons when the process was piloted. Another benefit noted was a reduction in flare gas emissions from the de-gasser. As well, it involves no irreversible changes in the process and resulted in only marginal increases in capital and operating costs. One limitation noted by the researchers was that in order to effectively remove BTX (benzene, toluene, xylene) from produced water, the condensate needed to be virtually free of BTX, in particular, benzene.

2.4 Biocides

2.4.1 Background

Biocides are used in two ways. Seawater systems are used on drilling and production facilities for cooling and firefighting water, and biocides are used in these systems to prevent the growth of marine organisms. Biocides must also be used in injection water used for production enhancement, as live sulphate reducing bacteria injected into hydrocarbon formations during re-injection could sour the reservoir by converting sulphur oxides to H_2S.

Without biocides, seawater piping and heat exchangers would become clogged with marine growth. Mussels are a particular problem. With a high flow in a flow through cooling system ideal conditions are created for rapid mussel growth, since they have ample food supply that can be filtered from the passing flow. Mussels can completely block these piped systems.

No levels for the use or discharge concentrations of residual chlorine are prescribed in the OWTG, although the Chief Conservation Officer may restrict the levels discharged. Approval is required for the use for a biocide other than chlorine in cooling water.

Concerns

The most common biocide used in seawater systems is chlorine. The main sources of chlorinated wastewater effluents (CWWE) in Canada are municipal wastewater treatment plant discharges and cooling water discharges from thermal and nuclear power generating stations. CWWE are considered “toxic” under paragraph 11(a) of CEPA (1999) based on the harmful effects of chlorinated effluent discharges from municipal wastewater treatment plants on freshwater biota. However, review of effects on the environment of CWWA has not been determined in terms of the toxicity on marine biota (CEPA, 2003a).

2.4.2 Current Practice

Biocide Use in Atlantic Canada

Chlorine is usually introduced to the seawater intake by a sodium hypochlorite generator. The rate of chlorine injection can be adjusted so that free chlorine remains below a design level at the discharge point and biological growth is prevented or inhibited throughout the piped system. For instance, for the Deep Panuke project the design chlorine concentration at the intake of 2 ppm would be expected to keep the discharge of free chlorine levels below 0.25 ppm. Normally the intake concentration would be 1 ppm, but this would be increased during periods of high larval mussel concentrations determined by a monitoring program (EnCana, 2002).

2.4.3 Pollution Prevention Opportunities

Pollution Prevention by Substitution

Where practical alternative biocides may be used to substitute less toxic substances for those currently used. The chemical selection guidelines (NEB *et al.*, 1999) provides the procedure for the evaluation, hazard analysis and acceptance of new substances.

Minimization

Monitoring and process control can limit the residual chlorine levels in the discharge water and adjust the input quantities of chlorine. A high residual chlorine level indicates that more is being generated than necessary and inhibition can be maintained with reduced chlorine input levels.

Electrolytic Systems

Electrolytic systems using copper and aluminum or iron anodes are employed in several marine applications including ships, e.g., the Canadian Navy, drill rigs, e.g., the Glomar Grand Banks and platforms. The anodes are fed by an impressed electrical current which results in the production of copper ions that provide biological control through the creation of an environment in which common fouling biota such as mussels cannot settle or multiply.

2.5 MEG

2.5.1 Background

Mono-ethylene glycol (MEG) is used for pipeline gas dehydration, and as corrosion and hydrate inhibition in combination with pH stabilization. Other glycols, such as triethylene glycol and propylene glycol can also be used. The largest amounts of glycol are used for gas dehydration. Glycols are also used in smaller amounts as an additive to WBM to add viscosity, for surface deicing and in BOPs.

Discharge of MEG requires the approval of the Chief Conservation Officer. Discharges of produced water with MEG present must be monitored and reported. (NEB *et. al.*, 2002, s. 2.15)

Concerns

MEG and other ethylene glycols (di- and tri-) are CEPA listed on the Priority Substances List 2. However, the assessment of ethylene glycols did not indicate that adverse effects are likely from the single largest source of these substances – aircraft de-icing. These sources were considered unlikely to result in adverse effects if discharges to freshwater aquatic environments are below concentrations of 100 mg total glycol/L, which is the current CEPA guideline level. Ethylene glycol decomposes rapidly in the aquatic environment, so in some receiving environments discharges may produce oxygen depletion. Potential marine effects are not identified in the assessment report. Further study is in progress and ethylene glycol has not been determined to be "toxic" or not "toxic" (CEPA, 2003b).

