Energy-Efficient Technologies for Reduction of Offshore CO_2 Emmissions

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Summary

This paper will discuss novel technologies for increasing the energy efficiency of offshore oil and gas platforms. Three case studies are in progress that are based on actual oil-producing platforms—two on the Norwegian Continental Shelf (NCS) and one in the Brazilian basin. The current focus is on developing compact, novel bottoming cycles for recovery of waste heat from the gas turbine and heat recovery from the compressor train for gas export. The technologies under investigation use steam and alternative working fluids, such as carbon dioxide (CO_2) and hydrocarbons. All the fluids investigated in this project are natural working fluids; hence, they will not cause any unexpected environmental issues in the future.

A case study was performed that considered an 18-year period of operation on an actual platform and a scenario in which one gas turbine was removed and replaced with a CO_2 bottoming cycle by use of the exhaust heat from a different gas turbine. The beauty of this scenario is that it would not increase the weight on the platform because the crate containing the gas turbine to be removed was of a weight similar to that of the crate containing the CO_2 bottoming cycle. The substitution would not affect the ability to cover the heat demand on the platform because a waste-heat-recovery unit (WHRU) could be installed on the platform's other gas turbine.

The case study indicates a significant reduction in CO_2 emissions of 22% (63 000 t/a), and does not involve adding additional weight or volume to the platform. If operating on the NCS, the annual savings in reduced fuel costs and CO_2 tax from implementing this scenario would be USD 17 million, although much lower in other territories.

Introduction

Improved energy efficiency is one of the most effective means of protecting and improving the global environment according to a new report from the International Energy Agency called *World Energy Outlook* (IEA 2012). This claim is valid also for the offshore oil-and-gas-producing industry. The key lies in new and compact technologies designed to streamline gas-fired power production. Such technologies are already in use onshore. If they can be widely adapted for use offshore, CO_2 emissions from oil installations could be reduced by as much as 25%. If the new technologies are applied on all Norwegian oil installations, this alone will result in CO_2-emission reductions large enough to make a real difference in relation to targets set out in the Norwegian government's white paper on climate policy (Miljøverndepartementet 2007). Full implementation, however, is not feasible, but even a smaller share may give important contributions.

Offshore oil and gas production are highly energy-intensive processes, and CO_2 emissions from offshore installations constitute a little more than one-quarter of all climate gas emissions from Norwegian territory. According to the Bækken and Zenker (2007), CO_2 emissions per oil equivalent produced on the NCS were reduced by approximately 20% in the period between 1990 and 2005. This was the result of a combination of improved energy efficiency mainly caused by reduced natural-gas flaring and installation of WHRUs. There were 58 WHRUs installed on the NCS in 2004 (NPD et al. 2004). These WHRUs covered approximately 90% of all heat demand for operations on the NCS.

Today, approximately 80% of the CO_2 emissions from offshore activities are derived from the gas turbines used to generate electricity on the installations. The turbines use natural gas from the reservoirs as their energy source. In these power plants, the natural gas is compressed together with large volumes of air before combustion, which in turn heats the air flow so that it expands and drives a turbine. The gas turbine drives a generator that produces electricity, or drivescompressors or other rotating machinery. However, large amounts of useful energy are lost as heat in the gas-turbine exhaust.

The turbine emits exhaust gases that are hot enough to enable this waste heat to be converted to physical work or electricity. In the EFFORT project (SINTEF 2012), funded by some of the major oil and gas companies, and the Research Council of Norway's PETROMAKS (2008) program, the potential for using the waste heat to generate additional electricity by use of an additional turbine "hooked up" to the power plant is investigated. The idea is to recover the energy currently lost (Mazzetti and Nekså 2012; Walnum et al. 2013; Nord and Bolland 2012, In Press).

In modern onshore gas-fired power plants, this "repeated" use of the waste heat is achieved with the surplus heat from gas turbines heating water in a boiler. The steam produced drives Turbine 2 (a steam turbine). Combined-cycle power plants of this type have been installed on three Norwegian gas fields: Oseberg, Eldfisk, and Snorre (Kloster 1999). However, such plants are heavy and very space demanding.

Platform installations on oil fields are equipped with large and heavy processing plants for separating oil and water. Thus, it is frequently considered totally impractical to use combined-cycle plants on oil platforms because of weight and space considerations. The focus of the EFFORT project is, therefore, to evaluate technologies that are both lighter and more compact (meaning everything must reside on a platform deck), and further, to adapt these technologies to the demanding constraints that must be taken into account on offshore installations.

