International Association of Drilling Contractors

IADC Advanced Rig Technology (ART) Committee
14.00-16.00 Wednesday, 13 September 2023
Hybrid meeting
Movenpick Hotel Amsterdam, Winterthur Room

Minutes

IADC Advanced Rig Technology Committee Co-Chairs Blaine Dow, SLB, and Sarah Kern, H&P opened the meeting and welcomed the attendees. IADC's Linda Hsieh gave an overview of the IADC antitrust policy.

ART Energy Efficiency Subcommittee update: The Emissions Reduction Recommended Practices for Drilling Rig Activities is in final draft form. After an initial round of feedback, which was light, the document was sent out again to several drilling contractors to solicit further feedback. The new round of comments is expected to close in the next 8-10 weeks. If possible, the final document will be presented to IADC's Executive Committee for review in November. A current draft is attached to these minutes.

Data, Controls and Sensors Subcommittee update: Subcommittee Vice Chair Andy Westlake, Seadrill, noted that Nathan Moralez, BP, is stepping down from his role as DCS Subcommittee Vice Chair. Andy Westlake agreed to step up and fill the role. The subcommittee is considering taking on a new project to draft guidelines around human factors engineering related to drilling automation solutions. Blaine Dow noted that, with the ART Committee now focused on completing ongoing projects before starting new ones, this project will be held until the Emissions Reduction project is completed. It was also noted the human factors topic is quite broad so there will be a need to break the project into smaller chunks that can be taken on by different individuals/groups. It may also be valuable to reach out to SPE's Technical Section on Human Factors before starting this project to ensure alignment and collaboration, although because drilling contractors are so involved with implementing human factors with drilling automation, it makes sense for this type of document to come from IADC instead of SPE.

The IADC Guidelines for Minimum Safety Features for Drilling Control Systems and Assets is still incomplete. Andrew Zheng, SLB, has volunteered to lead a group to finish the document but still needs volunteers. Anyone interested should reach out to him at zheng2@slb.com. A current draft is attached to these minutes.

Bit Dull Grading project update: Robert van Kuilenburg, Noble, noted that a small group of volunteers within the workgroup will tackle proofreading the document, and some copyright/permissions issues for images used in the document still need to be resolved. The workgroup also intends to update the WITSML schema for drill bits and add a WITSML schema for BHAs. Once those are done, the group may also create a WITSML schema for DDR Plus, which will include bit dull grading. The document should be ready to launch by year-end. A workshop for BHAs, similar to the one held in 2022 for drill bits, may be considered to boost interest in the project.

ART Committee Mission Statement: It was recognized that the mission statement for the ART Committee could be updated since “advanced rig technology” is always changing. Current mission statement states: “To improve safety and efficiency through sound operating procedures, design of automated systems and standardizing automation.” New statement will incorporate ideas around sustainability, integration and digital.

IADC DDR Plus update project: Matt Isbell, Hess, worked with John de Wardt, DE WARDT & CO; Cole Burdette, H&P; Anil Godumagadda, Patterson-UTI; and David Shackleton to delineate a potential path forward for IADC DDR Plus, with the recognition that industry adoption of DDR Plus has been low since it was launched in 2020. The group sees this as a caretaking exercise to make sure the IADC DDR codes/DDR Plus system stay relevant and has continued use and value for the industry. If no action is taken, the IADC codes will likely fall out of relevance eventually.

Initial proposal would be to coalesce a group of industry stakeholders and undertake a roadmap process to reframe how DDR Plus is positioned and think about its future. It was recognized that that biggest obstacle with DDR Plus adoption now is the digital infrastructure investments required for adoption, as most drilling contractors already have their own systems, so any effort undertaken would need to focus on making sure the DDR Plus can generate sufficient value to justify that investment.

It was emphasized that there is potential for IADC codes to be better positioned so it can work with the systems that contractors are already using, especially since the IADC codes are still “healthy” and already broadly used in the industry to 1)codify rig activities and 2)drive back-end processes for drilling contractors. However, it was also recognized that, even if the roadmap exercise it carried out, it could also lead to the conclusion that there is no value in additional work on the DDR Plus.

Blaine Dow and Sarah Kern agreed to work with Matt Isbell’s workgroup and present it to the IADC advisory panels in November.

The meeting was adjourned at 16:00.

Attendance:
Abdulah Alharbi, Nabors
Andrew Calderwood, Stena Drilling
Andy Westlake, Seadrill
Barry Braniff, Transocean
Blaine Dow, SLB
Bob Judge, HMH
Calvin Carter, SLB
Craig Colby, Diamond Offshore
Craig McCormick, Transocean
Dimitrios Pirovolou, Weatherford
Graham Dey, NOV
Herman Vizcarrondo, Bestoflife Corp
John de Wardt, DE WARDT & COMPANY
Juan Pablo Arias Tamayo, Training Consultors
Linda Hsieh, IADC
Luis Nascimento, Petrobras
Matt Isbell, Hess
Michael Weidenfeller, Caterpillar
Omar Montes
Riccardo Bramucci, Drillmec
Robert van Kuilenburg, Noble
Sarah Kern, H&P
Tdads

Revision: Draft April 7th, 2023

Emission Reduction Recommended Practices for Drilling Rig Activities

FOR IADC ART COMMITTEE USE ONLY

This draft is for IADC purposes only. Please do not share outside of the IADC ART Committee.

Disclaimer

Nothing contained in this publication is to be construed as granting any right, by implication or otherwise, for the manufacture, sale, or use of any method, apparatus, or product covered by letters patent. Neither should anything contained in the publication be construed as insuring anyone against liability for infringement of letters patent.

The verbal forms used to express the provisions in these recommended practices are as follows:

- the term ”shall” denotes a minimum requirement in order to conform to the specification;
- the term ”should” denotes a recommendation or that which is advised but not required in order to conform to the specification;
- the term ”may” is used to express permission or a provision that is optional;
- the term ”can” is used to express possibility or capability.

FOR IADC ART COMMITTEE USE ONLY

Foreword

These guidelines (recommended practices) prepared by the IADC Advanced Rig Technology (ART) Energy Efficiency Subcommittee, consisting of representatives from various IADC member companies, represent a composite of the practices employed by various operating companies, service companies, and drilling contractors. In some cases, a reconciled composite of the various practices employed by these companies was utilized.

FOR IADC ART COMMITTEE USE ONLY

Table of Contents

FOR IADC ART COMMITTEE USE ONLY

FOR IADC ART COMMITTEE USE ONLY

1. Introduction

The International Energy Agency predicts that almost 40% of the emissions reductions required to meet the Paris Agreement scenario will come from readily available abatement methods, incl. energy efficiency improvements. Energy efficiency and emissions reduction are increasingly present in the dialogue between drilling contractors, operators, and other stakeholders following the energy transition. While much is written and published on the intentions, future targets, and efforts to be taken to achieve these targets, there is little published on the tools and techniques to improve energy efficiency and thus reduce emissions from drilling operations.

This document captures and shares recommended practices to optimize the energy efficiency of rig operations which are under the direct control of the drilling contractor. The document focuses on steps that can be taken in the near term to optimize drilling operations regarding emissions. Consideration is given to the commonality and differences between different rig types, notably land drilling rigs, jack-ups, and moored and dynamically positioned floating rigs.

Along with energy efficiency optimization, which directly impacts the emission level, additional near-term passive emission reduction practices are included. The document does not cover methods of quantification and reporting of emissions, nor any aspects related to alternative fuels. Both will be the subject of other projects.

These guidelines (recommended practices) prepared by the IADC Advanced Rig Technology (ART) Energy Efficiency Subcommittee, consisting of representatives from various IADC member companies, represent a composite of the practices employed by various operating companies, service companies, and drilling contractors. In some cases, a reconciled composite of the various practices employed by these companies was utilized.

The purpose of this document is to highlight a number of practical measures and new technologies that drilling contractors can implement to improve energy efficiency and reduce GHG emissions.

2. Definitions

2.1 Normative References

This document contains no normative references.

This document is aligned with ISO 50001:2018 Energy management systems - Requirements with guidance for use [1] on relevant terms and definitions.

For a list of documents associated with these recommended practices, see Bibliography.

2.2 Terms and Definitions

For the purposes of this recommended practices document, the following definitions apply:

2.2.1
carbon dioxide equivalent
CO2e
an amount of a GHG whose atmospheric impact has been standardized to that of one unit mass of carbon dioxide (CO2). Other than CO2 emissions, contribute to CO2e through Green House Gas Warming Potential factors (GWP) as defined per the latest IPCC assessment report.

2.2.2
carbon intensity
A measure of operational emissions intensity. The intensity of emissions from drilling operations will depend on the particular operation being carried out; varies significantly throughout the well program; and is

FOR IADC ART COMMITTEE USE ONLY

impacted by relevant variables such as current, wave height, wind, and other environmental conditions. Carbon intensity can be defined in a number of ways, and it is recommended a clear definition relevant to the organization is used. A typical carbon intensity measure is the amount of CO_2e by weight emitted per unit of energy consumed per contracted day.

2.2.3
drilling contractor
The company that owns and/ or operates a drilling rig.

2.2.4
drilling rig activities
For the sake of this document, drilling rig activities include operation, transit/ rig moves, and time at a yard or stacked. Where operation covers drilling, hotel, station keeping, and similar drilling rig activities at the well site.

2.2.5
emissions
For the sake of this document, emissions include GHG. Non-GHG air emission reduction considerations are briefly covered in Appendix 1.

2.2.6
energy
In the context of a drilling rig, energy is primarily derived from fuel typically (marine) diesel and converted to useable forms such as electricity, heat, mechanical energy, etc.

2.2.7
energy baseline
EnB
Quantitative reference(s) which provide a basis for comparison of energy performance.

2.2.8
energy efficiency
Ratio or other quantitative relationship between an output of performance or energy and an input of energy

2.2.9
energy management system
EnMS
The management system to establish an energy policy, objectives, energy targets, action plans, and process(es) to achieve the objectives and energy targets.

2.2.10
energy performance
Measurable result(s) related to energy efficiency, energy use, and energy consumption.

2.2.11
energy performance improvement
Improvement in measurable results of energy efficiency or energy consumption related to energy use, compared to the energy baseline.

2.2.12
energy performance indicator
EnPI
Measure or unit of energy performance, as defined by the organization.

FOR IADC ART COMMITTEE USE ONLY

2.2.13
energy policy
Statement by the organization of its overall intention(s), direction(s), and commitment(s) related to its energy performance, as formally expressed by the company's top management.

2.2.14
energy target
The quantifiable objective of energy performance improvement.

2.2.15
energy storage
The capture of energy produced at one time for use at a later time to reduce imbalances between energy demand and supply.

2.2.16
energy storage system
ESS
Energy Storage Systems are the set of methods and technologies used for energy storage.

2.2.17
greenhouse gas
GHG
Gases that trap heat in the atmosphere are called greenhouse gases or GHGs. Typical GHGs associated with rig operation are CO2, CH4, and N2O, from combustion emissions. Other GHGs present on a rig may include HFCs, PFCs, SF6, and NF3. The standard list of GHGs as defined by the Inter-Governmental Panel on Climate Change (IPCC) is provided in Table 2.1 [5].

2.2.18
hazard identification studies
HAZID
The process of identifying hazards in order to plan for, avoid, or mitigate their impacts.

2.2.19
hybrid power plant
The plant with combined power generation and energy storage system.

2.2.20
non-GHG
For the sake of this document, non-GHG are substances not defined as GHGs by the IPCC.

2.2.21
operator
The company that has the legal authority to drill wells and undertake the production of hydrocarbons.