2.5.2 Current Practice

In the Atlantic Canada offshore, the Sable project uses MEG with other corrosion inhibitors in the transmission of gas and condensate from satellite platforms to the Thebaud central production platform. The MEG is recovered and conditioned for re-use. Triethylene glycol (TEG) is used to dehydrate gas before transmission to shore. The TEG is also regenerated and reused.

In the design of the Sable project, the use of propylene glycol was considered. This alternative was rejected since the toxicity in the marine environment of propylene glycol and MEG are similar and very low, and the propylene glycol is significantly more expensive.

In most processes, the glycol becomes contaminated, becomes waste and needs to be replaced or cost effectively reclaimed. Contaminated MEG is discharged to sea from the Thebaud platform. There are systems available to reclaim MEG, such as the Kvaerner system used on the Åsgard B platform.

2.5.3 Pollution Prevention Opportunities

Within Kvaerner Process Systems, a proprietary MEG reclaimer process technology has been developed since 1996. The unit provides the largest continuous reclamation capacity ever built and has been in operation since 2000. Kvaerner notes that in addition to hydrate prevention MEG provides pipeline corrosion protection. Pipelines can be constructed in carbon steel rather than duplex, resulting in major cost saving (Kvaerner).

There may be a tradeoff required in designing a system using MEG between the capital costs of construction and the operational cost of replacing contaminated MEG. Comprehensive pollution prevention planning as part of project design would consider both construction and operating costs.

There are also alternative products that can be used for hydrate control. An example is provided in Section 3.8.

3.0 Other Opportunities, Examples and Case Studies

This section presents seven topics that provide other opportunities for pollution prevention or examples not within the topics presented in the previous section. For instance, slender well design (Section 3.1) is an available technology that may be applied in Atlantic Canada. Its relevance to pollution prevention is in the potential both to reduce the volume of drill muds and cuttings and to reduce the air emissions and associated energy costs for a well. However, a risk of the technology is "running out of diameter" before the design total well depth is reached. Expandable tubular casings (Section 3.2) provide a technology in development that may reduce the risks or ultimately supplant slender well design.

3.1 Slender Well

Slender well technology has evolved from use in shallow onshore reservoirs to be used in deepwater applications. Drilling a smaller diameter well reduces the amount of mud used and the amount of cement and may reduce the drilling time by 30 %. This not only reduces costs but also reduces air emissions (Mitchell *et al.*, 2002)

Capability was added to the Bredford Dolphin semi-submersible drill rig to allow slender-well drilling in water as deep as 1500 m. Slender-well technology uses a 16" riser instead of the traditional 20 - 22" riser. The resulting reduction in deck load and riser load allows the use of smaller rigs in deepwater. The use of drilling mud is reduced considerably and the energy consumption per well is reduced (Dolphin News, October 2001). However, the harsh conditions offshore in Atlantic Canada may not be suitable for such smaller rigs. Slender well design still has the potential for faster well completion, requires less mud and cement and produces less cuttings, even if used on larger drilling units.

3.2 Expandable Casings

New technology is being developed and tested that uses expandable casing to eliminate the telescoping effect that is used in current well design. Onshore application of the new technology has demonstrated the potential for its use in the offshore. The technology can also potentially be used to overcome problems commonly encountered in deep wells before total depth is reached. This will allow slender well designs to be used with less risk of "running out" of well diameter before reaching the planned total depth. Other potential benefits are a reduction in the size of rig needed, which reduces emissions, reduction in drilling mud used and a reduction of up to 50% in drill cuttings. Rig cost savings as well as savings in consumable costs are expected. A MonoDiameter well is planned in the Gulf of Mexico in 2003. (Sumrow, 2002a)

Expandable casing technology has the potential for applications to all wells and all phases of well use. The technology is being tested to repair corroded casing and retain most of the well diameter, and consequently maintain high production rates (Sumrow, 2002b). With the capability of casing a well with the same diameter from surface to total depth, if wells can reach reservoirs with the wellbore at high diameters, fewer wells will be required to recover the full potential from reservoirs.