Statement of Theory and Definitions

The gas-turbine gross electrical-power output is defined as

$$\dot{W}_{gt} = (\dot{W}_{\text{shaft}} \cdot \eta_{\text{gen}}), \quad (1)$$

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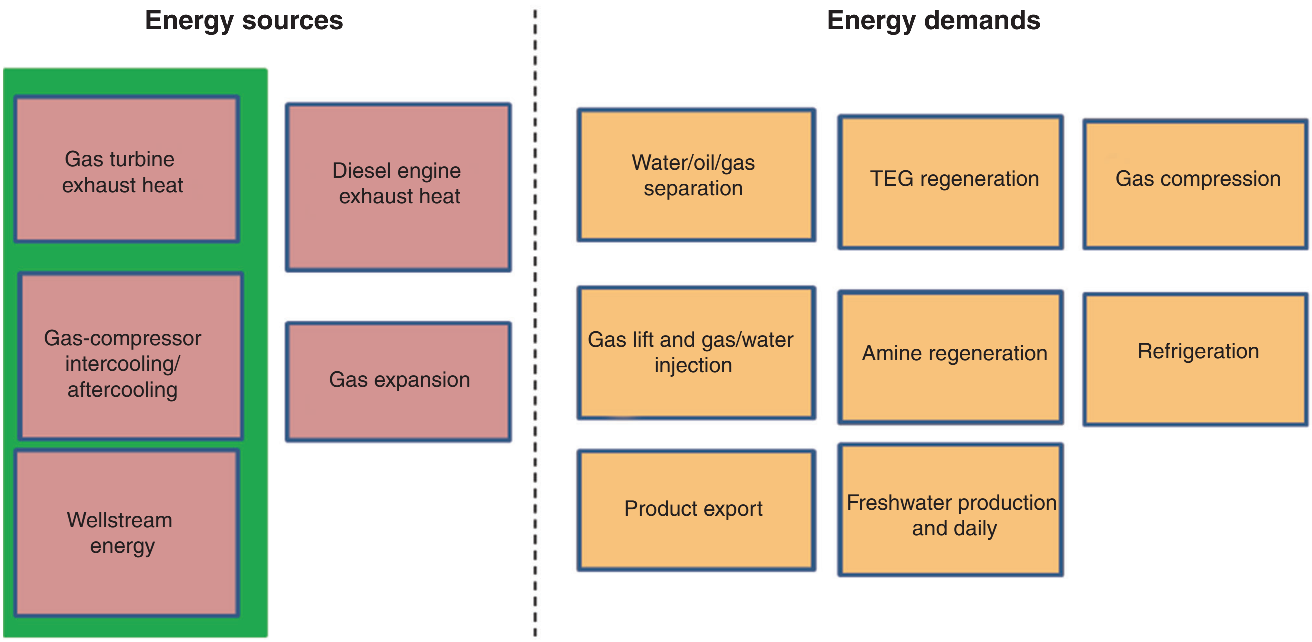

Fig. 1—Energy sources and energy demands on the platform. (Note: TEG is triethylene glycol.)

where $\dot{W}_{shaft}$ is the shaft power and η_{gen} is the generator efficiency, and

$$\dot{W}_{net,\,plant} = \dot{W}_{gt} + \dot{W}_{bc} \dot{W}_{aux}\,, \qquad (2)$$

where $\dot{W}_{aux}$ is the auxiliary power requirement and $\dot{W}_{bc}$ is the steam or CO_2-bottoming-cycle gross electrical-power output.

The net plant efficiency is defined as

$$\eta_{net,plant} = \frac{\dot{W}_{net,plant}}{(\dot{m} \bullet LHV)_{fuel}}\,, \qquad (3)$$

where $\dot{m}$fuel is the mass flow of fuel and LHV_{fuel} is the lower heating value (LHV) of the fuel.

The specific CO_2 emissions from the plant are defined as

$$CO_2 \text{ emitted} = \frac{\dot{m}_{CO_2}}{\dot{W}_{net,plant}}\,, \qquad (4)$$

where $\dot{m}_{CO_2}$ is the mass flow of CO_2 emitted from the plant in g/kW-hr.