2.2.22
organization
Person or group of people that has its own functions with responsibilities, authorities, and relationships to achieve its objectives.

2.2.22
power management system
PMS

FOR IADC ART COMMITTEE USE ONLY

The system that provides control of electrical generators, switchboards, and significant energy uses. Typically, a PMS can start/stop generators, limit power to certain users and/or provide power limitation setpoints to certain users to optimize the overall performance of the system.

2.2.24
service provider
The Third-party company supplying ancillary services for the drilling contractor and operator and gets called out to the rig site to perform specific duties as agreed by the operator. For the sake of this document, the drilling service provider is defined as a drilling contractor, ref. 3.1.5; hence, 3.1.21 doesn't cover drilling contractors.

2.2.25
significant energy use
SEU
Energy use accounting for substantial energy consumption and/ or offers considerable potential for energy performance improvement.

2.2.26
spinning reserve
The amount of unused capacity in online energy assets which can meet peaks in power demand or frequency drops within a given period of time. Spinning reserve is readily available capacity and not to be confused with total installed capacity, which might or might not be available at short notice.

2.2.27
thruster biasing
Counteracting of selected thrusters to increase utilization of the diesel generators or reduce thrusters load variations.

2.2.28
well specific operating guidelines
WSOG
The document is used to define operational limits and actions to be taken by the rig crew (specifically, DPO and driller) when these are exceeded.

2.3 Abbreviations

BOP	Blowout preventer	MODU	Mobile offshore drilling unit
CAPEX	Capital expenditures	NF3	Nitrogen trifluoride
CCS	Carbon capture and storage	NOx	Nitrogen oxides
CO	Carbon monoxide	N2O	Nitrous oxide
CO2	Carbon dioxide	OEM	Original equipment manufacturer
DG	Diesel generator	OGI	Optical Gas Imaging
DP	Dynamic positioned	OPEX	Operating expenses
DPF	Diesel particle filter	PFCs	Perfluorocarbons
DPO	Dynamic positioning operator	PLC	Programmable logic controller
DRE	Destruction Removal Efficiency	PM	Particulate Matter
EnB	Energy baseline	PMS	Power management system
EnMS	Energy management system	POOH	Pull out of the hole
EnPI	Energy performance indicator	P&A	Plug & Abandon
ESS	Energy storage system	P&ID	Process and instrumentation diagram
Ex	Explosion-proof equipment	RMS	Riser management system
FOC	Fuel oil consumption	RP	Recommended practices

FOR IADC ART COMMITTEE USE ONLY

GHG	Greenhouse gas	SEU	Significant energy use
GWP	Global warming potential	SCR	Selective catalytic reduction
HAZID	Hazard identification study	SFOC	Specific fuel oil consumption
HAZOP	Hazard and operability analysis	SIMOPs	Simultaneous operations
HPU	Hydraulic power unit	SPS	Special Periodical Survey
HFCs	Hydrofluorocarbons	SF6	Sulfur hexafluoride
HSE	Health, safety, and environment	SWBD	Switchboard
HVAC	Heating, ventilation, and air conditioning	UPS	Uninterrupted power supply
kWh	Kilowatt-hour	VFD	Variable frequency drive
LDAR	Leak detection and repair	VRU	Vapor Recovery Units
LED	Light-emitting diode	WAN	Wide area network
CH4	Methane	WSOG	Well-specific operating guidelines
MT	Metric ton or tonne		

FOR IADC ART COMMITTEE USE ONLY

3. General Emission Reduction Considerations

3.1 Corporate perspective on emission reduction

3.1.1 Corporate strategy

Identifying key internal and external factors that may affect the implementation of emissions reduction initiatives and achieving intended results is crucial. Factors may include, but are not limited to:

- Organization strategic directions and ambitions
- Organization mission and values
- Organization financial circumstances
- Legal requirements and public expectations in the areas of operation
- Cultural, social, and political factors
- Established processes, systems, and operational factors
- Technology and infrastructure
- Competition factor

Understanding the organization and its context is crucial in establishing, implementing, and maintaining continual improvement of the energy performance of the organization. The context of the organization may change over time; hence, the organizational context should be reviewed at planned intervals and through the activities such as management reviews, etc.

3.1.2 Leadership

Leadership should demonstrate its commitment through demonstrable actions and involvement in emission reduction matters by the allocation of the resources needed to form a decarbonization team in order to implement, maintain and improve fleet energy performance over time. This includes the systems of gathering and reporting the data on the energy performance and emissions.

Leadership management should initiate communication regarding emission reduction targets and goals in a timely manner, emphasizing the importance of energy performance improvement.

Consideration should be given to establishing key performance indicators (KPIs) tied to emissions reduction.

3.1.3 Decarbonization team

The decarbonization team should be cross-organizational and diverse while fully empowered by the leadership to take and communicate the decisions in the respective areas. The decarbonization team should ensure that energy performance improvements are implemented.

Leadership management should ensure that the responsibilities and authorities for relevant roles in the decarbonization team are clearly communicated within the organization. This may require updating organization charts, changes to the job descriptions, updating standard operating procedures, and changes to the training matrix.

3.2 Emission reduction means

3.2.1 Technical means

Emission reduction from drilling rig operations can be achieved by the various types of solutions, also called abatement methods, which can be split into three major categories ref. Table 1.

FOR IADC ART COMMITTEE USE ONLY

Each of the three categories has different implementation complexity and cost, including CAPEX and OPEX, lead time for the implementation, organizational changes required for the implementation of the selected method, regulatory involvement, and other considerations.

Abatement methods			
Type of abatement method	Operational improvements	Upgrades of the existing equipment/ plant	Change of operational principle
Solutions examples for the abatement method	1. Energy Performance 2. Flare optimization 3. Logistic optimization 4. Fuel additives 5. Unlocking operational efficiencies	1. Flare gas recovery 2. Energy storage 3. Installation of energy-efficient equipment	1. Alternative fuel 2. Power from the grid 3. CCS 4. Renewables
Implementation complexity	Low	Medium	High

Table 1

An essential part of GHG reduction is the cost-benefit (incl. carbon tax reduction) and return on investment analysis. Organizations must understand the impact of interventions both at the rig level and in terms of GHG reduction, but also in terms of CAPEX investment programs and OPEX and understand the return on investment of interventions when prioritizing what to do.

3.2.2 Marginal abatement cost curve

The prioritization of the abatement methods can be done by use of the marginal abatement cost curve (MACC). MACC is a tool used to analyze and compare the costs and benefits of different strategies for reducing GHG emissions. The MACC is a graphical representation of the costs of abating (reducing) a certain amount of emissions for different technologies or measures. It shows the cost of reducing one unit of emissions for each technology, ranked from the least to the most expensive.

The MACC is constructed by plotting the abatement cost of each technology or measure on the vertical axis and the abatement potential (i.e. the amount of emissions that can be reduced) on the horizontal axis. The curve then connects the points that represent the different abatement options.

The MACC allows decision makers to compare the costs and benefits of different strategies for reducing emissions, and to identify the most cost-effective options. It can also be used to identify opportunities for emissions reduction that offer the greatest environmental benefit for the lowest cost.

3.2.3 Behavioral means

The organization should define, maintain and evaluate competency requirements for all the personnel on the rig, with more advanced training requirements for personnel who may affect the performance of SEUs. Commentary evaluation of those personnel with the most significant impact on energy performance should be performed to identify and address (by training, etc.), any revealed gaps or improvements potentials. Where applicable, actions can be taken to acquire the necessary competencies by outsourcing, e.g., consultants or personnel with the relevant competencies.

Requirements for the competencies but also the results of the assessment should be documented.

The rig crew awareness can also be raised by the use of visual materials, such as projecting targets and trends on the screen in the areas of common usage, posters, newsletters, and similar.

FOR IADC ART COMMITTEE U

The crew awareness should also be developed by the inclusion of energy efficiency topics into regular HSE and other meetings onboard.

Including the operator is crucial for promoting awareness and following the correct procedures at the drilling site.

Consideration should be given to provide means of positive re-enforcement mechanisms such as incentives tied to emission reductions or similar.

3.2.4 Scope of work

Consideration should be given to create a common understanding about the goals, develop realistic base lines and realistic ways to achieve the goals is crucial to ensure a successful decarbonization effort.

Working within common targets developed for the upcoming drilling campaign, service companies should have elected representatives to report to a core decarbonization team which consists of operator and drilling contractor personnel. The cross-functional team should facilitate progress and report the achievements at the end of the campaign capturing lessons learned and best practices.

3.2.5 Continuous improvement

The organization should continually improve energy performance and the effectiveness of emission reduction measures. This can be achieved by measuring against KPIs, capturing lessons learned and best practices across the fleet and sharing the knowledge across the rigs.

A key element in continuous improvement is creating and maintaining accurate energy consumption baselines for the drilling rigs.

3.3 Emissions sources

For the sake of this document, emissions-generating types of activities onboard the drilling rig belong to one of the four categories below.

1. Combustion

Combustion is a high-temperature exothermic redox chemical reaction between a fuel and an oxidant (usually atmospheric oxygen) that produces oxidized, often gaseous, products in a mixture termed as exhaust. Combustion process onboard of the drilling rig typically linked to main engines operation.

2. Flaring

Flaring is a process used in oil and gas operations to burn off excess gas, typically methane, that cannot be processed or captured for use. Flaring releases carbon dioxide (CO_2), methane (CH_4), and other pollutants into the atmosphere, contributing to GHG emissions. While flaring is sometimes necessary for safety reasons, such as during emergency shutdowns, it is also used to dispose of unwanted gas or to prepare a well for production.

3. Venting

Intentional discharge of GHG and/ or non-GHG to the atmosphere which take place onboard the drilling rig and resulted from drilling operations. Venting is often used as a safety measure to prevent the build-up of pressure within a system (storage tank, pipeline, etc.).

4. Fugitives

Unintentional emissions of GHG and/ or non-GHG to the atmosphere or groundwater resulting from drilling activities. Fugitives can occur as a result of leaks or other unintended releases from equipment or

FOR IADC ART COMMITTEE USE ONLY

processes. Fugitive emissions are a common issue in industries such as oil and gas, where equipment such as valves, flanges, and seals can develop leaks over time. While both types of emissions, venting and fugitives, contribute to GHG concentrations in the atmosphere, the fugitive emissions can be particularly problematic because they can occur without the knowledge of the drilling rig operator and may continue for long periods of time before being detected and repaired.

3.4 Emission intensities

Emission intensities from drilling operations can be quantitative (usually per contracted days) or qualitative (example t/ft drilled). Although quantitative measures are easy to compare, those typically do not give insight how to improve the process. Qualitative measurements do provide a lot more insight in where areas of improvement lie. However qualitative insights do not provide ready insight in absolute emissions for reporting. A mix of both methods is recommended. With both methods careful consideration must be given to create the appropriate base lines and KPI's.

3.5 Key emission sources from drilling rig operations

It is essential to understand the impact on the emission intensity from the various type of drilling operations. As initial guidance, considerations outlined in Table 2 can be used. Where possible, an analysis of historical fuel consumption or emissions intensity data overlain with operational activity, area of operation, and where applicable, metocean data should be used to establish operations that trigger key emissions.

Rig activities	Primary Source		Secondary Source	
	Emissions	Intensity	Emissions	Intensity
Well testing	Flaring	High	Venting	Low
Drilling	Combustion	High	Venting	Low
Reaming	Combustion	High	Venting	Low
Tripping	Combustion	High	Venting	Low
Casing & cementing	Combustion	Medium	Fugitives	Low
International transit	Combustion	High	Fugitives	Low
Stacking*/ Yard	Combustion	Medium	Fugitives	Medium

*Excluding cold stacked units

Table 2

For the drilling rigs with dual activity capabilities, the activity at the auxiliary well center is usually limited to tubulars handling, testing, assembling, and disassembling. Thus, the dual activities typically increase the combustion source of emission due to the additional rig power consumption.

