MIGRATE Working Group (WG) 3: Environmental challenges

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1. Introduction

WG 3 will review environmental challenges associated with methane production from gas hydrates. Environmental risks are moderate compared to other deep-water operations since gas hydrates and the associated formation fluids do not contain toxic substances. Moreover, blow-out events are not a concern since gas hydrate deposits have low in-situ pressures and are maintained at or below hydrostatic pressure during the entire production process.

However, gas hydrates can constitute environmental risks by affecting seafloor stability and releasing methane into the water column. Sediments deposited at continental slopes are in some cases stabilized by gas hydrates cementing the grain fabric. Gas production from these deposits may induce slope failure causing severe damage to seabed installations and benthic ecosystems and methane gas emissions into the marine environment. Methane is an important greenhouse gas and any release of methane to the atmosphere would have an impact on climate change. The lifetime of methane in the atmosphere is much shorter than of CO_2, but CH_4 is more efficient at trapping radiation than CO_2. On a 100 year time scale, the comparative impact of CH_4 on climate change is about 28 times greater than CO_2 (IPCC, 2013).

Leakage of methane gas may also occur during the production process since the overburden sealing gas hydrate deposits from the marine environment has a limited thickness. It is important to recall that methane-hydrate accumulations are often associated with gas seeps (Berndt et al., 2014; Marin-Moreno et al., 2013; Phrampus et al., 2014; Roemer et al., 2012a; Roemer et al., 2012b; Roemer et al., 2014; Sahling et al., 2014; Smith et al., 2014; Torres et al., 2002; Westbrook et al., 2009). These seeps may influence the development of oceanic ecosystems on the seafloor. When considering gas production from methane-hydrate accumulations, the question regarding the fate of potential methane release consistently arises as leaks may occur. Such release may have impacts on the ecosystem associated with methane-hydrate settings. In fact, the areas surrounding hydrate deposits, particularly those outcropping on or close to the seabed, often support a large microbial/benthic community based on direct interaction with the hydrate itself or from gas release. These communities are delicate and could be seriously affected by changes in gas release rates, or exploitation of near seabed hydrates. In a similar manner exploitation of deeper hydrates that results in release of methane gas to the seabed may result in dramatic changes to any indigenous microbial/benthic community and whilst small gas releases may possibly stimulate the microbial community it is highly likely that large gas releases will have a negative impact.

Finally, methane may be present in the water column, and depending on depth and temperature it may occur as hydrate, free gas, or dissolved gas. Gas may be released directly at the seafloor due to dissociation of hydrate or as a result of dissolution or dissociation of dislodged hydrate as it rises through the water column (methane hydrate is less dense than seawater). Methane will dissolve in the water column as it rises resulting in elevated methane concentrations, and gas bubbles will expand as the pressure drop as the bubble rises through the water column (Zhang, 2003). Whilst it may be unlikely that methane will reach the atmosphere (except for catastrophic releases; de Garidel-Thoron et al., 2004) the spatial extent (and concentration) of methane in the water column will depend upon the depth and the local current and the rates of microbial methane consumption (i.e., Boetius and Wenzhöfer, 2013; Steeb et al., 2015). Therefore, in a production scheme, there is a need to better characterize the potential environmental challenges, and efficiently quantify the amount of methane discharged into the water column as well as its influence on the living communities in the surrounding area. To minimize the environmental risks, gas hydrate deposits located in the Black Sea could serve as production test sites since this marginal sea harbors anoxic bottom waters inhibiting the development of benthic ecosystems.

2. Aims

WG 3 aims to define an environmentally sound monitoring strategy and assess whether the legal framework regulating the exploitation of offshore oil and gas deposits needs to be adjusted to account for the specific environmental risks associated with the gas production from hydrates. To achieve the aims of WG 3 its participants will:

- Assess how slope stability may be compromised by gas production from hydrates under different geological boundary conditions;
- Identify suitable precursors/changes for slope failure to be targeted in a monitoring program;
- Develop a generic strategy for environmental baseline studies and the environmental monitoring of gas production from hydrates;
- Develop a specific environmental baseline and monitoring program for the planned production test;
- Develop a system for geohazard classification of marine gas hydrates and classify the main European gas hydrate deposits, determined from WG1;
- Evaluate whether national legal frameworks regulating offshore oil & gas production are appropriate for gas production from hydrates using Norway and Bulgaria as a case study.