3.3 Mud and Cuttings Disposal

In Cook Inlet Alaska OBM waste drilling fluids and cuttings have been re-injected during an exploration program. Although in Cook Inlet WBM can be discharged to sea, oil based muds or oily cuttings cannot be discharged. Bedrock conditions make oil based drilling fluids much more effective than WBM. There are no disposal sites for muds and cuttings on land near the exploration area and a dedicated onshore facility was considered too expensive. For an initial set of 2 exploration wells OBM cuttings and muds were annulus injected, with the requirement to store some wastes temporarily on land when annulus integrity became a concern. A dedicated disposal well was drilled for injection of muds and slurrified cuttings from two additional exploration wells. Future wells in the exploration and development by the operator Forest Oil on the Redoubt Shoal structure will introduce zero discharge of drilling fluids and solids using the dedicated injection well and developed fit-for-purpose cuttings re-injection system. (White et al., 2002)

3.4 Discharge of SBM Cuttings with Retained Oil to Sea as a Pollution Prevention Measure

The US EPA has approved the discharge to sea of SBM cuttings, with limitations, and considers the use of SBM as a pollution prevention technique. Limitations include base drilling fluids criteria and cuttings discharge criteria, which are similar to those of the Offshore Waste Treatment Guidelines (NEB *et al*., 2002). The decision was based on anticipated discharges related to the use of WBM and OBM and in consideration of non-marine environmental considerations including air emissions, energy use, land disposal, worker safety and spills.

SBM has been in use in the Gulf of Mexico since 1992. However, regulations were not developed to recognize the much lower toxicity of synthetic oils than diesel or crude oil. The discharge of SBM cuttings were allowed in the interim while new regulations were developed. Regulations published in January 2001 are likely to encourage the development of new drilling fluids based on synthetic oils (Sumrow, 2002c).

The EPA rule related to the use of SBM limits discharges only to SBM cuttings and only where best management practices are applied. The pollution prevention approach of product substitution provides stock limitations on base fluids for sediment toxicity, biodegradation rates, PAH content and metals content. Limits are set for mercury and cadmium content in stock barite. Discharge limitations also are provided that prohibit the discharge of diesel oil and formation oil, and set limits for sediment toxicity and aqueous toxicity. The quantity of SBM oil retained on cuttings is also limited.

In completing the rule, the approach of seeking maximum biodegradation rates was selected. Some consideration was given to the merits and potential environmental effects of selecting synthetic oils with slower biodegradation. However, the result of the more rapid re-colonization of affected benthic areas with rapid biodegradation was considered the preferred approach (USEPA, 2000a).

Well averaged discharge of retained synthetic oil on cuttings of 6.9% wet weight is allowed for base fluids with the environmental performance of C16-C18 internal olefins. The higher discharge rate of 9.4 % is allowed where the base fluid has the environmental performance of vegetable esters or low viscosity esters. Environmental performance refers to sediment toxicity and biodegradation (USEPA, 2000b).

To drill a deepwater well in 2001, offshore Nova Scotia, an offshore operator received approval to discharge properly treated SBM cuttings to sea, consistent with existing regulations. The discharge of the cuttings with adhered oil at less than 6.9 % wet weight was consistent with the OWTG. An on-board hydrocyclone cuttings dryer was added to treat cuttings after they were separated from the drilling mud. The wellsite was in over 1500 meters of water and was 350 km from Halifax Harbour, the closest location where cuttings could be shipped for disposal. Without discharge of cuttings to sea consistent with the OWTG, the operator would have been required to lease an additional dedicated supply vessel for the shipping of cuttings to shore and supply of empty cuttings boxes to the drilling rig. Cuttings where the retained oil was in excess of 6.9% wet weight, were shipped to shore and disposed of in accordance with accepted industry practice.

The cost of operation, energy required and associated emissions to operate the cuttings dryer were considered significantly less than those associated with operating the additional vessel as well as the related trucking and cuttings disposal costs and energy use, if those cuttings had been shipped to shore. Since the well was a wildcat well in deepwater, re-injection of slurrified cuttings was not practical. Higher potential health and safety risks were also considered, due to the handling and shipping of cuttings boxes to and from shore; however, these risks were not quantified. For the location of the well and the chosen drilling method, the combination of discharge of SBM cuttings per existing regulations and onshore cuttings disposal, was considered good pollution prevention. (industry, pers. comm.).