4. The main emission sources from drilling activities

The combustion-related emissions form the majority (up to 95% is not uncommon) of the overall emission footprint from the drilling rig unless there is a substantial amount of flaring activities involved. Hence, the primary focus of the recommended practice document is the energy efficiency of the drilling rig's significant energy users which directly affect drilling operations combustion-related emissions.

However, it is important to address the other three emission-generating processes. Below are some examples of how it can be achieved:

Flaring:
- Well fluids intake and process onboard the drilling rig.
- Better planning and management of well operations.

Venting:
- Implementation of best practices for capturing and controlling vented gas

FOR IADC ART COMMITTEE USE ONLY

- Use vapor recovery units (VRUs) or flare systems to capture and burn off the vented gas instead of releasing it into the atmosphere.
- Use of automated control systems which can detect and respond to changes in pressure, temperature, or flow, minimizing the risk of venting.

Fugitives:
- Improve monitoring and detection systems in order to identify leaks and prevent them from becoming larger issue.
- Promoting education and awareness where education and awareness campaigns can help promote best practices and encourage personnel to reduce fugitive emissions. These campaigns can focus on the environmental and financial benefits of reducing emissions and help create a culture of sustainability onboard the drilling rig.

4.1. Energy review

To obtain a full picture of the current state and opportunities for significant improvement of energy consumption, an energy review undertaken onboard can provide a detailed insight into the energy performance of the drilling rig.
The energy review should result in a list of energy performance improvement opportunities with associated costs and savings, from which priorities can be made.
The quality of the energy review is influenced by the availability, quality, and analysis of the collected data and the competence and availability of the people undertaking the analysis.
The defined intervals for updating the energy review can be different for each element of the energy review. Effective change management and robust communication processes support timely updating of the energy review in response to significant changes in facilities, equipment, systems, and processes.
Energy review should be a rolling target, updated whenever a current target is reached or situations change.

4.1.1 Energy review objectives

An energy review, or audit of energy supply (generation) and demand, provides a detailed picture of the current energy performance of the drilling rig.
The objectives of the energy review are to:
- Analyze energy use and consumption, identifying current types of energy use; past energy consumption; and current energy consumption
- Based on the analysis, identify Significant Energy Uses (SEUs)
- For each SEU
  - Identify current energy performance
  - Identify static factors that significantly impact energy performance and do not routinely change, for example, the size of prime movers, size of accommodation
  - Identify variable factors that significantly affect energy performance and routine changes, for example, weather conditions, operating conditions
  - Identify who controls or influences the energy performance of the identified significant energy use
- Identify and prioritize opportunities to improve energy efficiency
- Estimate future energy consumption

Targeted performance measures should be implemented through an energy efficiency plan which prioritizes interventions, including consideration of the impact/effectiveness of measures, costs, resources, and returns on investments.
While ultimately, zero or low-emission fuel sources are desirable, a general rebuild of the units or replacement of the power plant usually is not in the scope of an energy efficiency plan. However, some major engineering and capital projects may be part of an energy efficiency plan. A comprehensive energy efficiency plan should identify initiatives, cost estimates, energy efficiency improvements, and return on investment (including consideration of fuel-saving incentives in contracts and fuel price) to develop a

FOR IADC ART COMMITTEE USE ONLY

prioritized and scheduled list of interventions. Generally, this list will include an immediate and short-term set of activities where relatively simple and cost-efficient solutions such as retrofits including enabling smart power management capabilities, adjustments, change in the operational pattern, or even improved housekeeping would improve the overall energy efficiency of the drilling rig. Higher cost and more complex engineering interventions should be carefully scheduled to coincide with shipyard stays, for example, aligning engineering interventions with SPS schedules.

4.1.2 Energy review scope

The energy review should be a systematic assessment of energy supply/ generation and demands.

Typically, a rig will comprise

- Supply - Generation
  - Main power plant, auxiliary power generation, emergency generation systems
- Demand – Energy Consumers
  - Drilling
  - Marine/Navigation
  - Accommodation/Hotel

Systems should be assessed to determine actual energy use. Energy performance measures can be effective both on equipment and systems operating on a continuous basis and also on systems and equipment that have significant changes in demand – this is particularly relevant to managing supply efficiency and engine loading.
The highest potential in terms of energy performance improvement may be found in continuously running significant energy use consumers. This could include, but is not limited to:

- Generation
  - Engine auxiliaries incl. ventilation
  - Power systems, power management, and main power distribution components
  - Shore power transmission efficiency

- Drilling
  - Hoisting/ Lowering/ Rotating
  - Mud circulation and mud treatment systems
  - Hydraulic pressure units
  - Drilling system cooling systems
  - Compressed air systems

- Propulsion/Marine
  - Thruster system and auxiliaries incl. ventilation (specific to self-propelled drilling rigs)
  - Sea water cooling systems
  - Fresh water-cooling systems
  - Ballast, bilge, brine, and potable water systems

- Accommodation/Hotel
  - Ventilation and HVAC system
  - Accommodation, laundry, galley, and office spaces
  - Lighting systems

Systems assessment should employ a top-down approach, gradually looking into more detail until no more measurements can be done to verify performance.

FOR IADC ART COMMITTEE USE ONLY

4.1.3 Energy Reviewers qualification requirements

It is expected that personnel carrying out the energy review have a suitable background and experience with the systems in the scope of the Energy Review.

Auditors can employ tools, such as air sniffers, ventilation balancing tools, light meters, etc., to ensure the quality of the survey performed.

4.1.4 Data quality requirements

Accurate energy production and consumption data [6, 7, 8], are essential for a good quality energy review. Auditors should have access to rig energy monitoring systems to obtain historical and, where feasible, real-time energy production and consumption data. The resolution of the available data will be dependent on the individual rig's data collection systems.

4.2 Measuring energy performance

Understanding the energy performance of a specific drilling rig is essential to developing energy efficiency plans to reduce GHG emissions.

The energy performance of the drilling rig can be correlated with the following (or a combination of):

a) Fuel consumption of the diesel generators (or gas turbines)
b) Electric energy produced by generators powering the drilling rig equipment and systems, and
c) Demands of the main energy users (drilling, marine/propulsion, and hotel/accommodation).

In case the rig is powered from the grid, ref. 5.1.3 calculated fuel consumption may not be relevant, subject to the land energy source origin.

4.2.1 Directly measured fuel consumption

Conventional methods of energy performance monitoring onboard the drilling rig are linked to the direct measuring of fuel consumption from drilling operations and may include:

a) Bunker Delivery Notes
b) Flow meters (delivered with the engine)
c) Flow meters (retrofitted after the delivery, e.g., Coriolis mass-flow meters)
d) Fuel oil tank monitoring

The limitation of measuring the energy performance through fuel consumption is the lack of visibility for real-time energy consumption by individual rig systems and equipment. While this does enable an accurate calculation of total energy consumption (and emissions) over a time period of months, or a year, it does not provide visibility of energy demand fluctuations due to ongoing daily operations and conditions nor gives detailed consumption analysis on the equipment or systems level. Therefore it provides limited insight where significant improvements could be made.

4.2.2 Generated power measurements

Another method of energy performance monitoring onboard the drilling rig is a direct measurement of power produced by individual engines.

Emissions can be calculated by translating the produced power to fuel consumption using engines' SFOC test records from Factory Acceptance tests. Since main engines may have decreased performance over time, an adjustment factor may be required and may change over time. These calculations can also be used for predictive maintenance.

FOR IADC ART COMMITTEE USE ONLY

This method should be used on the rigs which are not retrofitted with the sensors at individual rig SWBDs and/ or equipment motors, where such a retrofit is not considered due to high marginal abatement costs.

The limitations of measuring the generated power consumption are in general, the same as for measuring the fuel consumption, i.e., the lack of visibility for real-time energy consumption by individual rig systems and equipment.

There is always a risk of too much detailed measurements, without the proper data quality verifications or a clear vision where the data should be used for.

4.2.3 Consumed power measurements

The recommended method is to measure power consumption at individual SWBDs powering a specific group of consumers, or ultimately, measure power consumption at the individual consumers, e.g., equipment motors. Measuring power consumption at the individual equipment is the most powerful method to drive targeted improvements.

This method allows for full granularity of energy consumption at the individual equipment level. It maps the consumption to the ongoing operations along with other internal and external factors, such as weather. The method may also allow to detect energy losses during transmission from the diesel generator to the individual consumer.

The availability of granular insight into energy consumption could facilitate the design, implementation, and testing of various energy performance optimization solutions, such as rig equipment upgrades, different operation methods, and crew behavioral changes.

4.2.4 Fuel consumption on dual-fuel rigs

Where the rig power plant is fueled by a blend of two or more different fuels, e.g., a blend of natural gas and diesel, fuel composition should be considered in calculating the emissions but also comparing energy performance at different times where the composition may be different.

If the calculated fuel consumption method is used for dual fuel rigs, the substitution rate in percentage should be added to processing the data to segregate diesel and natural gas consumption rates.

4.3 Measuring key emissions other than combustion

4.3.1 Gas sensors on vent and exhaust stacks

Locally fitted instrumentation on exhaust stacks could be essential for verification and/ or calibration of emissions from, e.g., dual-fuel engines or but also for generators running on natural gas.

Third-party logging services can provide data on estimated emissions vented via the MGS vent line based on gasses detected in mud and cuttings.

Exhaust measurement systems should be carefully selected to ensure accuracy, repeatability and user friendliness. Maintenance requirements could be significant as well as the regular calibration efforts.

4.3.2 Flaring impact assessment and recording

The volumes and composition of flared media may be recorded and recalculated to a metric tonne of CO_2 equivalent if such data is provided by the operator.

FOR IADC ART COMMITTEE USE ONLY

The volume of gas flared is typically measured in standard cubic feet (SCF) or standard cubic meters (SCM). Operators can measure the volume of gas flared using flow meters, pressure gauges, or by using a flaring estimation model based on the characteristics of the flare and the process.

The gas composition can vary depending on the source of the gas and the process. The composition determines the amount of CO2 and other GHGs emitted during flaring. Operators can analyse the gas composition using gas chromatography or other analytical methods.

4.3.3 Fugitives detection, recording

Detection and control should be established via logbooks or ERP data where losses of substances converted to 'fugitives' volumes can be traced.

Implementing of systems such as infrared cameras, optical gas imaging (OGI), drones, and remote sensors can help, by the timely detections, reduce fugitive emissions.
The leak detection and repair (LDAR) program should be in place where sniffers or other detection methods should be considered onboard the rigs to detect and eliminate the leaks of media with significant GWP, e.g., areas with natural gas lines and equipment, plants using refrigerants, and similar.

4.3.4 Emissions from energy providers

When external power is used, e.g., power from the grid, the drilling contractor should request verified grid emission factors and other relevant emissions data, incl. volumes and composition, related to the consumed power generation in order properly quantify Scope 2 emissions.

FOR IADC ART COMMITTEE USE ONLY

5. Drilling Rigs Common Equipment and Systems Considerations

This section includes considerations that should be given (where applicable) to improve energy performance and reduce emissions from drilling operations by optimizing the use of drilling equipment and systems. The list of considerations is not exhaustive and should be used for inspiration of emission reduction and energy efficiency conversations onboard the drilling rig and in the headquarters.
It should be realized that often emission reductions lead to a reduction in operational spending as well.

