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Best Available Techniques Applied to the Offshore Oil and Gas Industry

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ABSTRACT 300146:

Best Available Techniques (BAT) is a principle originally defined in the EU directive on Integrated Pollution Prevention and Control (IPPC). The overall ambition of the directive is to reduce emissions and impacts on the environment as a whole. The purpose of a BAT assessment is to identify the technique with the best environmental performance among all available techniques for a certain industrial application. Such assessment should also take into account technical and economic constraints. A wide variety of industries fall under the scope of the IPPC requirement for BAT in Europe.

The BAT approach is more and more applied in countries outside of EU, and adopted by private organisations as a best practice. In the offshore Oil & Gas industry in Norway, for instance, the BAT approach is now applied to many systems, such as power generation, produced water management, VOC recovery, or, more recently, leak detection and remote sensing. The particularity of the site-specific constraints as well as a lifecycle perspective, typical of the offshore Oil & Gas industry, makes the application of the BAT approach challenging for this sector. Best Available Techniques for offshore applications are therefore site-specific, and require a case by case assessment. In addition, in countries such as Norway, there is no guideline or directive describing how to perform a BAT assessment, which hence needs interpretation and adjustment for each individual application.

DNV has developed a methodology for BAT assessments specifically for the offshore industry. This methodology is based on a ranking of the environmental performance as well as

technical feasibility, reliability and costs of available industrial concepts. The approach is applicable to various stages of offshore Oil & Gas projects. This paper will describe the BAT methodology for the offshore Oil & Gas industry, and give relevant examples of its application to various systems commonly found on offshore facilities. Challenges and future opportunities will also be presented and discussed.

INTRODUCTION:

The principle for Best Available Techniques (BAT) was first introduced in 1984 in the European Union Air Framework Directive (AFD), which applies to air pollution emissions from large industrial installations. The BAT concept was then extended to the control of pollution to air, water and soil through the Integrated pollution prevention and control directive (IPPC, 96/61/EC), through 2008/1/EC, and finally its successor directive (Industrial Emissions Directive, IED) published in 2010 (2010/75/EU).

Applying BAT to offshore activities is required by the Convention for the Protection of the marine Environment of the North-East Atlantic (OSPAR Convention, Annex III, article1). This includes the Norwegian waters. Norway is not a EU member state, however, the Norwegian law requires the application of the Best Available Techniques principle, and directly refers to the IPPC directive in the guidelines for the Activities Regulations and interpretations for the Pollution Control Act. This paper focuses on the use of BAT in Europe, and more particularly for the upstream Oil & Gas sector in Norway.

Best Available Techniques:

Definition

As defined by the IPPC directive (2010/75/EU, article 3.10), the term “best” means that the technique should be the most effective in preventing or reducing emissions and impacts to the environment as a whole. Annex IV of the IPPC directive lists considerations to be taken into account when determining best available techniques. Based on this list, preventing or reducing emissions and impacts to the environment as a whole includes among other: reducing waste and emissions, using less hazardous substances, recovering and recycling substances, and reducing the use of raw materials. Every technique has its pros and cons, and there is therefore a need for a holistic approach when comparing techniques. This may include a trade-off between emissions or energy use for example. LCA (Life Cycle Analysis) type of approaches may be suitable for providing this holistic perspective.

The definition for “available” includes “*developed on a scale which allows implementation in the relevant industrial sector, under economically and technically viable conditions*“ This makes it possible for operators to justify the use of one technique rather than the other based on its technical applicability to the specific installation, its economic accessibility to the organisation, but also its commercial availability on the local market (“*as long as they are reasonably accessible to the operator”,* 96/61/EC article 2.11*)*.

The word “techniques” is to be interpreted in the broader way. It includes the technologies or systems applied (e.g. flotation for water treatment), but also lifetime perspectives such as the way in which the installation is designed, built, operated, maintained and decommissioned.

A wide variety of industries fall under the scope of the IPPC requirement for BAT in Europe. A list is provided in the Annex 1 of 2010/75/EU, and includes but is not limited to: combustion of fuels in installations with a total rated thermal input of 50 MW or more, refining of mineral oil and gas, production of organic chemicals, waste management, and independently operated treatment of waste water.