3. Hazard identification

During the first year of the project the hazards related to gas hydrate production have been identified and discussed. Whereas the risk analysis is an essential instrument to ensure safety of operation, we consider important to stress that, even if in the common use and in dictionaries the terms “risk” and “hazard” are often used as synonyms, “risk” and “hazard” have well defined meanings in the procedures for risk assessment:

- Hazard is a potential source of harm or damage.
- Harm or damage is always the consequence of an accident.
- Risk is a combination of the likelihood (L) of the harm occurrence and the severity of that harm (damage D). Risk formula is (R= $f\ (D,\ L) = D \times L$). R can be represented by the risk matrix.

The identified hazards have been classified in three categories as follow: 1.) Seabed deformation hazard; 2.) Gas release hazard; 3.) Production related hazard.

3.1. Seabed deformation hazard

The current understanding of phenomena involved in gas hydrate formation and the physical properties of hydrate-bearing sediments is still limited, as well described in the review paper of White et al. (2009). Formation phenomena include pore-scale habit, solubility, spatial variability, and host sediment aggregate properties. Physical properties include thermal properties, permeability, electrical conductivity and permittivity, small-strain elastic P and S wave velocities, shear strength, and volume changes resulting from hydrate dissociation. The magnitudes and inter-dependencies of these properties are critically important for predicting and quantifying macroscale responses of hydrate-bearing sediments to changes in mechanical, thermal, or chemical boundary conditions. These predictions are vital for mitigating borehole, local, and regional slope stability hazards, because the gas hydrate production can have small (such as hydrate dissociation) and large (such as sliding, induced seismicity) impacts on the seabed deformation.

Sediment strength and the extent to which sediment deforms under a load are critical inputs for the analysis of potential failures around wells (Masui et al., 2008; Rutqvist and Moridis, 2007) and for evaluating seafloor stability over larger length scales (Nixon and Grozic, 2007; Sultan et al., 2004a). The presence of methane hydrate increases stiffness, enhances pre-failure dilation, and leads to higher strength. White et al. (2009) described shear resistance and dilation mechanisms occurring at different levels of hydrate saturation in the pore space. Moreover, effective stress strength parameters can depend strongly on the hydrate formation history (White et al., 2009). This suggests that a deep knowledge about the geological setting and its temporal evolution are required.

In addition to sedimentological, physical and geotechnical studies, sea floor morphology should be considered because of its influences on the seafloor stability. Accurate multi-beam swath bathymetry, high-resolution side-scan sonar data and high-resolution seismic records can be indispensable to model the seafloor stability. Yamamoto et al. (2014) suggested that it is important to monitor the seafloor subsidence and instability by using seafloor deformation monitoring devices, particularly if the gas hydrate is present in shallower sediments.

About the possible influence of temperature change on hydrate stability, it is worth to underline that the time scale of potential hydrate exploitation and natural changes are different. In fact, recent modelling of West Svalbard of Thatcher et al. (2013) suggested that the delay between the onset of warming and emission of gas can amount to about 30 years when gas hydrate deposits are destabilized by bottom water warming.

In conclusions, about seabed deformation hazard, emphasis must be placed on further developing comprehensive in situ sediment characterization through borehole logging tools that incorporate the simultaneous measurements of multiple properties from the minimally disturbed material surrounding the probe (White et al., 2009). In addition, continuous monitoring of important indicators on the seafloor such as subsidence should be considered within baseline studies as well as during the production phase.

3.2 Gas release hazard

In the following paragraphs, we discuss in details the impact of methane leakage on ecosystem and seawater chemistry currently only studied at natural gas leakage sites.