5.1 Power plant

The drilling rig power plant consists of one or more prime movers as the source of raw power and a means to transmit the raw power to the end-use equipment and systems.

5.1.1 Conventional power plant

The conventual drilling rig power plant uses diesel engine(s) as prime movers.

To optimize energy use for stand-by engines pre-heating considerations can be given to utilize heat recovered from the running engine cooling water circle.

Heat recovery from exhaust gases can be difficult to arrange at low engine utilization, such as seen on the drilling rigs (20-45% band) while the rig is at the well site; however, while in transit, this can be considered for self-propelled MODUs. With the rigs retrofitted with the energy storage solution, the utilization of the engines can be higher. Thus, heat recovery can be considered within the boundaries of allowable backpressure and efficiency.

5.1.2 Hybrid power plant

The hybrid drilling rig power plant also uses diesel engine(s), natural gas, or dual-fuel (e.g., methanol-diesel, ammonia-diesel, etc.) as prime movers. In addition, hybrid rigs are outfitted with a means of energy storage to absorb peak loads to enable a reduced number of engines online at one time. The latter will allow the engines online to run at higher loads, closer to the optimum energy efficiency curve.

5.1.3 Power from the grid

The conventual practice for quayside stacked MODUs is to use shore (electrical) power. This practice has recently been extended to MODUs in operation near fixed installations offshore. These MODUs are tied into the installation's electrical power system, which is typically fed by the onshore electrical grid through a subsea power cable. However, power available at the fixed installation can be a limiting factor as only more recent installations were designed and built with the required additional capacity.

Proximity and access to the electrical grid for land drilling rigs make this method to be a real alternative to conventual or hybrid power plants.

Power from the grid can also be paired with traditional prime- movers, such as an engine-generator package to for peak demand and peak shaving as well as avoid downtime in the event of grid power loss.

Some additional considerations for using electrical power from the grid:

- This may require a step-down transformer and harmonic filtering equipment
- Depending on the reliability of the grid, consider a transfer switch to quickly switch to generator power as a backup
- Consider differences in grid voltage at different locations before building equipment to ensure the transformer can utilize all expected supply voltages
- Size the transformer based on expected power consumption
- Utility power will significantly reduce noise, potentially allowing the rig to operate in more urban areas with noise restrictions
- If running utility poles to location is cost-prohibitive, consider using temporary dragline cable, which can be re-used at multiple locations
- In general, if utility power is available within a reasonable distance from the well site location, it is financially worth considering
- Can be paired with energy storage to reduce peak demand and perform peak shaving, as well as prevent voltage deviation on the grid
- When using peak shaving devices proper protections need to be in place to keep the main power grid safe in the event of a blackout of the main power grid

5.1.4 Dual fuel power plant

Dual Fuel Generators – Calculating Emissions and Fuel Consumption:

- The complexity of calculating fuel consumption and emissions increases significantly when utilizing dual fuel
- Emissions and fuel consumption data from engine manufacturers are typically provided at a 0% substitution rate and a maximum substitution rate
- Actual substitution rate varies based on load, as well as environmental factors like temperature, altitude, natural gas quality, and engine health

FOR IADC ART COMMITTEE USE ONLY

- Datalogging needs to capture the substitution rate in real time in order to perform interpolation between the two data sets

Dual-Fuel Generators – General Guidance:

- Subject to methane slip (unburned methane passing through the exhaust as well as crankcase emissions) severity and substitution rate, switching from diesel only to dual fuel might result in increase CO2e emissions. Hence, the methane slip shall be reduced or eliminated by available solutions on the market.

- Dual fuel equipment will include a catalyst in the exhaust manifold

- Some types of non-GHG emissions can be significantly reduced, such as CO and PM

- If natural gas is locally available from wellheads on site or nearby pipelines, there can be potential emissions savings from not having to truck in diesel. If natural gas is brought in via CNG or LNG trailers, these savings will not apply.

- In the future dual-fuel engines category can also cover methanol engines, with high pressure injection providing load step performance equal to the diesel engines. These engines use a small amount of pilot fuel and can switch seamlessly to diesel and methanol mode

5.1.5 Land rigs power plant using natural gas

<u>Emissions Performance</u>

- Replacing diesel generators with generators that run on 100% natural gas may be able to reduce GHG and NOx emissions
- Natural gas engines have significantly lower PM emissions than diesel rigs (>95% lower).
- Lean-Burn engines can reduce GHG and NOx emissions on a wide range of field gas, supported by oxidation catalysts for THC and CO emissions reduction
- Rich-burn natural gas engines are equipped with a three-way catalyst (TWC), to achieve low NOx (over 99%) , THC, and CO emissions.

<u>Transient Response & Power Performance</u>

- Natural gas engines do not have the transient response and range of high performance of the diesel engines used by the O&G industry for decades. However, they can be paired with equipment to make a power system that has acceptable performance, even exceeding that of a diesel only power system. Early natural gas power systems utilized load banks to do this. But this wastes energy (increased fuel costs) and has become less popular in the last decade with the implementation of energy storage systems (ESS) to assist in transient response.
- Lean-burn natural gas engines typically have good overall efficiency and are often paired with an ESS to meet transient requirements.
- Rich-burn engines have poor efficiency at very low loads, so utilizing energy storage to prevent the engine from running at low loads will significantly improve efficiency, more than on a diesel rig.

FOR IADC ART COMMITTEE USE ONLY

5.2 Drilling plant

5.2.1 General considerations for land rigs

This covers the majority of onshore drilling rigs, which are equipped with 3-4 generators with 1 MW capacity each, and a 1500 hp drawworks, with no energy storage system.

- Generators share the load equally, so operating more generators results in a lower load on all of the generators online. Operate the fewest number of generators possible to support the rig demand

- Run only a single generator during operations like cementing, rig walk, nipple up/down, BOP pressure testing, downtime, or any other operation that doesn't require mud pumps or drawworks at a high rate of speed. However, risks of a single generator failure should be recognized and assessed.

- During tripping and casing activities, 2 generators can typically suffice. 3 generators may be needed if tripping out from TD with a very high hook load, or if tripping wet (no pill pumped prior to POOH)

- During drilling operations target a 65-85% generator load. Additional generator capacity should only be added when the operations require. Implement a power control and load distribution software system which measures actual load versus generator load and can actively shut down or start up generators depending on current operational power needs

- After turning the mud pumps off, immediately shut excess generators down, as long as mud pumps will not be needed as per operations activity plan

- If the drilling practice is to keep pumps at full speed when hoisting off-bottom for a connection, more spinning reserve will be needed

- If mud pump speed is reduced before hoisting off-bottom, less spinning reserve will be required, enabling more efficient generator load targets

- Implementing technology to allow the driller to start and stop generators remotely will allow for more frequent changes and enable further optimization

5.2.2 Hydraulic ring mains

The hydraulic ring main management system should ensure optimal energy performance by utilizing accumulators and/ or electronic control.

Optimizing the pump operation by adjusting the speed (with VFD), pressure, and flow rate can reduce energy consumption.

Pumps in the hydraulic ring main should be equipped with an intelligent start system allowing optimal pumps utilization to cover the demands.

Using efficient hydraulic components, such as valves, actuators, and filters, can reduce energy losses and improve system efficiency.

Regular maintenance and repairs can prevent leaks and reduce energy losses.

Insulating the hydraulic ring mains can reduce energy losses due to heat transfer. Insulating the pipes and fittings can reduce heat loss and improve system efficiency.

5.2.3 Rig mud pumps

The optimal use of rig mud pumps and ancillary systems should be considered. Ancillary systems should be switched off when rig mud pumps are idle. During the well planning stages, calculations should be performed to understand the number of mud pumps required to achieve the desired flow rate at the expected pressure range. Using the minimum number of mud pumps to achieve the overall flow rate will increase efficiency.

FOR IADC ART COMMITTEE USE ONLY

The control system should be designed to automatically shut down ancillary systems such as lubrication and cooling and should be switched off when rig mud pumps are idle.

In case the rig mud pump is used as a backpressure pump drilling with MPD/ PMCD techniques, consideration should be given if a dedicated backpressure pump of a smaller capacity should be installed instead.

Preferentially charging pumps should be isolated from each other, or switched off to avoid backflow.

5.2.4 Hydraulic lift systems (RAM rig, Cylinder Hoist Rigs)

A ram rig is not a standard drilling rig; instead of the conventional drawworks for lifting/ hoisting, it is fitted with a Hydraulic Cylinder Lift system.
Dependent on the rig type (single or dual mast) the number of lifting cylinders will be determined. For example, the main well can have five cylinders, and the auxiliary well might have 3 cylinders. Each cylinder should have the capability to lift an equal percentage of the full capacity.
The lift system is supplied from an HPU consisting of multiple main lift pumps, some of these can be assigned to either lift or active heave compensation, plus there are several feed pumps.

5.2.5 Drawworks

Optimal use of drawworks and ancillary should be considered. Ancillary system should be switched off when drawworks are idle (with the addition of a safety interlock which prevents drawworks from being used when ancillary systems are switched off) or ancillary systems should be equipped with VFD controls that operate based ambient conditions and operations ongoing.

Hoisting at full speed may require additional generators to start triggered by a load-dependent starting system. If it is possible to limit drawworks speed for some operations, energy performance or the power plant can be optimized.

Use of passive heave compensation means may be considered in lieu of active heave compensated drawworks.

Means of drawworks power regeneration should be considered, ref. 5.1.2

Drawworks availability requirements may be re-considered subject to operation nature, and such reconsideration may ease the requirements for ancillary systems utilization in standby mode.

The use of peak shaving devices should be considered for drawworks due to the cyclic nature of usage.

5.3 Service providers

Drilling service providers, such as but not limited to solids control, mud loggers, cementing, casing running, MPD, well testing, upper and lower completion, etc. crews should maintain the same level of energy performance awareness as the core rig crew. This can be achieved by extending the awareness campaign and internal processes and procedures toward the service provider's personnel onboard the drilling rig.

The drilling service providers should periodically review their inventory stored onshore or free-placed on the drilling rigs and renew or upgrade to pursue better energy performance.

The drilling service providers should always look for energy-efficient technologies and methods of operation and present them to the drilling contractors and operators for review.

FOR IADC ART COMMITTEE USE ONLY

5.4 Ventilation system

All the fire dampers and flaps should be inspected on a regular basis to confirm operability and integrity and also prevent excessive loads on the ventilation system fans.

Considerations should be given to install a variable speed on the ventilation fans to monitor its pressure, flow rate and air temperature.

Considerations should be given to use sensors to measure temperature, humidity, and air quality in the drilling rig compartments, which can be used to adjust ventilation rates based on demand.

Considerations should be given to use occupancy sensors to detect the presence of personnel in the unmanned areas and reduce energy consumption by adjusting ventilation rates based on demand.

Regular maintenance and cleaning of the ventilation system can improve system efficiency by reducing air resistance and ensuring that the system is operating optimally.

5.5 Lighting

The use of LED lights should be considered where possible.

The use of lighting in combination with motion sensors should be considered wherever it is safe and practical.

The use of tower crown-mounted flood lights in lieu of conventional derrick lights should be considered where practical and still providing adequate illumination.

5.6 Boilers

If a boiler is installed on the rig for deicing and defrosting purposes, it should be assessed if a waste heat recovery system, e.g., main engines exhaust gas boiler(s), should be introduced.
Boilers for creating steam heat to prevent equipment from freezing can be a significant energy consumer. To make this system as efficient as possible, the following practices are recommended:

- Ensure all steam lines are properly insulated
- Ensure all steam traps are functioning properly
- Perform an analysis of the steam distribution system to ensure the proper amounts of heat reach each designated area. Measure the ambient temperature in each area and adjust steam venting as necessary to prevent excessive localized heating.
- Require regular inspections of the system to identify leaks and fix them promptly
- Most boilers can be converted to natural gas with relatively minimal design modifications. If natural gas is available onsite from prior wells or nearby pipelines, this could be an opportunity to reduce trucking diesel to the site.