Description and Application of Equipment and Processes

Methodology for Case-Studies Development. Through workshops, industry partners and researchers identified relevant energy sources and demands in the offshore processes where undertaking energy-efficiency measures is likely to give significant impact. Among the identified energy sources shown in **Fig. 1**, the three sources outlined in green were considered applicable as starting points for the research in EFFORT case studies. This selection was made on the basis of the following considerations:

- Gas-turbine exhaust heat: Gas-turbine exhaust heat is considered the main source of excess heat applicable for power production on the platform. The potential for energy-efficient use is high; several cycles and working fluids will be assessed. The challenges are weight, size, and robustness of the energy-efficiency-improvement concepts. In the bottoming cycle, exhaust heat from the gas turbine is used to heat a working fluid, such as CO_2 or steam, which is then allowed to expand in a turbine combined with a generator to produce electricity. A schematic of a basic bottoming cycle using the heat from the exhaust of an offshore gas turbine is shown in **Fig. 2.** The process can be made more complex (e.g., by adding several stages or pressure levels to increase efficiency), but this will be a trade-off with weight and volume.
- Gas-compressor intercooling/aftercooling: For platforms with significant gas production, the intercooling/aftercooling needed when compressing export gas is another source of waste heat. The gas undergoes a series of steps (compression, intercooling, further dehydration, compression, and aftercooling) before it is ducted into the export pipeline. Typically, the heat-source inlet temperature is 125°C. The intercooling ensures that the dehydration takes place at optimum conditions and reduces the power demand of the second compression; the aftercooling is necessary to reduce temperatures to below 100°C at the pipeline inlet. The heat-source temperature is much lower than that from a gas turbine, but the density of the compressed fluid enables compact heat-recovery heat exchangers. Because it is also necessary to cool the compressed gas before it is injected into the pipeline system, the additional equipment for power production is therefore lower.
- Wellstream energy: This is potentially a large energy source, both for heat recovery and for pressure recovery. However, accessibility and designing robust concepts that will not risk interference with production are great challenges. A design that is based on plateau production will also meet challenges when entering into an off-plateau production phase. Alternate systems must be established to cover for reduced power production from the wellstream. The use of energy from the wellstream (or separated water) is only applicable for high-temperature/high-pressure fields. High levels of impurities often occur, which make both heat exchange and expansion challenging. Power production through pressure reduction is

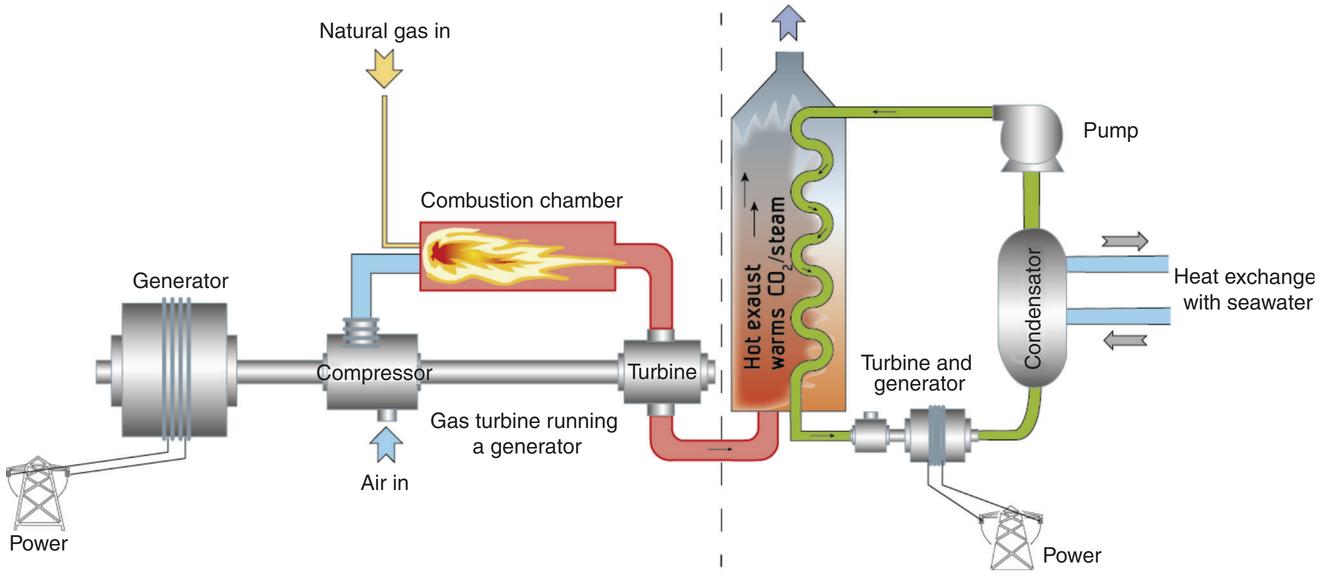

Fig. 2—Bottoming cycle applied to gas-turbine hot exhaust.