Purpose

The purpose of BAT is to provide a flexible framework that does not prescribe the use of one specific technique or technology for controlling emissions, but calls for an application-specific, or site-specific assessment. Nevertheless, one of the key features of the IPPC directive is also to stimulate exchange of information on BAT between member states and industries. Therefore, the European IPPC-Bureau organizes this exchange of information and produces BAT reference documents (BREFs). Those are sector-specific documents identifying Best Available Techniques, providing BAT conclusions with associated emission and consumption levels. There are currently 35 BREF documents available (Institute for Prospective Technological Studies, 2013).

BAT for Oil and Gas

Best Available Techniques is increasingly being required and applied in the upstream Oil & Gas sector. In Norway, this is stipulated in the Pollution Control Act (*Forurensningsloven/ Forurensningsforskriften*). The Norwegian requirement is broader in its application than the IPPC directive, which means that BAT is required in Norway for a wider variety of emission sources or control systems. This includes for instance leak detection and remote sensing systems.

The Norwegian standard NORSOK-S003 on Environmental Care (Standards Norway, 2005) uses BAT as one of its bearing principles. This is one of the most advanced standards for environmental considerations in the upstream oil and gas. This standard is generally applied by Operators for the design and operation of offshore installations, and is often set as a requirement for engineering contractors in charge of FEED (Front-End Engineering and Design) and EPC (Engineering Procurement and Construction) phases. In their internal guidelines and standards, oil and gas operators also require the use of Best Available Techniques, such as Statoil (Statoil, 2011), BG (BG, 2010) or Total (Total E&P, 2005).

In a typical design phase for an offshore installation, the operator would include compliance with BAT in the requirements to the engineering contractor. This contractor is often the one taking decisions at a systems or technology level, unless the operator has specific requirements. Therefore, the BAT approach is often within the engineering contractor’s responsibility. Similarly to many other studies carried out at the design stage, the BAT approach is a static assessment performed during a certain project stage. To be able to use the full potential for a BAT assessment there is a need to update this BAT assessment along all design phases. Even if use of BAT is increasingly being required and applied in the upstream Oil & Gas sector, some industry actors are still not aware of this practice. Organizations sometimes choose techniques before carrying out a BAT assessment. This may lead to non-compliance with BAT requirements and regulations, and to substantial time delays and costs if the BAT assessment leads to changes in design.

Specific needs for a method

A challenge is the lack of an established methodology or reference document when performing BAT assessments for the offshore Oil & Gas sector, which leads to individual company interpretations and implementations. There are currently no BREF documents established for the upstream Oil & Gas sector. Some existing BREF documents may be applicable for specific systems, such as the document on Large Combustion plants (Institute for Prospective Technological Studies, 2013a) which may be used for selecting power generation systems and evaluating emission control techniques (e.g. low NO_X). However, existing BREF documents are primarily directed towards onshore industries.

There are a number of differences between the onshore and offshore sectors which make the application of BAT challenging for the upstream Oil & Gas sector in Norway.

At the concept level first, most offshore installations are designed for approximately 20 years life time, or more, with no opportunity to be brought back to a yard for modifications, except for drilling rigs and some Floating Production Storage and Offloading (FPSO) units. This means that opportunities for later changes in the design are very seldom for most installations. In the case of need for modifications, those changes may also be very costly and technically challenging as they would need to be carried out at site offshore. Choices in terms of design and BAT in particular may have an impact on the next 20 years or more for one installation. This has two consequences. First, operators and engineering companies tend to be risk adverse, and will in most cases select well proven techniques. They will hence not always participate to the development of new technologies, even if this is one of the principles in stated in IPPC ("*Member States shall, where appropriate, encourage the development and application of emerging techniques*", 2010/75/EU, Chapter II, article 27). Second, the best available technique is a dynamic concept, and new technologies may emerge in the 20 years horizon which will become BAT. With the installation located offshore, and with costly and technically challenging modification operation, there needs to be strong incentives for operators to consider upgrading systems over the installation life. The value of lost or deferred production offshore is often more significant than for a land based facility.

In addition, the offshore Oil & Gas sector in often characterized by strong site constrains. Space and weight are often at a premium, and safe and reliable operation is a priority. Therefore, the best technique for the environment as a whole may not be the most technically feasible. One example is the use of combined cycle systems for offshore power production. Those systems are typically more energy efficient than simple cycle gas turbine generators, thus reducing fuel use and limiting emissions to air (Kloster, 1999). However, combined cycle systems require the use of a Heat Recovery Steam Generator (HRSG) which purpose is to generate steam from the waste heat contained in the gas turbines exhaust gases. HRSGs are typically very large and heavy pieces of equipment. Even if smaller and lighter HRSGs have been designed for offshore application, very few operators and engineering companies have dedicated the space and weight and accepted the operational risk linked to implementing combined cycle power generation systems offshore (Nord and Bolland, 2012).