Boilers used for making water can also be a significant energy consumer. Alternative ways of producing water should be implemented, such as installing reverse osmosis units.

5.7 Flaring

As certain operations require the disposal of gasses, flaring (combustion) of gasses is highly preferred over venting in terms of GHG impact. High-efficient flaring maximizes the emission of CO_2 over methane emissions (methane slip) as the methane is combusted. Methane is at least an order of magnitude more damaging to the environment than CO_2. The DRE (Destruction Removal Efficiency) is an indicator of this flare efficiency. Roughly, a 1% improvement in flare efficiency translates into a 10% reduction in GHG

FOR IADC ART COMMITTEE USE ONLY

emissions. Therefore, managing flare efficiency will have an immediate positive impact on the rig emissions. Flare efficiency can be estimated with Thermal Imaging (beyond visible light), handheld cameras (routine inspection), or inferred from inline ultrasonic flowmeters using dedicated analytics (real-time continuous).

Flaring volumes can be reduced or eliminated if storage/transfer facilities are available for media that is being flared.

Consideration should be given to methods for converting flared gas into useful energy such as creating alternative fuels.

5.7.1 Managing Flare Destruction Removal Efficiency (DRE)

The majority of offshore flares are unassisted (no steam or air is injected to control flare efficiency). However, operational changes upstream to the flare stack could change flare efficiency. The flare tip condition needs to be upheld to prevent the worsening of flare efficiency over time. Weather conditions (shear winds) will also impact the DRE – active measurement and control of DRE are required to minimize GHG emissions.

FOR IADC ART COMMITTEE USE ONLY

5.8 Marine systems

5.8.1 Cooling water systems

Considerations should be given to introduce additional cooling water ring(s) in case some SEUs are located at a significant elevation from the primary cooling water ring main and delivering cooling water to them is inefficient.

Consideration should be given to deploying to the depth seawater intake risers where the surface water temperature does not provide an efficient cooling effect and triggers larger volumes of water to be consumed.

Consideration should be given to periodically evaluate the volumes of cooling water bypassing the heat exchangers due to the thermostat settings. Where possible, the cooling water pumps should be adjusted to run at medium or low speed or be controlled by VFD.

Cleaning of heat exchangers at regular intervals is recommended to avoid pressure losses and a increased demand in water flow (energy losses).

Air cooling systems could be considered for certain users to minimize power consumption.

5.8.2 Compressed air systems

Leaking air could be a major reason for increased power demand of the air compressors. Regular maintenance and repair of the compressed air system can improve system efficiency by reducing air leaks and ensuring that the system is operating optimally. This can include checking for leaks, replacing worn or damaged components, and ensuring that piping is free of obstructions.

Using high-efficiency compressors can reduce energy consumption. Compressors with variable frequency drives (VFDs) can adjust compressor speed based on demand, reducing energy consumption during low-demand periods.

5.8.3 Refrigeration system

Setting the temperature of the refrigeration system to the minimum required level can reduce energy consumption. Over-cooling can waste energy and increase operating costs.

Refrigeration logbooks record all refrigerant consumption should be considered and can be used to determine yearly losses, which can be translated to emissions using the GWP factor for the refrigerant in use.

Regular maintenance and repair of the refrigeration system can improve system efficiency by reducing refrigerant leaks and ensuring that the system is operating optimally. This can include checking for leaks, replacing worn or damaged components, and ensuring that piping is free of obstructions.

5.9 Maintenance

Proper maintenance is essential for improving the energy efficiency of drilling rigs. Regular maintenance helps to ensure that equipment is operating at optimal levels, reducing energy consumption and associated costs. Also utilizing condition-based monitoring systems is a proactive approach to enhance maintenance programs.

Here are some ways to improve the energy efficiency of drilling rigs through proper maintenance:

- Conduct regular inspections: Regular inspections can help to identify and address potential issues before they become more significant problems. This can include checking for leaks, inspecting equipment for damage or wear, and ensuring that equipment is functioning correctly.

- Perform periodical maintenance: Periodical maintenance can help to ensure that equipment is operating at optimal levels. This can include changing filters, lubricating moving parts, and replacing worn or damaged components.

- Use high-quality components: Using high-quality components can help to reduce the frequency of repairs and increase the lifespan of equipment. High-quality components are less likely to wear down or break, reducing the need for replacements and repairs.

- Train rig crew on proper equipment use: Proper equipment use can help to extend the lifespan of equipment and reduce energy consumption.

- Implement energy management programs: Energy management programs can help to identify areas where energy consumption can be reduced. This can include conducting energy audits, implementing energy-efficient lighting and HVAC systems, and using energy-efficient equipment.

- Continual remote equipment monitoring and advanced diagnostics by the OEM can help owners improve asset efficiency and reduce both operating costs and emissions

It is also important to ensure that the maintenance of rig equipment or systems is not only adjusted to the reliability and operational performance but also with regard to energy efficiency.

FOR IADC ART COMMITTEE USE ONLY

6. Land Drilling Rigs Specific Equipment and Systems Considerations

6.1 Rig moves

Planning the rig move route carefully can help to minimize the distance traveled and reduce fuel consumption. By identifying the most direct route, operators can reduce the time and energy required to move the rig.

Optimizing truck speed can help to reduce fuel consumption. Lowering truck speed can reduce wind resistance and improve fuel efficiency.

Considerations should be given to ensure the right size and number of trucks can help to optimize fuel consumption. Oversized or overloaded trucks can consume more fuel than necessary, leading to increased energy consumption.

Considerations should be given whether there are any equipment and/ or parts that can be centrally stored which are currently being moved between locations without being utilized on the locations.

7. Jack-up Specific Equipment and Systems Considerations

This section includes considerations that should be given (where applicable) to improve energy performance and reduce emissions from drilling operations by optimizing jack-up drilling rigs' specific arrangements, equipment, and systems. The list of considerations is not exhaustive and should be used for inspiration of emission reduction and energy efficiency conversations onboard the drilling rig and in the headquarters.

7.1 Marine systems

7.1.1 Raw water system

Consideration can be given to recovering hydropower from the dumped seawater by the installation of turbines in the dump chutes installed on the jack-up legs.

8. Moored MODU-Specific Equipment and Systems Considerations

This section includes considerations that should be given (where applicable) to improve energy performance and reduce emissions from drilling operations by optimizing moored drilling rigs' specific arrangements, equipment, and systems. The list of considerations is not exhaustive and should be used for inspiration of emission reduction and energy efficiency conversations onboard the drilling rig and in the headquarters.

8.1 Mooring operations

Where possible, the use of mooring spread is to be assessed as an alternative to DP operations; however, it should be a subject of overall costs and emissions potential assessment.

More robust mooring spread designs should be considered in lieu of DP assistance while moored.

9. Self-propelled MODU Specific Equipment and Systems Considerations

This section includes considerations that should be given (where applicable) to improve energy performance and reduce emissions from drilling operations by optimizing self-propelled drilling rigs' specific arrangements, equipment, and systems. The list of considerations is not exhaustive and should be used for inspiration of emission reduction and energy efficiency conversations onboard the drilling rig and in the headquarters.

FOR IADC ART COMMITTEE USE ONLY

9.1 Thrusters

Thrusters play a critical role in ensuring a safe a reliable drilling operation while in Dynamic Positioning (DP) mode. The thruster system does, however, also add significantly to the overall energy consumption of the drilling unit. It should therefore be evaluated carefully how the system is being operated to avoid waste and excessive power consumption from the thruster systems.

9.1.1 Thruster's utilization

Stopping thrusters that are not required for the drilling rig's ability to maintain positioning and redundancy philosophy is the most effective way to reduce energy.

It is strongly recommended that the drilling unit has systems and procedures in place to evaluate the thruster need and balance the system accordingly. For example, this could include a daily capability plot for the rig, created in simulation mode using an unfavorable heading of, e.g., 20-30 degrees and running with a reduced number of thrusters online. This will assure the rig team that the reduced number of thrusters enable**s** safe operations, also in case of a worst-case failure as defined by the DP equipment class.

9.2 Thrusters ancillary systems

9.2.1 Ventilation in thrusters' compartments

The minimum ventilation requirements should be assessed, and fans in the room to be adjusted accordingly.

9.2.2 Thrusters HPU

The minimum number of thrusters HPU online should be considered.

9.3 DP operations

9.3.1 Optimized DP operations

The use of solutions such as smart DP, real-time WSOG, or similar should be considered to optimize watch circles where possible. Optimized watch circles allow less frequent position adjustment and thruster "hunting" or "searching" at minimum thrust. Where "thruster hunting" or "thruster searching" is a phenomenon that can occur on a DP vessel when the thrusters are rotating but not providing sufficient thrust to maintain the vessel's position.

9.3.2 Minimum number of thrusters

The use of solutions that can calculate in the background worst-case scenario as per rig DP FMECA and apply live environmental data in order to advise on the possible reduction in the number of thrusters while still staying within limits, including contingency, should be considered.

Rig DPO should continually assess the maximum number of thrusters required for given environmental conditions, vessel orientation, and ongoing operation. The number of thrusters online should be reduced if it is deemed safe.

Station-keeping simulations addressing similar environmental conditions should be available on the bridge to bake DPO decisions.

FOR IADC ART COMMITTEE USE ONLY

9.4 Main power plant configurations

Power plant emissions can be minimized by operating diesel engines at the maximum fuel efficiency point, typically at or near 80% of the maximum load. This consideration needs to be balanced by the need to have reserve power online, e.g., for safety reasons.

9.4.1 Split bus-ties configuration

The design of a power management system will influence the necessity of split bus operations. An evaluation, in the form of a risk assessment or similar, is recommended for DP vessels designed for closed bus operations choosing to operate in a split bus tie configuration. The evaluation is required to take into account factors, including maintenance flexibility, probability of partial blackouts, and fuel consumption.

The use of energy storage devices could be considered as "spinning reserve" allowing engines to be switched off. This will prevent engines running at low loads and allow the vessel to operate in split bus.

9.4.2 Closed bus-ties configuration

It is recommended DP drilling units designed and built to classification standards approved for closed bus-ties operate in closed bus-tie mode. Current classification standards include ABS EHS-series [2], DNVGL-OTG-10 DP-Classified vessels with closed bus-tie(s) [3], etc.

To accommodate vessels designed and built for closed bus operations before the most recent classification societies' common bus notations have been introduced, the units need to be evaluated on a case-by-case basis. Factors to be taken into consideration include client requirements, original vessel design/construction/verification criteria, advanced computer modeling, operational history, upgrades, and blackout recovery philosophies.

Closed bus-tie configuration can improve a drilling unit's environmental impact through a reduced number of engines online while running at higher loads.

Close bus-tie operation is now also possible with the implementation of a DC grid system using DC/DC convertors and solid-state breaker switches. This will allow true closed bus-tie operations at all times. Standard closed bus-tie switches are not suitable for this, not allowed during critical operations.

9.5 Transit

It is expected that self-propelled (or DP) MODUs to transit between drilling locations using their propulsion system powered by a MODU power plant. Hence, facilitating the propulsion by the mean of facing less resistance in the water or air has a direct positive impact on the energy performance. This can be achieved by specialized coating, air lubrication, or similar methods.

Similar considerations may also be applied when MODU is transported on a heavy lift vessel or towed by towing vessels.