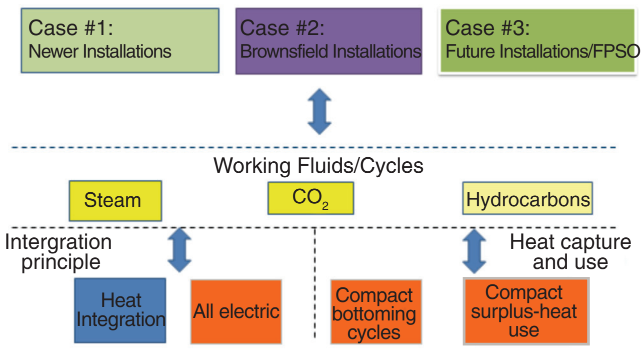

Fig. 3—EFFORT case studies. (An FPSO is a floating production, storage, and offloading vessel.)

theoretically possible, but challenging because of the impurities and multiphase-flow conditions.

- Diesel-engine exhaust heat: The potential for energy recovery from diesel engines is scarce. Because the source cannot give a constant-rate supply, secondary systems that cover for fluctuating energy production will also need to be investigated. Furthermore, diesel engines offshore are rather small units (3 to 4 MW).
- Gas expansion: Gas expanders could be considered as replacements for throttling valves in different parts of the processes. A challenge may be robustness and reliability of expanders if they are to be installed in gas streams containing impurities.

For all energy sources, transients and fluctuations will have a major impact on how the use of waste heat can be performed efficiently. Technology and systems must be designed to ensure a supply of energy that responds to the varying offshore energy demands. The focus of the work to this point has been on the first two sources of waste heat—the gas-turbine exhaust and the gas-compression intercooling/aftercooling. The wellstream energy will be evaluated at a later stage of the project.

EFFORT Case-Studies Approach. *EFFORT* Cases. The case studies are an integral part of the EFFORT project. They were selected to be representative of different platform environments (i.e., newer installations, a brownfield installation, and future floating installations). Three specific platforms have been chosen for the case studies (**Fig. 3**).

Case-Study Approach. The case studies use available data such as temperatures, mass flows, heat requirement, heat content, and stream compositions. The scope of the EFFORT case studies is limited to the energy-intensive processes, and considers bottoming cycles and other waste-heat-to-power-production schemes offshore and how to increase the efficiency and reliability of these systems.

The expectations for the greenfield case studies focus mainly on process and component design and the way in which new technology can be applied offshore. The starting point will cover a wide range of technologies without eliminating cycles or working fluids. The technologies will be benchmarked by weight and volume requirement per megawatt (MW) power output, compactness, and potential for improvement with further development. Other performance factors will include capacity, efficiency, and safety aspects.

For the brownfield case study, the objective is to investigate the potential for increasing energy efficiency, primarily by retrofitting, with the intent to reduce emissions of CO_2 ¬and increase power production to meet the increasing power demand on the platform. The brownfield case will also serve as a reference case by providing an opportunity to study historical production data from 20 years of operation to evaluate the potential value of implementing different measures at the start of the operation.

Working Fluids. The studies begin with a screening of potential working fluids and their behavior, both for the intercooling/aftercooling concept and the gas-turbine exhaust-gas temperature-recovery concept. An estimate is made of heat-exchanger size and weight. Alternative, natural working fluids are evaluated. All the fluids investigated in this project are natural working fluids; hence, they will not cause any unexpected environmental issues in the future (Nekså et al. 2010). The focus is on different Rankine cycles (e.g., transcritical CO_2 cycles, organic Rankine cycles, and steam-power cycles) (Walnum et al. 2013; Nord and Bolland 2012, In Press; Nekså et al. 2010; Andresen et al. 2011; Walnum et al. 2011). Steam cycles are a mature technology for onshore applications, and are expected to be more efficient for some applications, but also potentially less compact than power production by use of organic fluids and CO_2. There is limited room for improvement and adaptation offshore (Kloster 1999); however, once-through steam generators (OTSGs) are an interesting concept for reducing space and weight for steam and the other fluids. Steam power cycles will also be an important reference for evaluation of cycles and systems for