An approach to BAT for the offshore Oil & Gas sector

DNV GL has developed its own internal methodology for BAT assessments for the Oil & Gas industry. It is a step-wise approach that may be applied at different stages of the design or operational phase of offshore installations.

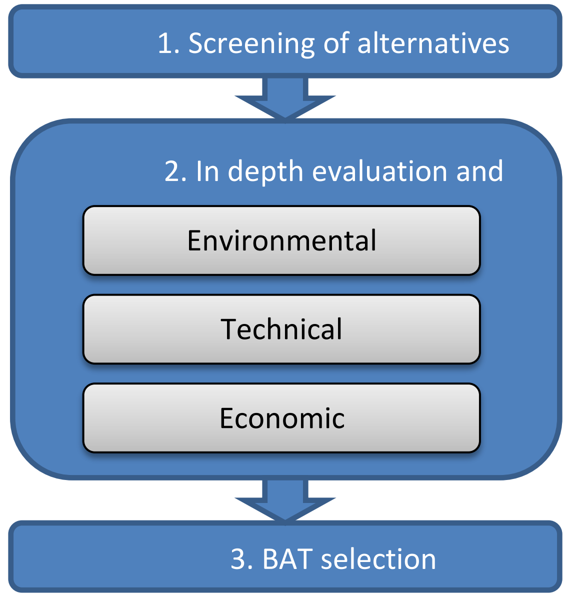

Figure 1 BAT methodology

Screening of alternatives [1]

The first step includes a screening of available alternatives. During a workshop, or as a desktop exercise, alternatives are listed and a high level evaluation of the implications in terms of environmental performance, technical applicability and economic availability is carried-out. This evaluation may be based on the operator's or engineering companies' input, on publicly available information, vendor data, or experience from previous projects. The aim of the screening step is to establish a short list of 2-5 alternatives that may be studied and compared more in detail. Only those alternatives that are deemed to perform the best from the environmental perspective, while being technically and economically feasible are selected.

In depth evaluation and ranking [2]

The next step is an in-depth evaluation of each alternative. It consists of an estimation of the resources use and emissions, including waste generation and reuse/recycling potential. At this stage it is important to clearly define the boundaries of the system, similarly to what is done in an LCA, since this will form the basis for the comparison of alternatives on the environmental basis. Alternatives are ranked based on their environmental benefits. In some cases it is necessary to establish a trade-off between criteria and media, for example emissions and energy use, or waste generation (e.g. if the technique involve filters).

Once alternatives are ranked from the environmental perspective, the technical implications of each alternative are investigated. Typical technical constrains include space and weight requirements, the techniques availability and maintainability, consequences on the safety level (e.g. due to use of gas or pressurized steam), and the technical compatibility with the overall design. Alternatives may then be ranked on the technical criteria, or given a technical feasibility score from 1 to 3, 1 being "technically feasible", to 3 "technically not applicable".

The next activity from step 2 is to investigate the economic availability for each alternative. This should involve an evaluation of the capital expenditures and also operational expenses. CAPEX (Capital Expenditures) may be established based on vendor quotes or data on earlier projects. OPEX (Operational Expenditures) should include maintenance costs, potential repair or replacement costs, but also costs linked to emissions (e.g. CO_2 tax) and the opportunity cost of using natural gas as a fuel on the installation instead of exporting and selling it. Similarly to the technical criteria, alternatives are then ranked on the economic perspective. The ranking may include a comparison the abatement cost for emissions (e.g. US Dollar per ton of CO_2 equivalent), or, when data is lacking, a simple assessment of the cost acceptability for the organization.

BAT selection

Finally, in step 3 alternatives are compared and the best available technique is established. The aim is to determine the best compromise between environmental performance, technical feasibility and economic availability, as illustrated in the figure to the right. Priority is given to the environmental performance.

The level of details and the depth of the assessment are adapted depending on the project phase. For a BAT assessment at the concept stage, the first step (screening of techniques) may be sufficient.