9.5.1 In-field transit with suspended BOP (Hopping)

In-field transit with BOP hopping saves BOP running time, reducing the overall emission intensity per drilling program.
In-field transit is usually done at a low speed of 0.5-1.0 knots; hence, utilization of the power and propulsion plants should be considered.

FOR IADC ART COMMITTEE USE ONLY

9.5.2 Optimal transit speed

Optimal transit speed is a balance of the following factors:

a) MODU fuel consumption at various speeds and draughts
b) MODU deck capacity at various drafts (how much equipment should be offloaded) Transit draft versus the variable deck load to be considered.
c) Earliest contract commencement date

Optimal transit speed knowledge for various MODUs in a company's fleet should be available within the organization and be considered when preparing the activity plans for an individual MODU.

9.5.3 Enhanced routing planning

While the enhanced routing planning for the offshore industry is not as critical as for the maritime industry, there is still a significant potential for energy performance improvement through smart routing planning.

Enhanced routing planning may assess the following aspects.

a) Metocean conditions, such as prevailing wind, current, and sea
b) Bunkering capacities in various locations
c) Optimum transit speed
d) Crew change simplicity in multiple locations
e) Any planned stops for rig upgrades or SPS

9.5.4 Hull cleaning

Marine growth is usually referred to as species that attach to or grow on submerged structures such as the hull, thruster propellers, etc.

This can cause inefficiencies in thruster operations and lead to additional energy consumption while transiting the drilling rig between two locations due to the added friction through the water.

Cleaning of marine growth should therefore be conducted at regular intervals, as far as practicable, and should be considered as a part of transition/voyage planning.

9.5.4 Hull coating

Hull coating introducing a low friction effect may be considered. The low friction effect is achieved via the improvement of hull roughness and long-lasting antifouling effect.

10. Accommodation/ Hotel

This section includes considerations that should be given (where applicable) to improve energy performance and reduce emissions from drilling operations by optimizing the use of accommodation equipment and systems. The list of considerations is not exhaustive and should be used for inspiration of emission reduction and energy efficiency conversations onboard the drilling rig and in the headquarters.

10.1 HVAC system

Considerations should be given replacing old, inefficient HVAC equipment with energy-efficient models can significantly reduce energy consumption. Energy-efficient HVAC systems are designed to operate more efficiently and can reduce energy consumption by up to 30%.

The upper boundary of the optimum temperature band in accommodation should be considered. However, in tropical/high-humidity climates, the optimum temperature for comfort must be balanced against the

FOR IADC ART COMMITTEE USE ONLY

required initial chilling temperature for humidity removal to prevent mold, condensation, and associated maintenance and health problems.

The upper boundary of the optimum recirculation air percentage band should be considered.

Considerations should be given if the HVAC system can be balanced at regular intervals.

10.2 Accommodation superstructure boundaries integrity

Proper insulation can help to reduce the amount of energy required to heat or cool a space.

All the doors to the accommodation superstructure should be inspected regularly to ensure air tightness and avoid leaks of cooled air into the atmosphere.

All the doors to the accommodation superstructure should be fitted with self-closure devices.

All the fire dampers and flaps should be inspected on a regular basis to confirm operability and integrity and also prevent excessive loads on the HVAC system fans.

10.3 Galley, laundry and provision store equipment and operation

Considerations should be given to upgrade to energy-efficient appliances were replacing old, inefficient appliances with energy-efficient models can significantly reduce energy consumption and associated costs. Energy-efficient appliances are designed to operate more efficiently and can reduce energy consumption by up to 30%.

Catering and accommodation service company should have energy efficiency mindset embedded into daily operations, e.g.,

a) washing machines should be filled with the weight allowing for the optimum energy performance of the machines
b) dish washers should be filled with the weight allowing for the optimum energy performance of the machines
c) galley equipment, e.g., fridges, to be used to the optimum capacity
d) Use of energy-efficient cooking methods, such as using pressure cookers or steamers
e) Use of lids on pots and pans can reduce the amount of energy required to cook food by trapping heat and reducing cooking times.

Means of capturing and recirculation of heat or water should be considered.

The provision store should be outfitted with an airlock or similar arrangement to avoid warm air inlet into the compartment.

11. Hotel/ Accommodation/ Camps

Hotels and accommodation camps energy efficiency initiatives may include:

- Efficient lighting: Switching to energy-efficient lighting options like LED bulbs can significantly reduce energy consumption
- Temperature control: Proper insulation and temperature control can help reduce the amount of energy required for heating and cooling the accommodation
- Use of renewable energy sources: Installing solar panels or wind turbines can provide clean and renewable energy for the camp

FOR IADC ART COMMITTEE USE ONLY

- Efficient appliances: Using energy-efficient appliances like refrigerators and air conditioners can help reduce energy consumption
- Behavior change: Encouraging energy-saving behaviors among camp residents can also help reduce energy consumption

The mean of energy efficiencies for hotels/ accommodation camps can vary depending on the specific measures taken to save energy. However, by implementing a combination of the above measures, energy savings of up to 30% or more can be achieved.

12. Cargo and lifting operations

This section includes considerations that should be given (where applicable) to improve energy performance and reduce emissions from drilling operations by optimizing cargo and lifting operations. The list of considerations is not exhaustive and should be used for inspiration of emission reduction and energy efficiency conversations onboard the drilling rig and in the headquarters.

Optimized loading/unloading plans should be considered avoiding very time-consuming operations providing little value". An example is to avoid the requirement to empty bulk tanks 100% - where the last 5% takes 80% of the transfer time.

12.1 DP supply vessels operation

If the boat's operation is suspended for a period of time, it should be assessed by the drilling contractor and operator if the boat can stay at the distance where the boat DP system can be relaxed or turned off, optimizing the energy performance of the boat power and propulsion plants.

FOR IADC ART COMMITTEE USE ONLY

Appendix 1. Non-GHG emissions reduction

A-1. NOx reduction

A-1.1. Selective Catalytic Reduction (SCR)

Selective Catalytic Reduction (SCR) is a technology used to reduce nitrogen oxide (NOx) emissions from diesel engines, gas turbines, and other combustion processes. It works by injecting a reducing agent, usually ammonia or urea, into the exhaust gas stream before it enters the catalytic converter. In the converter, the reducing agent reacts with the NOx to form nitrogen (N_2) and water vapor (H_2O), both of which are harmless and non-polluting. If properly designed, this system can reduce NOx emissions by > 90%.

The SCR process requires a catalyst, which is typically made of a ceramic or metallic material coated with a layer of active metals, such as vanadium, tungsten, or titanium. The catalyst facilitates the reaction between the reducing agent and NOx, reducing the amount of NOx emissions that are released into the atmosphere.

This setup requires a significantly sized storage tank for the urea fluid, which should be equipped with a heating system to prevent freezing. A pump is required to circulate the urea fluid from the tank up through the catalyst bricks.

A-1.2 Different types of prime movers

SCR is most commonly used with diesel prime movers due to the high levels of NOx produced from burning diesel. However, SCR can be used with any exhaust stream.

A-2. Particulate Matter reduction

Particulate Matter emissions are most significant with diesel combustion, but natural gas also produces particulates. A diesel particulate filter (DPF) can be installed to filter out particulate matter; however, there are some challenges with implementing this system. If the engine load is low for extended periods of time (12+ hours), the particulate filter can get clogged up with oil particles which cannot be burned off due to the low exhaust temperatures. The engine must be managed so that it can run at high load periodically to burn off these particles. If this is not addressed, back pressure will increase, which can lead to further problems.

If the engine load cannot be reliably managed, the system may need a bypass for exhaust gas to escape without going through the filter if the back pressure is too high. Alternatively, the filter could be artificially heated to mitigate the buildup of oil particles.

FOR IADC ART COMMITTEE USE ONLY

Bibliography

[1] ISO 50001:2018 Energy management systems - Requirements with guidance for use

[2] ABS Guide for dynamic positioning systems 2021

[3] DNVGL-OTG-10: DP-CLASSED VESSELS WITH CLOSED BUS-TIE(S)

[4] UK DBEIS. Greenhouse gas reporting: conversion factors 2021

[5] IPCC Fourth Assessment Report

[6] IADC Rig Sensor Stewardship Guidelines

[7] API RP 8FV1, Field Verification of Rig Devices for Oil and Gas Well Drilling Operations, 1st Edition

[8] Operators Group on Data Quality

FOR IADC ART COMMITTEE USE ONLY

[1] International Association of Drilling Contractors, 10370 Richmond Ave, Suite 760, Houston, TX, 77042. www.iadc.org.

International Association of Drilling Contractors (IADC)

Guidelines for Minimum Safety Features for Drilling Control Systems and Assets

DRAFT

Executive Summary

Rig floor operations pose significant challenges to Oil and Gas (O&G) Operators, Drilling Contractors, Service Companies, and Drilling Equipment Integrators to reduce potential risk. To reduce the risk of (1) human to machine collision, (2) machine to machine collision/damage, (3) internal damage to the machine itself, (4) non-compliance with regulatory requirements, (5) exposing vulnerabilities with automation, the IADC - *Guidelines for Minimum Safety Features for Drilling Control Systems and* Assets sets forth recommendations to help further reduce risk to rig floor operations.

This document specifies recommendations for employing safety features on the rig's drill control system by means of applying software logic, instrumentation, and a combination of both. Guidance is derived through experience and the following standards;

- Machinery Directive 2006/42/EC
- BSI/IEC 62061 Standard, 2010
- ISO 13849-1 Standard

This document gives recommendations to help organizations identify safety features and the operational criticality level of different task/processes and sets forth a robust rig floor safety strategy to reduce the potential risk.

DRAFT

TABLE OF CONTENTS

DRAFT

Introduction and Background

The Upstream Oil and Gas sector has a long history of drilling equipment related collisions and human induced machine damage events which have led to the development of the IADC Guideline for Rig Control Systems Minimum Safety Features.

This guideline makes recommendations on safety features that should be employed in a drilling control system (DCS) to enhance safe operation of a rig.

Safety is a responsibility of everyone involved in the well construction, completion, and intervention processes. Safety is not only understanding how to manage unsafe events but also providing all the necessary steps to prevent them. It is important that drilling contractors understand the design, operation, and safety features of both the control system and machinery involved and how these machines interact with each while being managed by the DCS. Typically, driller's and crew members have a good understanding of the various well construction processes but it's also important for them to understand how to safely deviate, if necessary, from these processes. This includes understanding the rig's control system safety features that are in place to prevent unsafe events and how to safely deviate if needed.

When a machine is integrated into the control system, a minimal set of safety features should be employed to ensure safe functionality of the machine and its interaction with other machines. This includes emergency stops (primary, secondary, hardwired, wireless, etc.), internal interlocks, and operational interlocks.

As machines interact with each other during drilling sequences, a matrix outlining interlocks for every machine should be created. This matrix should include internal interlocks (internal to the machine) and general interlocks applicable to the process.

The status of all interlocks and operational states should be presented to the user through the human machine interface (HMI) or supervisory system. These interlocks or safety features should not hinder the process but rather enable a smooth and fluent collaboration amongst all machines integrated on a drill floor for various processes and tasks.

Having a good safety practice should ensure that all system interlocks are working and enabled and the relationship between machines is safe for operations.

In order to have a good visualization of interlocks and the operation of an anti-collision system among machines, a starting point would identify the interlocks of single machines, machines by operation group and by process.

Control systems and machine safety is a crucial topic, not only for drilling operations that are of high risk, or the cost of the assets, but also for human interaction.