3.2.1 Impact of gas release on the ecosystem and likelihood to reach the atmosphere

The production of methane from hydrate accumulations involves a perturbation in their stability field to release free methane, the valuable product. Yet, there is no literature dealing with the quantification of methane leaks during production tests and its fate, nor on its impact on the associated ecosystems. However, several studies have been devoted to the consequence of methane release from hydrate destabilization during past climate change (Dickens et al., 1997; Kennett et al., 2003; Norris and Röhl, 1999). They argued that hydrate destabilization contributed to an increased amount of methane in the atmosphere that accelerated climate change. This involves that methane bypassed the water column to reach the atmosphere. However, the assessment of the physicochemical transformations of methane in the water column remains controversial, and its probability to reach the atmosphere depends on water depth and other site-specific parameters (Hu et al., 2012; Kessler et al., 2011; Ryerson et al., 2011; Ryerson et al., 2012; Yvon-Lewis et al., 2011; Zhang et al., 2014). Thus, if one really wants to evaluate methane contribution from hydrate production to the global atmospheric budget, it is necessary to have a sound knowledge of the methane fluxes from seeps and to carry out investigation on the processes which degrade this molecule in the sediments and the water column with the latter involving sound knowledge on physical properties of the local water column (i.e. currents, temperature).

Such investigations are also essential due to their link with fluid migration within the sedimentary column, and the development of living communities which populate those structures (Andersen et al., 2004; Olu-Le Roy et al., 2007; Ondreas et al., 2005; Sibuet and Vangriesheim, 2009).

During its migration in the anoxic part of the sediment, and before being released in the water column, part of the methane is oxidized via a microbial-mediated reaction called Anaerobic Oxidation of Methane (AOM) (Boetius et al., 2000; Borowski et al., 1996, 1999; Joye et al., 2004; Kastner et al., 2008; Niewohner et al., 1998; Reeburgh, 1976; Regnier et al., 2011; Snyder et al., 2007; Yang et al., 2010). This reaction takes place at a specific sedimentary horizon, and allows the mitigation of methane release to the seafloor, and therefore naturally prevents its transfer into the water column (and accordingly to the atmosphere). It is coupled with the reduction of sulfate to sulfide:

$$CH_4 + SO_4^{2-} \longrightarrow HS^- + HCO_3^- + H_2O$$

Sulfide forming by AOM sustains rich chemosynthetic communities at the seafloor that can be divided in three major groups, the Vesicomyid bivalves, Mytilidae and Siboglinid polychaetes (Andersen et al., 2004; Duperron et al., 2005; Olu-Le Roy et al., 2007; Ondreas et al., 2005), which live in symbiosis with bacteria capable of performing specific redox transformations, which in one way or another, contribute the methane mitigation (Cavanaugh, 1983; Nadalig et al., 2002). Moreover, there are large mats of sulfide-oxidizing bacteria often found on the seafloor, consuming the sulfide with oxygen. These mats are often used as indicators for methane presence/consumption in the seabed. It has been demonstrated that the intensity of the methane flux and its duration over time strongly influence the development of specific chemosynthetic communities (DeBeer 2006, Lichtschlag 2010, Felden 2013). The microbial AOM community serves as an efficient filter consuming a major portion of the ascending methane (Boetius and Wenzhoefer 2013). This microbial filter may also mitigate methane emissions during gas hydrate production.

3.2.2 Methane concentration in the water column as a function of temperature and mixing

Methane from natural gas hydrates can be released either as free gas or as dissolved gas (Gentz et al, 2014). During their ascent through the water column, methane gas bubbles are dissolved in ambient seawater and oxidized by aerobic microorganisms using dissolved oxygen as terminal electron acceptor. This explains the rapid disappearance of CH_4 after the Gulf of Mexico oil spill (Atlas and Hazen, 2011).

Experiments showed that strong vertical density gradients in the water column developing during the warm season may limit the ascent of methane gas to the surface and methane release into the atmosphere. During winter the vertical mixing in the water column is enhanced and consequently methane is released into the atmosphere (Gentz 2014).