3.5 Hydrate Control

Hydrates are water/hydrocarbon solutions that form crystals at temperatures higher than the freezing point of pure water. They can form in flowlines and either reduce the flow of hydrocarbons or block flow completely. Hydrates can be removed by pigging, but usually hydrate inhibitors are injected to prevent their formation. Methanol or glycol are commonly used to inhibit hydrate formation, however, as much as 1 for 1 volumes of these conventional inhibitors to water are needed. Insulation of flowlines or active heating can be used on oil flowlines. However, for start-up and shut-in or re-start flow assurance chemicals are needed when these methods are used.

Two types of low dosage hydrate inhibitors (LDHI) have been developed - anti-agglomerates and kinetic inhibitors. Anti-agglomerates function by bonding to microscopic ice crystals and preventing the formation of large crystals. Kinetic inhibitors delay hydrate formation but do not prevent it, so are not effective in extended pipelines in cold conditions. LDHI can be effective at a ratio of 1% to the total flow volume. Shell tested the use of an anti-agglomerate LDHI on the Popeye field in the Gulf of Mexico. For a production rate of 60 MMcf/d of gas, 3,000 b/d of condensate and 430 b/d of water, 175 b/d of methanol was being injected. Less than one gallon of LDHI was used per barrel of water in the test. Flow was maintained without hydrate formation or increase in flow pressure. Following a 2 day flowline shut-in, restart was successful without the need to inject methanol. Using LDHI production has increased to 100 MMcf/d with associated water production up to 1,500 b/d. This will result in an increase in recoverable gas reserves of 7.5 bcf. (Furlow, 2002; Anonymous, 2002).

3.6 Natural Gas STAR

Kerr-McGee is a participant in the US Environmental Protection Agency voluntary Natural Gas STAR Program, which helps gas companies to identify cost effective methods to reduce emissions of methane. The company was the Gas STAR Production Partner of the year in 2000 in recognition of its methane emission reduction achievements. Since joining in 1996 Kerr-McGee has demonstrated a cumulative emission reduction of more than 8.5 Bcf, which includes the period since 1992. Gas STAR participation has provided an extension of its environmental program, which had already included best management practices. The creation of a recognized recording method for past, current and future emission reductions is an important value provided through Gas STAR participation (US EPA, 2001 a). The positive public recognition received is highly prized by corporations.

Other Gas STAR participants have also received recognition. Texaco Exploration and Production has recorded 860,000 Mcf of emission reductions that saved $1.7 million over four years (EPA, 2000). Unocal Gulf Region similarly adopted the Gas STAR program as a pilot program and demonstrated reductions of 640,000 Mcf over three years for savings of $1.9 million. The success of the program has led to the adoption of methane emission reductions as a corporate wide policy by Unocal Corporation (US EPA, 2001 b).

As Kerr-McGee has been the most successful of these three participants, their program is described in more detail. Kerr-McGee first developed senior support for the program and developed a company implementation plan. Activities were focussed on: identifying opportunities to incorporate BMPs into new facilities; evaluation of the usefulness of BMPs at older facilities; and completing inventories of past methane emission reduction activities.

Kerr-McGee communicated its commitment throughout the company and supports implementation throughout its North American divisions with a centrally managed program. For new facility construction or maintenance projects, the EH&S division works with project team members to identify opportunities for implementation of Gas STAR BMPs and other pollution prevention activities. Integration in the early design stages of emission reduction technologies can save time and effort required to retrofit controls.

Kerr-McGee has determined that economic benefits result from emission reduction technologies in 50 to 60% of new construction and maintenance retrofits. Although the company incorporates control measures to be safe and responsible corporate citizens, the overall economic benefit of emissions reductions is an important outcome. The average annual savings of $3.2 million has resulted in a net savings from emission reductions of over $25 million (US).

The primary retrofits and process changes have been: use of vapour recovery units; installation of flares; replacement of gas-actuated instruments with compressed air-actuated ones, and their use in new installations; recapturing of Wilden pump vent gas; and installation of low-bleed pneumatics in high emissions areas. (US EPA, 2001 a)

Details of this program not only demonstrate the benefits of government organized voluntary programs, but also illustrate the benefits that companies recognize and gain from the public advertisement of results, especially when there are awards received. Non-financial benefits can be part of the balance sheet in pollution prevention planning decisions.