1. Standards and Best Practices for Machine Safety

The following standards and best practices provide valuable recommendations, insight, and guidance toward machine and process safety. This includes standards and practices from BSI/IEC, ISO, EC, etc. There are no specific rig floor safety standards for the Upstream Drilling and Completion sector of the O&G market; however, there are industrial standards for the process and nuclear sectors.

1.1 BSI/IEC 62061 Overview and Application to Drilling Assets

This section provides an overview of the BSI/IEC standard with clauses that discuss equipment and process safety requirements. The BSI/IEC 62061 guidance for design of safety-related control systems for machinery provides good recommendations and practices to estimating risk and assigning performance levels. BSI/IEC 62061 and ISO 13849-1 are similar in recommendations but use different methods for assigning safety integrity levels. Below are some of the clauses that can be pulled out of BSI/IEC 62061 and contextualized to use for drilling rigs.

DRAFT

BSI/IEC 62061 *Clause #1 [State Clause]*

BSI/IEC 62061, *Subsection x.x.x.x Element: Risk Assessment*:
In this section, IEC 62061 mentions the importance of risk assessing. This includes the following;

1.2 ISO 13849-1 Overview and Application to Drilling Assets
This section provides an overview of the ISO 13849-1 standard with mention to clauses that discuss guidance on establishing process and personal safety practices.

1.3 EU Machinery Directive Overview and Application to Drilling Assets
This section provides an overview of the EU Machinery Directive with clauses that discuss guidance on establishing process and personal safety practices.

1.4 ANSI B11.TR3 – 2000 Overview and Application to Drilling Assets
The section provides an overview of the ANSI B11 technical report with mention to clauses that discuss recommended methods for risk assessing and risk reduction to machine tools. The report also provides some guidance on the selection of appropriate protective measure to achieve tolerable risk.

1.5 ANSI R15.06 – 2012 Overview and Application to Drilling Assets
This section provides an overview of the ANSI R15.06 standard with mention to clauses that discuss manufacture and integration of industrial robots and robot systems.

2. General Information
The following section provides guidance on the minimum information that should be provided by the system integrator or original equipment manufacturer. There are a number of different rig supervisory and control system (RSCS) vendors and the RSCS should be treated like all other pieces of drilling equipment. Attention should be given to evaluate safety functionality offered.

2.1 Vendor Minimum Requirements
At a minimum, the RSCS vendor should provide the following:

- Procedures or Manuals that include:
  - Startup Procedure
  - Shut Down Procedure
  - Detailed Information of Each Screen
  - Detailed Information for Each Piece of Equipment Controlled
  - Detailed Information for Each Rig Process

- Alarm & Response Documentation, including:
  - Alarm Number
  - Displayed Alarm Text
  - Description of Event or Condition that Triggered the Alarm

- ♦ RSCS Action Taken (Driller Notification, Driller Confirmation, E-Stop Type, etc.)

- Training: (classroom, onsite, or both)

2.2 Historian (recommended)

Not all RSCS offerings include a historian or data logger. A historian can be a valuable tool when investigating downtime events or incidents.
A historian is like traditional third-party data acquisition systems with the following exceptions:

- Historians record more discrete sensor data and alarms (encoder counts, hook load strain gauge channels, etc.).

- Historians records either on the RSCS scan rate, which can be upwards of 10 hertz, or change in state. Traditional data acquisition systems typically record at 1 hertz or change in state.

- Historians store their data on the rig due to the volume being collected and typically overwrite the data once every 30 to 45 days. It is not typically streamed offsite.

- Historians can be accessed locally or remotely for investigation purposes.

3. Internal Machine Interlocks

Internal Machine Interlock, for the purposes of this document, refers to the RSCS' application of interlocks that are contained within a discrete machine or equipment skid such as a mud pump, drawworks, or top drive. It does not refer to machines with on board stand-alone control software limited to only the control of that machine, machine to machine interface, or machine to machine collision avoidance.

3.1 Risk Identification Process

A risk analysis similar to Table 3.1 should be performed for each machine under the control of the RSCS to identify potential actions that can damage the equipment or create an unsafe environment. The outcome of the risk analysis should consider all the machines sub-components. This process should be performance on all systems or machines to ensure that they are protected from self-damage.

DRAFT

Table 3.1
Drawworks Internal Risk Identification

Off/Not Adequate \ On/Adequate	Motors	Blowers	Lubrication Pump(s)	Brake	Air Pressure	Motor Encoder	Drum Encoder(s)
Motors		Y M DC(1)	Y M DC(1)	No	No	Y H DN(2)	Y H DN(2)
Blowers	Y M DC(1)		Y M DC(1)	No	No	Y H DN(2)	Y H DN(2)
Lubrication Pump	No	No		No	No	No	No
Brake	No	No	No		Y H ES(3)	No	No
Air Pressure	No	No	No	No		No	No
Motor Encoder	No	No	No	No	No		No
Drum Encoder(s)	No	No	No	No	No	No	

"Y" or "N" — "Yes" there is an issue or "No" there is not an issue.
"L", "M", "H" — Low, medium, or high risk severity.
"DN", "DC", "ES" — RSCS Action: Driller Notification, Driller Confirmation, or Emergency Stop

(1) Long term use would cause equipment damage but the driller allowed to choose to run in this scenario based upon their evaluation of well conditions. Note, the interlock could be different based upon the equipment's state when the condition occurs; the RSCS could prevent the equipment from starting in this scenario, but could just notify the driller if the conditions changed while already running. Driller Confirmation may be a one-time requirement or reoccurring requirement on a preset frequency.

(2) Need to understand the redundancies in the system and develop multi-tiered alarms. Driller Notifications may be one-time requirement or reoccurring requirement on a preset frequency.

(3) Drawworks brakes should be fail safe so if there is no air (or hydraulic) pressure to release the brake, an e-stop is generated. If simply low air (or hydraulic) pressure that would cause the brake to drag it might be a Driller Confirmation based upon their evaluation of well conditions

3.2 Internal Tracking Control

For all equipment being controlled, the RSCS system should continuously monitor the state of the equipment subcomponents and all sensors associated with the equipment and its subcomponents to be able to trigger alarms, soft-stops and/or e-stops as detailed in the RSCS alarm manual.

4. Drilling Process Automation Interlocks

For highly mechanized and integrated rig floor designs, different robotic-like machines must work and interact with each other to execute different well construction processes. It is critical to ensure that each machine is protected from damaging itself as well as other machines during manual and automated process control. The following sections outline recommendations for implementing machine-to-machine interlocks.

DRAFT

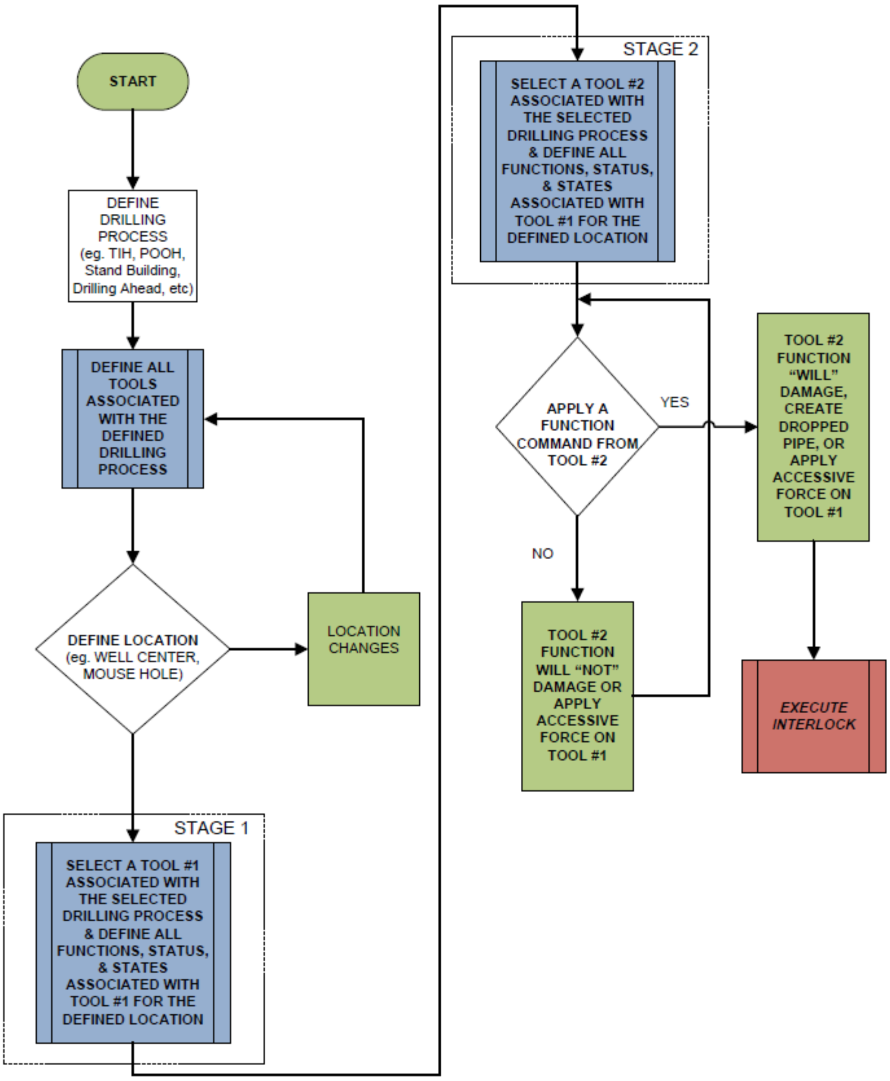
It is recommended that drilling machine to machine hazards are identified and risk assessed to ensure that an interlock is in place to prevent the hazard from happening. As an example, use the machine-to-machine hazard identification to flow chart to identify whether a hazard exist between a specific interaction between machines.

Then risk assess the scenarios to determine whether that specific hazard has the potential for a major impact to the crew's health and safety, or environment in which the rig is operating, and/or the business. A machine to machine risk analysis should be done for every type of rig with integrated drilling equipment. The analysis should include the following;

a. A list of all equipment included in the rigs design, this typically includes the drawworks, mud pumps, topdrive, mechanized slips, mechanized roughneck, mechanized pipe conveyor system, mechanized fingerboards, and mechanized vertical pipe machine.
b. Identify the process in which the machines from 'a' will function and work.
c. Machine-to-machine interlocks are about machine commends versus another machines current state.
d. Simulate an interaction between two machines involved in the same process. Simulate one machines functional commands versus another machine's current status.
    a. If the machines functional commands will **not damage** or apply **excessive force** on the receiving machine, then no interlock is needed.
    b. If the machines functional commands **damage** or apply **excessive force** on the receiving machine, then an interlock is needed. See diagram 6.1

DRAFT

Diagram 4.1
Machine-to-machine Risk Identification



Once a risk has been identified, it is important to assess the risk according to your organizations risk levels. General risk assessment strategies include risk assessing a scenario to evaluate its impact to health, safety, and the environment. Your policy should include something similar. If the assessed scenario poses a risk to people, plant or process then it's recommended to implement a process automation interlock.