Modeling of gas bubble ascent can predict the evolution of bubble sizes and the fractions of methane gas reaching the surface and the atmosphere under idealized conditions. However the internal dynamics of large-scale bubble plumes and the interactions with ambient bottom currents and density stratification adds further complexity that is not yet fully resolved by numerical models (von Deimling et al. 2015, Leifer 2015, Wiggins 2015). Hence, hydro-acoustic measurements and further field data are required to monitor and forecast the fate of methane gas released at the seabed and to improve the existing models (Chong et al. 2016).

3.2.3 Sea water chemical and physical properties change (salinity and pH of seawater)

Dissociation of dislodged hydrate in the water column will result in local changes of the fluid chemistry due to the release of fresh water. However, the extent will dependent on the volume of hydrate dissociation - this may have only limited spatial effect on pH and water chemistry including salinity - due to subsequent mixing with the seawater, if only a small amount of hydrate is destabilised Note that the decreased chlorinity is used as indicator to prove for gas hydrate dissolution in marine sediments. Moreover, in the oxic ocean water column methane can be oxidized by Aerobic Oxidation of Methane, according to the reaction (Reeburgh, 2007):

$$CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O$$

Open ocean water column methane oxidation rates are generally viewed as being quite low, but fractional turnover rates of days and months have been observed at methane concentrations of about 20 nM which results in an increase in acidity, favoring carbonate dissolution (i.e., Magalhães et al., 2012). Methane release followed by aerobic oxidation may decrease the pH and oxygen content of bottom waters. This may affect pelagic and benthic ecosystems if very large amounts of methane are emitted over an extended period of time (Biastoch et al., 2011).

The Anaerobic Oxidation of Methane (AOM) occurs below the sediment surface, where sulfate-reducing microbes play an important role. Sulfate penetrating into the sediment from the seawater (29 mM), is converted into sulfide which is consumed and re-oxidized to sulfate by chemosynthetic organisms settling at the seabed. In addition, anaerobic oxidation of methane produces another distinctive product: isotopically light calcium carbonate (Reeburgh, 2007). In most cases, AOM has only a small effect on the composition of ambient bottom waters. It serves to mitigate the methane flux into the water column and provides sulfide for chemosynthetic ecosystems.

Numerical models have been developed and applied to simulate the anaerobic oxidation of methane in marine sediments (Luff and Wallmann, 2003) and the aerobic oxidation in the water column (Steinle et al., 2015). These models should be further enhanced and employed to better understand the environmental impacts of methane leakage induced by gas hydrate production.

3.3 Production related hazard

Exploitation of methane hydrate and production of methane gas from methane hydrate via depressurization, thermal stimulation (Sakamoto, 2008), inhibiter injection (Kawamura, 2006) and gas swapping/exchange have been proposed. With all methods, gas permeability and water permeability in the methane hydrate sediments are important factors for estimating the efficiency of methane gas production.

For depressurization, the gas production rate increases with increasing pressure drawdown. However, high pressure drawdown causes the sediment to cool to equilibrium temperature in proportion to equilibrium dissociation pressure because of the endothermic reaction of methane hydrate dissociation. The gas production rate then decreases as the sediment temperature decreases (Kamata et al., 2005).

For hot water thermal stimulation by low temperature injection, the pressure near the methane hydrate-decomposed region increases, and decomposition of methane hydrate increases with temperature (Minagawa et al., 2015).

For gas swapping/exchange, the principle relies on the difference between the hydrate stability fields of the two hydrate formers methane and carbon dioxide in the low pressure range. One of the main advantages of this method consists on avoiding the geomechanical destabilization of the sedimentary layer as it may happen for the other methods (e.g. depressurisation or thermal stimulation). On May 2012, COP oil company (ConocoPhillips) with a partnership with US DOE and the Japanese JOCMC completed the first methane-hydrate production test coupled with sequestration of CO_2 on a pilot site in Alaska. The primary objective was to demonstrate the feasibility of a CO_2/N_2 injection into methane hydrate-bearing sediments and to assess the CO_2-CH_4 exchange, together with the storage integrity.

The German gas hydrate initiative SUGAR – Submarine Gas Hydrate Reservoirs is a collaborative R&D project with 20 partners from SMEs, industry and research institutions (information on phase 1 and 2 of the project: http://www.geomar.de/en/research/fb2/fb2-mg/projects/sugar-2-phase/). Results from this project can act as good starting points for the investigation and the assessment of production related hazards.