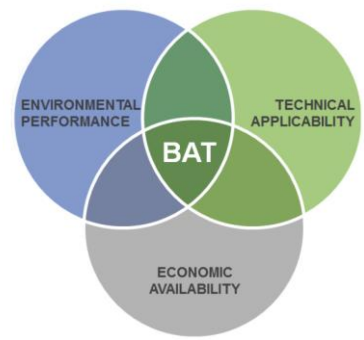

Figure 2 Simple BAT concept

Performing the BAT assessments as early in a project as possible, and updating it during the further development is expected to result in the best savings in terms of time, economy and environmental performance in the end for the operator. This methodology is applicable for both new development and life extension projects. A wide range of systems and techniques on an offshore Oil & Gas installation may be assessed, including power and heat generation systems, recovery of Volatile Organic Components (VOC), produced water treatment, and leak detection systems.

RESULTS:

The methodology was used in several BAT assessments. In this paper three different cases are described.

Case #1: Power generation system on an FPSO for the North Sea, UK sector

Case #1 is related to the FEED phase in the design of an FPSO (Floating Production Storage and Offloading) unit for the North Sea, in the UK sector. The design was a tanker converted to an FPSO. The authors were in charge of the environmental discipline in the engineering team of a FPSO owner and operator, and had direct access to all the design data as well as direct communication with the other disciplines in the project: process, mechanical, electrical, etc. This is considered to be an optimal situation for a BAT assessment. The maximal electrical power requirements for the FPSO during normal operation were evaluated to approximately 30 MW. The power needs along the FPSO life (20 years) were established based on the expected oil and gas production profile. The screening of alternatives included the use of gas turbines in various numbers and sizes, as well as the use of diesel reciprocating engines, and the implementation of a combined cycle system.

Engines were assessed to be unsuitable due to the reliability, space and weight constrains on the FPSO. Combined cycle system was considered not enough proven for offshore use, and to require too much space and weight. Therefore only the gas turbines were selected to be evaluated in depth.

Several configuration and model of turbines were compared: 2, 3 or 4 turbines, with the use of a spare or not. In coordination with the mechanical discipline, turbine data was collected from vendors, and the specific thermal efficiency of each configuration was forecasted, based on the expected profile of production. This made it possible to predict emissions, fuel consumption and energy efficiency over the field life.

Table 1: Summary of comparison of environmental performance for four different gas turbine generator alternatives

	Configuration	Driver Candidates	Efficiency at Base Case production level
Alternative 1	2 x 100 %	GE LM6000	28.9 %
Alternative 2	3 x 50 %	GE LM2500	31.6%
Alternative 3	4 x 33 %	Solar Titan 130 GE LM1600	27.5%
Alternative 1b	2 x 100 % (except at peak load)	GE LM2500+G4 RR RB211-GT61	31.5% < 31.7%

Alternatives were then compared based on their reliability, suitability for the predicted power need, and footprint requirements. The economic evaluation included investment costs as well as fuel consumption (gas) and CO_2 emission costs. In order to make the comparison easier, a three colour index was used: green for feasible, yellow for feasible with challenges, and red for non-feasible.

Finally the selected alternative was the one providing the best trade-off in terms of efficiency over the field life (alternative 2). It also had medium investment costs, but the best savings on fuel and emissions costs. This alternative was considered technically applicable for this project.

Case #2: Produced water treatment system on an FPSO, Norwegian sector

In early 2013, the authors were contacted by an FPSO owner and operator who was in the final stages of having an FPSO constructed in a South Korean yard. The FPSO was to be commissioned for operations on the Norwegian Continental Shelf.

Being in the final stages of the construction phase meant that the entire FPSO, including topsides facilities and process systems, was already designed and being assembled. The authors were therefore contracted to carry out a BAT verification of the existing systems. The design, concept and equipment selection processes in the earlier project phases had for unknown reasons not been carried out and/or documented according to BAT principles as is normally required by Norwegian regulations. This constituted a challenge since the BAT approach is primarily made for decision making.

One of the main process systems to be assessed was the produced water treatment system. On the Norwegian Continental Shelf, the maximum allowed oil concentration in discharge is 30 ppm (OSPAR Commission, 2001). However, the high level goal of the Norwegian regulatory bodies is zero environmentally harmful discharges to the sea, and it is expected that the oil in water concentration limit will get more stringent in the future. In addition, in their discharge permit from the Environmental Agency, operators are often required to achieve a lower oil in water concentration, typically 10-15 ppm. For this facility specifically, produced water was to be re-injected in the reservoir during normal operation, and discharged to sea only during limited period of time (estimated up to 5% of the time). The discharge permit had not been given yet.