TABLE 1—GAS-TURBINE PARAMETERS	
Parameters	
Model type	GE LM2500+G4
Gas turbine fuel	methane
Gas turbine inlet P (bar)	0.010

TABLE 2—POWER AND EFFICIENCY OF GE LM2500 SERIES GAS TURBINES

Turbine	Power (MW)	Efficiency
LM1800	17.4	0.34
LM2500	25.1	0.36
LM2500+	30.2	0.38
LM2500+G4	32.5	0.383

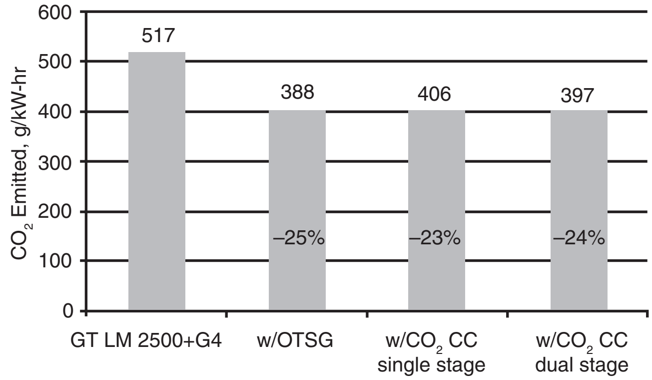

Fig. 4—CO_2 emissions from GT LM2500+G4 gas turbine with different bottoming cycles. (Note: CC is combined cycle.)

the novel working fluids, in one- or two-stage configurations that have already been implemented on some offshore installations.

Technological/Economical Analysis and Key Performance Indicators (KPIs). The main KPIs for evaluating the technologies are reduction in CO_2 emissions and equipment-when-wet weight and volume. These KPIs can be applied multilaterally.

CO_2 Footprint. The success of the technological improvement should be measured by means of the overall system efficiency, which is directly proportional to CO_2 footprint or the measured reduction in CO_2 emissions (tonnes of CO_2/BOE) or tonnes of liquefied natural gas produced.

Weight and Volume. The constraints relating to weight and volume are crucial for both greenfield and brownfield case studies. Implemented equipment will require several times its own weight in structure on the floating structure. Technologies that do not meet the stringent offshore criteria for weight and volume will not be considered. The cycle components will be compared on the basis of weight and volume per MW of energy produced from the power-production cycles.

Economic Analysis. On the NCS, taxes are an important factor in driving energy-efficiency improvements such as investments in energy-efficient bottoming cycles and rewheeling of compressors. However, tax levels vary greatly across countries, regions, and companies, and, consequently, are introducing an abundance of uncertainty into the technological/economical analyses of the profitability related to energy-efficiency improvements. If economics is evaluated, key factors that must be adjusted for different regions of the world are fuel-cost savings and CO_2 taxes.

Gas Turbines. For the purpose of the comparison studies of different bottoming-cycle concepts, a standard gas turbine was selected as the power source (**Table 1**). It is not the actual turbine that is onboard the case platforms, but it is very close in performance. Pure methane was selected as the fuel. This was for the purpose of comparing the performance of CO_2 bottoming cycles, as described in Walnum et al. (2013), with the information published in Nord and Bolland (2012). For the improved-energy-efficiency scenarios described later, several turbines were considered. The properties of the turbines are shown in **Table 2.**

Presentation of Data and Results

Performance of Steam and CO_2 Bottoming Cycles. Steam and CO_2 bottoming cycles have been evaluated for producing power from the waste heat of the same gas turbine. Calculations on applying an OTSG to the GE LM2500+G4 gas turbine have been performed by Nord and Bolland (2012, *In Press*). CO_2 bottoming cycles have been applied to the same gas turbine by use of the same operating parameters provided in Walnum et al. (2013). The performance of the bottoming cycles is shown in **Table 3.** It can be seen that the steam and CO_2 bottoming cycles have similar efficiency. Further, it can be observed that the combined-cycle net power output increases by more than 30% compared with the simple-cycle gas turbine.

CO_2 emissions for the different bottoming cycles are shown in **Fig. 4.** The efficiencies of the steam and CO_2 bottoming cycles are similar, indicating very similar capacities for reducing CO_2 emissions. The OTSG steam cycle results in a 25% reduction in CO_2 release, while the reduction in CO_2 release for the dual-stage combined-CO_2 cycle is 24%.