In the SUGAR II sub-project B2 e.g. methods for the production of CH_4 from gas hydrates were investigated in laboratory experiments. These focused on the conversion of the methane hydrate to CO_2 hydrate in the reservoir. Note that the replacement by CO_2 and the subsequent formation of CO_2 hydrate could mitigate the release of fresh water, reducing the impact on the microbial/benthic community. In fact, if large amounts of hydrate are destabilised in-situ, i.e. during exploitation of the hydrate then the addition of large volumes fresh water could have a significant effect on the local water chemistry – particularly salinity through dilution of seawater/pore-water.

In general, gas swapping in hydrates is, however, a slow reaction/process. A promising approach to accelerate the exchange reaction and to achieve higher CH_4 production rates is the injection of hot supercritical CO_2 and the combination of this approach with depressurization via separate injection and production wells.

Submarine venting of natural liquid CO_2 and presence of CO_2 hydrates have been recently observed at the Japanese offshore site called Yonaguni Knoll IV hydrothermal field. The two investigated seep sites, Abyss Vent and Swallow Chimney, are located in the Okinawa Trough (1380–1382 m water depths) and is characterized by a few holes in the seafloor emitting hot fluids (Inagaki et al., 2006).The hydrothermal system is part of a sedimentary basin covered by volcanic rocks. A bacterial community has been characterized at different depths in the marine sediments: the bacterial density is high in sediments lying above the CO_2 hydrates (more than 10^9 cells per cm^3) but much lower at the interface between CO_2 hydrates and liquid CO_2 (10^7 cells per cm^3) at a temperature of 4°C. The most active bacterial community in the vicinity of CO_2 hydrates-bearing sediments of this site contains anaerobic methanotrophic archaea (ANME) and sulfate reducing bacteria (SRB). CO_2-saturated seawater (between 1 and 1.7 mol/L) inhibits sulfate reduction and anaerobic methane oxidation (AOM) in these deep-sea sediments (de Beer et al., 2013). While most microbes need to maintain a near neutral cytoplasmic pH, and do so even under the most extreme external pH levels, the extremely high levels of CO_2 will pass the membranes, dissipate the ΔpH across the cell membrane, and thus disrupt the cellular pH homeostasis. Moreover, AOM, with its very low energy yield, will not be possible due to end-product inhibition.

The CO_2 hydrate formation which may hinder or trap the movement of CO_2 in both the deep and shallow sub-surface may actually provide a long term storage unit if the original caprock is to fail (Tohidi et al., 2010). A more complete understanding of the effectiveness of the precipitation of CO_2 hydrate to inhibit CO_2 migration in the overburden would be of great value also to the CCS community (Rochelle et al., 2009).

Environmental risks associated with methane hydrate production can strike:

- Rich ecosystems flourishing around outcropping methane hydrate deposits at the deep-sea floor. The associated risk can be: Destruction of these ecosystems (by CH_4 or/and CO_2); c.f. *Gas release hazard*.

- Continental slope sediments that are often cemented and mechanically stabilized by methane hydrates. The associated risk can be: Destabilization of continental slopes; c.f. *Seabed deformation hazard*.

The following measures were proposed by the SUGAR project to account for these potential hazards:

- Outcropping hydrate deposits should not be exploited. Only those deposits that are covered by extensive layers of impermeable fine grained sediments should be developed. These deposits are not colonized and used by benthic fauna. The impermeable sedimentary apron will also inhibit the release of methane into the environment during hydrate mining.

- Hydrates deposited in steep slope areas should not be developed. Hydrates will only be exploited in even terrain and extensive geotechnical surveys will be performed prior to hydrate production to avoid slope failure.

4. International regulatory framework and the developing of a generic and specific strategy for environmental baseline and monitoring program

During the last meeting, the WG3 discussed also about the existing regulations and legal procedures for gas hydrate exploitation at international and national level. This is important also for properly address the environmental impact assessment and risk analysis, in the way to develop a general and specific strategy also for monitoring of operations. Taking into account the specific characteristics of the matter, and of the "precautionary approach", this study will evaluate existing regulations for offshore oil and gas production and the emerging legal framnwork for the mining of deep-sea resources.