When applying a multi-element approach to produced water treatment systems, the focus is not on one process element, but the whole chain from bulk oil removal and separation to the final water polishing. In this case the boundaries for the analysis was set to the process elements downstream the main oil and water separation. This meant the produced water treatment process downstream a 1st stage separator, 2nd stage separator and an electrostatic coalescer.

For assessing the environmental performance, the primary parameter is of course the content of the treated water, i.e. concentrations of hydrocarbons, various natural inorganic and organic compounds, chemical additives (e.g., biocides, corrosion inhibitors) and Naturally Occurring Radioactive Material (NORM). In this case only the oil in water concentration was chosen as a parameter when assessing the treated water quality. There are however other parameters, especially in this case, when the produced water is to be re-injected into the reservoir most of the time. Three more parameters were subsequently defined for evaluating the environmental performance: waste generation, need for chemicals and energy use.

This resulted in the following assessment of the environmental aspects for two alternative treatment systems to the one chosen for the FPSO.

Table 2: Summary of comparison of environmental performance for three different produced water treatment systems

Environmental aspect	Selected Design (CFU)	C-Tour	MPPE
Oil in water concentration after treatment	15 ppm	1-5 ppm	<1 ppm
Waste generation	None	None	Packing material and extraction fluid expected to be degraded over time
Need for chemicals	May be need for flotation chemicals	No	Extraction fluid, but no continuous consumption of chemicals
Energy use	-	-	Steam is necessary

The result showed that as the C-Tour system would likely be able to treat the produced water to a lower oil in water concentration than the selected treatment system (Compact Flotation Unit - CFU), and performed equally for the other aspects. Therefore it was assessed that it had a better environmental performance on the overall. The third system assessed, a MPPE system, would be able to treat the water to a lower oil in water concentration, but would not perform as well for the other aspects. Therefore, C-Tour was the preferred option from the environmental perspective.

For the BAT verification work, it would suffice to show that the C-Tour alternative was technically feasible and economically available to show that the selected treatment system (CFU) in fact was not the best available technique. On the cost perspective, little information was available for all three alternatives. However, as the C-Tour already had been in operation on several installations on the NCS it was assumed to be economically available for this project. The next step was discussions with a supplier regarding the chemical properties of the expected oil in water and suitability for the process. There was also an assessment if there would be enough condensate available from the hydrocarbon production to treat the amount of produced water according to design specifications with the C-Tour system. Based on the findings, it was then concluded that C-Tour system would be technically feasible.

The result of the verification thus showed that the chosen treatment system (CFU) could not readily be regarded as BAT, and that in this case, C-Tour was BAT. One challenge is that the FPSO was already being built, and therefore, the cost of changing the produced water treatment technology at this stage would be much higher than if the decision was taken during design. Based on this, it could be discussed whether the C-Tour technique was really economically achievable for the project at this stage.

In addition, produced water was to be injected up to 95% of the time. The actual environmental benefits of treating water to a lower oil concentration would therefore be realized only 5% of the time when water would be discharged to sea. At this point, one could argue that from an ALARP (As Low As Reasonably Practicable) perspective, the use of C-Tour on this project may be discussed. The FPSO owner eventually decided to keep CFU as the treatment technique. At the time of this writing the Norwegian Environmental Agency is reviewing the application for discharge permit for the field.

Case #3: Leak detection system on an existing fixed platform in the North Sea, Norwegian sector

There are strong requirements for leak detection on the Norwegian Continental Shelf, and operators are required to detect pollution of significance within a short time, usually between one and three hours. Grimsrud *et al.* (2014) developed a methodology for assessing and selecting remote measurement techniques for specific fields. This methodology includes a BAT approach for identifying applicable leak detection technologies.

The authors applied this methodology for an existing fixed production platform in the North Sea. A set of leak detection technologies were listed and reviewed during a workshop. The

BAT approach was applied for this review, and participants evaluated each technology based on the environmental, technical and economic criteria.

Environmental performance was evaluated in terms of detection capabilities. This includes physical coverage, sensitivity, and coverage frequency. Technical applicability for the existing platform took into account whether the systems are available and proven for offshore use, if the design compatible with constrains on the existing facilities. Economic availability for the operator includes both the installation and the operating costs for the technique. The installation costs include the equipment itself, but may also include potential structural overheads. The operating costs will include the continuous handling of data provided by the measure and the maintenance of the sensor.