Diagram 4.2
Rig Floor Machine-to-Machine Safety Interlock

Rig Floor Machine-to-Machine Safety Interlocks — Machine Command / Machine Location/Status	IBOP Close State	**Drawworks**	Hoist/Lower Normal Speed Cmd	Hoist/Lower Creep Speed Cmd	Active Heave On State	Active Heave Off State	**Vertical Pipe Racking System**	Upper/Lower Grippers Close State	Upper/Lower Grippers Open State	Hoist/Lower w/ Grip/Rol/Cl Close Stat	Upper/Lower Roller Close State	Upper/Lower Roller Open State	Upper/Lower Claw Close State	Upper/Lower Claw Open State	**Mechanized Slips**	Slips Open State	Slips Closed State	Rotate PS CW/CCW w/ Slips Open	Rotate PS CW/CCW w/ Slips Close	**Mud Pumps**	On/Off: On State (Speed > 0 rpm)	On/Off: Off State (Speed < 0 rpm)	Stop/Resume: Resume State (Speed	Stop/Resume: Stop State (Speed < 0	**Iron Roughneck**	Torque Wrench On State	Torque Wrench Off State	Spinning Wrench On State	Spinning Wrench Off State	**Mechanized Horizontal to Vertical System**	Cmd Boom to WC	Grippers Close	Grippers Open	Hoist/Lower w/ Grippers in Close Stat	Hoist/Lower w/ Grippers in Open State	Rollers Close	Rollers Open	Hoist/Lower w/ Rollers in Close State	Hoist/Lower w/ Rollers in Close State	**Mud Bucket System**	MB Extend	MB Retract
Topdrive:																																										
Cmd Spin/Torque								1		1							1		1							1		1				1										
Cmd Rotation (Speed > 0 rpm)								1		1							1		1							1		1				1										
Cmd Elevators Open									1			1		1		1		1																								
Cmd IBOP Close																					1		1																			
Cmd IBOP Open																																										
Drawworks:																																										
Cmd Hoist/Lower Normal Speed								1		1	1						1		1							1		1				1				1						
Cmd Hoist/Lower Creep Speed																																										
Cmd Active Heave On Cmd								1		1	1						1		1							1		1				1				1						
Cmd Active Heave Off Cmd																																										
Vertical Pipe Racking System:																																										
Cmd Upper/Lower Grippers Close			1		1																					1		1														
Cmd Upper/Lower Grippers Open																																										
Cmd Hoist/Lower w/ Grip/Rol/Cl Close			1		1																																					
Cmd Upper/Lower Roller Close			1		1																																					
Cmd Upper/Lower Roller Open																																										
Cmd Upper/Lower Claw Close																																										

5. Collision Avoidance

For any given operation on the rig, there are usually multiple pieces of equipment working simultaneously to accomplish a set operation/objective, such as moving a stand from the fingerboard setback area to the well center or lowering the drillstring into the wellbore. The risk for equipment collision is high due to the limited space on the rig floor, as well as the proximity of equipment to each other. There are various design philosophies for machine-to-machine collision avoidance. This section addresses risk assessing potential collision scenarios and applying a suitable collision avoidance philosophy to prevent damage to rig floor equipment. This section also covers people-to-machine and people-to-tubular collision avoidance.

5.1 Collision Risk Identification

A rig equipment collision risk analysis should be performed to identify any collision risk associated with all equipment under control or monitor by the drilling control system. This should cover the collision risk related to two or more equipment being monitored or controlled by the control system, such as a moving Drawwork that could lead to collision between the top drive/elevator with an iron roughneck; it should also cover the collision risk related to an equipment being monitored or controlled by the control system, and a fix installation rig equipment or rig structure not being monitored or controlled by the control system, such as a moving Drawwork that could lead to collision between the block and the crown block.

The outcome of the collision risk analysis will list all equipment that may be involved in collision one way or the other. Table 1 shows an example of the outcome of such analysis.

The Collision Risk Matrix highlights the collision risk associated with any two equipment on the rig (yes/no). It may also include impact severity of each risk (low, medium and high). As shown in Table 7.1, row 1 shows how the movement of

DRAFT

Drawworks could potentially collide with Roughneck (yes), Rig (yes), Equipment A (no) and Equipment B (yes). In this example, the Top Drive and the Elevator is lumped together with the Drawworks during the collision risk evaluation, as the operation of Drawworks could lead to Top Drive and/or the Elevator in collision with the rig (crown saver, or the rig floor).

The Collision Risk Matrix is used to define equipment safe operation zone for collision avoidance, which will be discussed in the sections below. For those risks with high impact severity, extra level of control to avoid collision may be introduced, to be discussed later.

Table 5.1 Collision Risk Matrix

	Drawworks	Roughneck	Rig	Equipment A	Equipment B
Drawworks	No	Yes (medium)	Yes (high)	No	Yes (low)
Roughneck	Yes (medium)	No	No	Yes (low)	No
Rig Floor	NA	NA	NA	NA	NA
Equipment A	No	Yes (low)	No	No	No
Equipment B	Yes (low)	No	No	No	No

5.2 Position Tracking

For any equipment that has the potential risk to collide with other rig equipment as indicated in the Collision Risk Matrix should have its position properly track within the drilling control system. The position tracking scheme should have enough resolution to determine its relative position with other equipment with the collision risk.

5.3 Collision Avoidance Control

The Drilling Control System should include equipment collision avoidance control. For any equipment identified in the Collision Risk Matrix, the control system should track the position of the equipment at all time, to ensure that at no time any two or more equipment in the matrix would come in contact.

5.4 Failsafe Collision Avoidance Control

For those collision risks with high impact severity, the drilling control system may introduce failsafe function to further reduce such a risk. For example, if the collision risk associated with equipment A and B has high severity impact, instead of tracking the position of each equipment individually and compare the distance thereafter, a failsafe collision solution could be a direct distance measurement between both equipment such that when this distance is less than a thresh0ld, the control system automatically takes action to slow, stop or change the direction of the moving equipment to avoid collision.

5.5 Exception Handling on Collision Avoidance

DRAFT

The collision avoidance control should include equipment interlock to handle exception related to component failures. For any two equipment (or structures) that have collision risk, as shown in Table 7.1, if the control system is not able to track the relative position of one equipment to the other, the control system should have internal equipment interlock to prevent either equipment from moving.

5.6 Example Interlocks to Consider:

- Drawworks/Crown Saver
- Drawworks/Rig floor
- Hoist/TDS Torque Wrench Cannot hoist with TDS torque wrench engaged (embed release time)
- Elevator/Racking Board Prevent hoisting at ~10’ below racking board if link tilt status is “drill” position
- Elevator/Racking Board Prevent link tilt going to “drill” position ~10’ below racking board & higher

6. Recommended Safety Practice for Bypassing

From time to time, the operator may have to bypass the safety functions from the control system in order to continue with certain operations. For example, if the position sensor the drawwork (i.e. encoder) fails, the safety interlock between the drawwork and the rig structure may have to be disabled in order to move the block. Such safety function bypass, including equipment interlock and collision avoidance, may be needed during rig commissioning, rig maintenance and drilling operation.

This section describes recommended practice for bypassing these safety functions.

6.1 Bypassing safety functions

The control system may provide options for the user to bypass a safety function, such as an interlock or a collision avoidance function. When the user chooses to bypass a safety function, it means that the control system would no longer provide the protection that safety function is designed for.

For example, if the interlock between the drawwork and the crown saver is bypassed, the drawwork may collide with the crown saver.

The control system should provide the following minimal features regarding safety bypass:

- The control system provides visible display of any safety function that is bypassed
- When a collision avoidance related safety function is bypassed, the affected equipment should run at a reduced speed
- The safety bypass is only temporary and will be automatically disabled after the lapse of a preset time

6.2 Recording safety function bypasses

The control system should record all safety functions that are bypassed, including the start and end times when the bypass is effective.

DRAFT

7. Human System Integration/ Human Performance Engineering

Modern drilling rigs have complex machines with many layers of automation and controls; however, despite all the mechanization and robotics most current drilling rig control systems are designed with low levels of automation across most processes. Their level of automation taxonomy (LOAT) typically classifies in the C0 and D0 levels described in the Society of Petroleum Engineers (SPE) Drilling Automation Technical Section (DSATS) Human System Integration guideline.

For the next generation drilling control systems increased focus on the Human System Integration (HSI) is critical for the safe and efficient operation of drilling rigs. Two major areas are distinguished in HSI:

7.1 Situation Awareness

This is everything from visual indicators to crew interaction and dynamics. This is the basis for any drilling control system.

7.2 System Control

System control builds on situation awareness and takes specifically into account the human performance combined with the system requirements. A good designed system will multiply the strengths of each actor while mitigating the weaknesses.

It must be noted that within the Human Performance Engineering (HPE) and HSI field there are various principles, philosophies, and methods for insuring good human system integration practice. It is not possible to provide a complete overview of all methods and knowledge generated in the 40+ years HPE became important.

The purpose of this guideline is to present a limited overview of tools and methods that can be used to design or improve drilling control systems. A list of relevant sources will hopefully aid the user in exploring the field in more detail.

The last section of the guidelines deals with measuring performance and/or task loading of the operators. It is recognized that there can be no well-designed system if performance is not measured and validated.

The following recommendations are proposed:

1. **Generic Background in Human Performance Engineering**

   This chapter will describe the development of the Human Factors field and some important milestones.

   - History
   - Significant Events in the Past
   - Success stories from other industries
   - Changing requirements on drillers and other personnel

2. **Situation Awareness**

DRAFT

This chapter will describe the main issues in maintaining optimal Situation Awareness, risks and mitigation measures.

- Human information processing capability
- Information content of user interfaces

3. System Control

This chapter will describe the human machine interaction on a control level. Control performance and task loading of the operator will be presented both on a theoretical level.

- Predicting human task loading in different automation strategies
- Control Elements
- Etc.

4. Human Task Loading and Performance Measurements

This chapter will present some of the tools that are available to measure system performance and human task loading.

- Physiological Measures
    a. Cardiac
    b. Respiratory
    c. Etc.
- Subjective Measures
    a. NASA TLX Scale
    b. SWAT
    c. Etc.
- Performance Measures

5. Literature

The following documents provide a good introduction into the field of Human Factors

1. Mannan S., Hasan R, Krishnamoorti R, van Oort E., Pettigrew J, Robinson P., (2016). "**Human Factors and Ergonomics in Offshore Drilling and Production: The Implications for Drilling Safety"**, Ocean Energy Safety Institute, http:oesi.tamu.edu.
2. Gordon R. (1996). "**The Contribution of Human factors to accidents in the offshore oil industry"**, Reliability Engineering and Systems Safety 61 (1998) 95-108.
3. Yang-Pelaez J.,Flowers W. (2000). "**Information Content Measures of Visual Displays"**, IEEE Symposium on Information Visualization Oct 9-10,2000
4. Wei ZG., Macwan AP., Wieringa PA., **"A quantitative measure for degree of automation and its relation to system performance and mental load"**, Human Factors, 1998, Jun 40(2):277-95.
5. Grootjen, M; Neerincx, M.A., **"Operator load management during task execution in process control"**, Human Factors Impact on Ship Design, Genoa, 2005.

DRAFT

6. North Sea Offshore Authorities Forum, **Multi National Audit "Human and Organisational Factors in Well Control"**, 2012-2013, http://www.hse.gov.uk/offshore/nsoaf.pdf
7. ISO 11064, "**Ergonomics Design of Control Centers**"

8. Conclusions

This section closes out the discussion and recommendation for deploying a Guideline for Minimum Drilling Control System Safety Features.

More and more drilling automation networks are interfacing with more and more peripheral control networks that support the drilling, interventions, and completions processes. It is important for end-users to understand their processes and which systems could be at risk of damage to itself or another piece of equipment.

This IADC Guideline attempts to identify good international and national practices that can be adopted and applied to the drilling industry. The asset owners should identify vulnerabilities and assign the vulnerability a risk rating based on internal company risk. This will prioritize its importance and that resilient engineered solutions are applied. If the risk associated with an assessed scenario is low then applying safeguards might not be feasible. Other variables that could limit the implementation of a safety feature is the overarching rig network and how each automation network interfaces with each other. This should be considered during the assessment process.

DRAFT