For this topic, in the setting of the international law of the sea, (UNCLOS was signed by 157 and ratified by 167 Countries), the International Seabed Authority (ISA) was established as an Institutional body responsible for managing of the mining sector and for the protection of the marine environment from any harmful effects which may arise during mining activities, including exploration. With this task ISA has already prepared a document, entitled "Environmental baseline in the Clarion Clipperton Zone" (focused on polymetallic nodules, sulphides and ferromanganese crusts), in which some criteria for definition of environmental baseline are already set up:

- Chemical Oceanography: chemistry of water column

- Bioturbation: mixing of sediments by organism

- Monitoring system: establish at least one station within each habitat type or region

- Assess benthic communities: structure genetics of organism associated with the nodules and surrounding habitats

- Physical Oceanography: carbon flux in deep water, temperature and turbidity, current velocity

- Sediment properties: chemical streams, sorting, and grain size
- Assess pelagic communities: recording of the species and levels of trace metals in the dominant species

It needs to be evaluated whether the term "seabed resources" as employed by UNCLOS and ISA also refers to gas hydrates.

In this sense, WG3 may take into account the general approach and criteria set by ISA also for gas hydrates, and compare them with the scientific needs for develop a specific environmental impact assessment and monitoring program. This is also important to create a procedure in according to UNCLOS principles PART XI, XII, XIII that several Member States, have to transpose in their regulation.

In addition, it is important to consider the safety of operators during production and the legal regulation that can be applied to gas hydrate production, considering that the gas hydrate reservoirs are shallower than conventional reservoirs. The regulation about conventional gas should be considered as starting point.

Directive 2013/30 is the EU reference of the EU Member States for preventing major accidents in offshore hydrocarbon exploration and exploitation and limiting the consequences of such accidents. Although the methane hydrates are never mentioned in the Directive, Article 1 clearly states that the Directive covers all offshore activities associated with a fixed or mobile installation relating to exploration and production of oil or gas. The Directive specifies the keywords, the involved entities and the tools concerning procedures to ensure safety in the "upstream" operations offshore. Among the definitions of the Directive, we could focus on the following ones:

- "offshore" means situated in the territorial sea, the Exclusive Economic Zone or the continental shelf of the State (Member State for the Directive) within the meaning of the United Nations Convention on the Law of the Sea;
- 'offshore oil and gas operations' means all activities associated with an installation or connected infrastructure, including design, planning, construction, operation and decommissioning thereof, relating to exploration and production of oil or gas, but excluding conveyance of oil and gas from one coast to another;
- "major accidents". an accident is defined as "major", if it involves release of liquid or gaseous hydrocarbons or dangerous substances, explosion, fire, loss of well control or structural damage which are related to actual or potential personal injuries. A major accident is also any other incident which implies fatalities or serious injury to five or more persons or a major environmental accident (Strada et al., 2015);
- "installation" means a fixed or mobile facility, used for offshore oil and gas operations.; "Production installation" means a fixed or floating installation that is necessary for the offshore extraction of oil and gas from the underground strata of the licensed area including offshore processing of oil and gas and its transportation through connected

infrastructure;"non-production installation" means an installation other than a production installation (such as a mobile drilling units).

- "well operation" means any operation concerning a well that could result in the accidental release of materials and consequently in a major accident, including the drilling of a well, the repair or modification of a well;
- safety and environmental critical elements (SECE) are the parts of an installation (including computer softwares) which are necessary to prevent or limit the consequences of a major accident, or the failure of which could cause a major accident.

The Directive also defines the following parties involved in the procedures to ensure safety of operations:

- Competent authority is the public authority, responsible for safety of offshore o&g operations;
- licensee is the holder (or joint holders) of a license;
- operator is who conducts offshore oil and gas operations, including planning and executing a well operation or managing a production installation;
- owner is the the dutyholder for a non-production installation and is the entity legally entitled to control the operation of a non-production installation;
- contractor means any entity contracted by the operator or owner to perform specific tasks on behalf of the operator or owner.