Out of 21 techniques, 15 were screened and reviewed during the workshop. Those techniques varied from topside and subsea application, such as direct visual observation of spills at sea, radar, use of living biosensors, etc. In an internal second evaluation session, a total of six techniques were evaluated to be fully available from the technical and economical perspective. Four techniques were evaluated to be inapplicable technically to the specific facilities being studied, at least one due to its current development status (i.e. not yet proven for offshore use).

Each technique has its gaps in terms of detection capabilities, and therefore leak detection systems often include the use of a combination of different techniques. Based on the 15 techniques reviewed, a few Best Available Techniques for the specific field were selected and combined into different systems. An example of a system is the combined use of visual observation, detection radar, satellite imagery and a mass balance technique. There is therefore a need for a more holistic BAT view for comparing and selecting entire systems.

Further steps in case #3 differ slightly from the BAT methodology presented in the present paper. However, the overall purpose is similar. In order to have a quantifiable basis for the comparison of systems, an overview of potential leaks from the different production and offloading equipment on site is established based on historical data and site operating conditions. The environmental performance of a detection system is quantified using the following formulae:

$$EP = \sum_{i}^{n\ leak\ points} P_{leak\ i} \times Q_{leak\ i} \times \mathrm{t}_{detec.}$$

$P_{leak\ i}$ corresponds to the probability for a leak i to happen, $Q_{leak\ i}$ is the oil leak flow rate, $\mathrm{t}_{detec.}$ is the detection time. The resulting value could be defined as the volume of oil that could be accidentally released to sea every year on average on a statistical basis.

Based on this value, it was then possible to compare different systems using an ALARP approach, where the cost of an additional technique in the system is weighted against the gain in terms of spill risk reduction. Based on the results from the ALARP assessment, the Operator was able to select one combination of techniques for use on their field.

DISCUSSION:

Experience from the three cases gives factors for a successful implementation of the BAT principle. First and foremost, it is important that the principle is taken into account early in a project development project. BAT is essentially a decision-making tool, and it is most effective when used as such. This means that it can become difficult to apply the principle to a project where decisions have already been made, as seen in case #2.

Good communication is also required between the parties carrying out the BAT assessment and those making the decisions. This is generally easier when both teams work together, as in case #1. The BAT approach needs to be project and site-specific, and the most information available to perform the BAT assessment, the most relevant the conclusions will be. In that sense, the use of a workshop is beneficial as a tool for communicating about the BAT principle, and for collecting data, as in case #3 and also proposed in the methodology step 1.

Performing BAT assessments involves many uncertainties when taking a lifecycle perspective for offshore projects. Different future costs such as operating costs and emission costs as well as future fuel price typically have high uncertainty over a 20 years period. As an example, the CO_2 tax in Norway increased from 200 Norwegian Kroner per ton in 2012, to 410 Norwegian Kroner per ton in 2013 (1 Norwegian Kroner is approx. 0.17 US Dollar at the time of this writing). This is more than double fold, and this changes significantly emissions costs when looked over a long time perspective. However, as described earlier in the offshore Oil & Gas sector there are very seldom opportunities to carry-out major design changes once the facilities are operating, due to remoteness, technical complexity and costs. Design decisions have facility lifetime implications, and it is therefore essential to consider BAT in that perspective and to reduce uncertainties to the minimum. By including BAT assessments in a decision making process, the assessments and analysis in the BAT can support the decision making and support a long term perspective.

To be able to go into deeper analysis and to expand the BAT assessment with e.g. cost effectiveness calculations and As Low As Reasonably Practicable (ALARP), the BAT methodology can provide yet more value to companies in decision making processes. This also allows combining and bringing together different areas of expertise, such as environment and science, technology and development and economy and investments.

Within technology development, whether BAT at a company level is supporting new technologies can be questionable. As described earlier, lifecycle constrains and risk adverse decision makers lead to conservative decision making, in the way that mostly well-proven techniques will often be selected. This may not be the most optimal situation environment-wise. In this perspective there is a need for authorities to challenge decision makers and provide incentives for supporting technology development and adopting new techniques with a better environmental performance as a whole. This is particularly important for emerging topics such as offshore oil leak detection systems for example.

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