3.7 Produced Water

The Troll C subsea water separation and injection system has been successfully piloted and operated in the operation of Norwegian productions wells in 350 m of water (Horn and Soelvik, 2002). This first system separates water from the wellstream on the seafloor and re-injects it through a dedicated well into a low pressure aquifer, which avoids transportation of the water over the 3.3 km tie back to the main platform. Eight wells can be processed through the station, although only 4 can be processed at one time. Over the first year of operation the injection rate has gone from 2,000 m^3/d to about 3,500 m^3/d with peaks to 4,500 m^3/d. Design capacity is 6,000 m^3/d. With nearly 100% availability the station has injected about 1,000,000 m^3 of produced water with an oil content between 15 and 600 ppm.

3.8 Carbon Dioxide Injection and Sequestration

There is increasing interest in the sequestration of CO_2 as part of the management of GHGs. Possible sequestration locations are: the deep ocean; aquifers; oil reservoirs; and natural gas reservoirs. Injection in oil producing formations provides enhanced oil recovery. Studies of CO_2 injection for enhanced natural gas and condensate recovery are taking place as well as testing of injection for coal bed methane production. An advantage of injection into hydrocarbon formations is the expected sequestration period on the order of millions of years. Aquifer injection may provide sequestration times in the order of a few thousands of years. Deep ocean sequestration may retain the CO_2 for periods of hundreds of years (Moritis, 2003).

Carbon dioxide injection has been used for enhanced recovery of oil since the 1970s. One project in Canada receives CO_2 at EnCana's Weyburn oil production facility through a 328 km pipeline from a North Dakota synfuel plant. Prior to this use the CO_2 was vented through the coal to methane process (Moritis, 2003).

Six UKOOA members, BP, ChevronTexaco, Shell, Agip, and EnCana, and are participating in a Norwegian project to move CO_2 to underground geological formations. In this, the first case of industrial scale CO_2 sequestration in the world, CO_2 has been injected in the Sleipner field in the North Sea since 1996. The Sleipner produces significant amounts of CO_2 along with natural gas. The gas is captured at high pressure using an amine solvent and then injected into a saline aquifer 1000 m below the seabed. Currently around 1 million tonnes of CO_2 is injected per year, which is roughly 3% of Norway's total emissions. A driver for this project is the existence of a CO_2-tax in Norway, making the compression and re-injection similar in cost to the discharge of the gas.

Statoil also plans to reinject produced CO_2 into an aquifer at a depth of 2,600 m beneath the Snohvit development. CO_2 at 5 to 8% in produced gas from three offshore fields will be separated onshore and piped back to a subsea injection well (Moritis, 2003).

3.9 Design Approaches

Good pollution prevention includes the holistic consideration of the design of a project. One Atlantic Canada operator uses a “brown paper” approach to exploration drilling projects. The project team participates in a workshop session where multiple options are developed and the team members broadly evaluate each option in a non-judgmental inclusive environment. This is a brainstorming session where everything is on the table.

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4.4 Contact Information for Organizations Consulted in Preparing the Document

Personal Communications

David Burley, Manager, Environmental Affairs, C-NOPB, Phone: (709) 778-1403

Mike Coolen, Director of East Coast Operations, Canadian Superior Energy Inc., Phone: (902) 474-3960

Andre d'Entremont, Health, Safety and Environmental Coordinator, Kerr-McGee Offshore Canada Ltd., Phone: (902) 423-8857

Stephen Full, Environmental Analyst, East Coast Operations, Encana Resources, Phone: (902) 422-5574.

Doug Gregory, Manager, East Coast Operations, Shell Canada Limited, Phone: (902) 474-2001

Doug Hollett, Manager, Atlantic Canada, Business Development, Marathon Canada Limited, Phone: (902) 423-3950

Geoffrey V. Hurley, Senior Environmental Analyst, Loss Management, East Coast Operations, EnCana Resources, Phone: (902) 474-5350

Jim MacDonald, Frontier Drilling Supervisor; Shell Canada Ltd., Phone: (902) 474-2000.

Francine Power, Petro-Canada Offshore Development & Operations, Phone: (709) 778-3500.

Cal Ross, ExxonMobil Canada Ltd., Phone: (902) 490-8900.

David Taylor, Husky Energy, Phone: (709) 724-3900.
Urban Williams, Senior Environmental Advisor, Terra Nova Project, Petro-Canada Offshore Development & Operations, Phone: (709) 778-3764.

Tom Windeyer, EnCana Resources, Phone: (902)b 492-4500.

Appendix A

Operator’s Guide to Offshore Waste Treatment Guidelines for Canada’s Offshore Areas