The operator and the duty-holder (owner) of a non-production facility must submit a report on major hazards- respectively for production and non-production installations - to the Competent Authority.

The operator and the duty-holder (owner) of a non-production facility must submit a report on major hazards- respectively for production and non-production installations - to the Competent Authority. The report on major hazards (RoMH) is one of the key documents for the safety management of offshore oil and gas operations. The RoMH contains a lot of information, such as the policies for major accident prevention, safety and environmental management system and the demonstration that all the major hazards have been identified, their likelihood and consequences assessed, including any environmental, meteorological and seabed limitations on safe operations, and that their control measures including associated safety and environmental critical elements are suitable so as to reduce the risk of a major accident to an acceptable level.

Notification of well is another key document that contains information on the well work program, the risk assessment (incorporating a description of subsurface hazards and the particular hazards associated with the well operation - including any environmental, meteorological and seabed limitations on safe operation) and a description of the well configuration at the end of operations.

Concerning the legal situation of unconventional hydrocarbon production, some EU Member States rely mainly on the general mining, hydrocarbons and environmental legislation and its related permitting procedure transposing the EU legislation to regulate such activities (as for conventional gas extraction) and very few have adopted specific requirements. Operators may be obliged to request several permits under different acts (e.g. water law, mining waste law). In order to address the specificities of unconventional gas exploration and exploitation, several EU Member States have adopted or are reviewing their legislation or develop guidance focused on unconventional gas developments. A few useful examples of regulatory provisions applying specifically to unconventional gas activities were identified in some EU Member States (e.g management of induced seismicity). For example, the Norwegian Petroleum Department (NPD) acknowledges the presence of unconventional oil and gas on the Norwegian Continental Shelf, including gas hydrates. However, in the NPDs view these resources are not especially suitable for production due to the size and physics of the hydrate reservoir. Since none of the unconventional oil and gas resources in Norway are viewed as very suitable to production by the NPD, there are no laws or regulations directly aimed for these resources. Thus, in Norway the law applying to these resources would be the general law on petroleum activity.

Anyway, none of the countries assessed have set in place measures to control and monitor the effects of hydraulic fracturing in the ground with the exception of induced seismicity in the UK.

Gas hydrate are considered unconventional fossil fuels in the EU even if the official document (http://eur-lex.europa.eu/resource.html?uri=cellar:a46647dd-843b-11e3-9b7d-01aa75ed71a1.0001.01/DOC_1&format=PDF) mentions that methane hydrate production and underground coal gasification technology are in the early stages of development and there are no examples worldwide of commercial production. Regulating methane hydrate is a new challenge of the law of the sea and its implementation at European and national level. Like conventional oil and gas activities, it is probable that any actions dealing with the production of natural gas from methane hydrate would utilize a risk assessment approach, primarily based in scientific sources. However perceived risks do not fully correspond to the scientific certainty related to causal link of action (exploration and/or exploitation) to effect (i.e. environmental damage). There are circumstances, as the exploration and exploitation of methane hydrates, where science is not able to provide full certainty yet– that is when the precautionary principle comes into play. This scientific uncertainty may form the premise for a precautionary approach to methane hydrate exploration and exploitation. Such an approach can be a useful tool for enhancing the protection of marine environment. It would be valuable because current law of the sea provisions, including at European and national level, are very general and their applicability is frequently challenged.

5. Final remarks

A multidisciplinary group (geophysicists, geochemists, biologists, modellers) is required to predict and describe the possible scenarios. Next year WG3 will focus the attention on monitoring activities, such as modelling and environmental baseline assessment, in order to evaluate the level of risks and to answer to important questions such as: How to differentiate between natural hydrate destabilisation (e.g. climate change, continued re-equilibration after ice age) and induced through production activities? How to determine ‘proof’ for regulatory and/or liability purposes? How long do you need to monitor in order to capture natural episodic or seasonal processes during the crucial baseline monitoring?

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