The CO_2 cycles have the potential of being much less space demanding than the steam cycles (Persichilli et al. 2012; Robb 2012). The CO_2 cycles operate at pressures greater than ambient and partly supercritical. Thus, flowlines can often be smaller and the system will not need any CO_2 purification, while steam bottoming cycles will require a water-treatment system that is relatively space

TABLE 3—COMPARISON OF PERFORMANCE OF STEAM AND CO_2 BOTTOMING CYCLES

	Simple Cycle*	Combined Cycle Steam OTSG*	Combined Cycle CO_2, Dual Stage
Gas turbine	GE LM2500+G4	GE LM2500+G4	GE LM2500+G4
Net power output (MW)	32.2	42.9	42.0
Gas-turbine gross power output (MW)	32.5	32.1	32.1
Bottoming-cycle gross power output	—	11.3	10.4
Plant efficiency	38.6	51.0	50.0

* Data from Nord and Bolland (2012)

and weight demanding. Conversely, the CO_2 system requires extra recuperators to be efficient. Work is ongoing to achieve an accurate weight and volume comparison of the two systems.

Scenarios for Improving Offshore Energy Efficiency. To date, energy-efficiency improvements on offshore platforms on the NCS have primarily been a result of reduced flaring and recovery of waste heat from gas-turbine exhaust for use in oil and gas processing. Other possibilities involve increasing the effectiveness of gas turbines and power production from onboard waste heat. In this case study, we look at an oil-producing platform with a projected power-consumption profile ranging from 67 to 47 MW over the 18-year period investigated. The power consumption increases during the first 10 years, then plateaus in the middle of the period before decreasing gradually over the remainder of the period.

Scenario 1: Reduce Size of Existing Gas Turbines To Operate at Higher Average Load. One method of improving energy efficiency is to reduce the turbine size as much as possible, while still meeting the power demands of the platform. Today, gas turbines are often oversized, even when compared with power demands at peak conditions. Although exchanging the turbine involves a cost, it does not lead to any increase in weight or volume of the platform equipment.

The efficiency of a gas turbine is very dependent on the load on the turbine. The efficiency of two different gas turbines is shown as a function of load in **Fig. 5.** When the load on the LM2500+G4 turbine decreases from 90 to 60%, the efficiency of the turbine is reduced from 37.9 to 31%. This is a 20% relative reduction in efficiency. The smaller 15-MW turbine (LM1800E) is slightly less effective at only 34.1% at full load. It has a more gradual reduction in efficiency as the load is decreased.

Many offshore turbines run in the 60 to 70% load range. An obvious opportunity for improving offshore energy efficiency, therefore, is to exchange the gas turbines with smaller turbines that can then operate at a higher efficiency, provided they can still produce enough power for current and future operations. The concept of exchanging turbines to obtain higher effectiveness should be relatively "low-hanging fruit" when considering improving energy efficiency and reducing the CO_2 emissions associated with oil and gas production because it does not involve taking up additional space or increasing weight on the platform—neither does it involve much additional risk.

The platform in this case scenario has three turbines, two of which are 30 MW and can be replaced with 25-MW turbines. In this case, the projected load on the 30-MW turbines ranges from 0.5 to 0.8 over a period of 18 years. If the 30-MW turbines are exchanged for 25-MW turbines, then the load will increase to the 0.6-to-0.9 range.

The corresponding reduction in projected CO_2 emissions for the platform ranges from 4000 to 10 000 t/a of CO_2. The average reduction is 5900 t/a. Over the 18-year period investigated, there would be a reduction of 106 000 t of CO_2 from the platform, corresponding to a 2.0% reduction of the total CO_2 emissions from the platform in the same period.

The change in CO_2 emissions as a result of reducing the turbine size is relatively small for the 18-year period. However, by looking more closely at the data, it is apparent that the effect of reducing turbine size is much greater toward the end of the life of the platform when the power demand is reduced and the load is lower. The relative decrease in CO_2 emissions goes from approximately 1 to 3.5% toward the end of the period.

As can be seen from Fig. 5, the decrease in efficiency for the larger LM2500+G4 turbine is much greater than that for the smaller LM1800E turbine. Hence, at low loads, the smaller turbine is relatively more efficient. The effectiveness of Scenario 1 will therefore vary with production and load profiles on the platform. The maximum potential for reduced CO_2 emissions can be up to 5% under optimum turbine-load conditions. Under the right circumstances, installing smaller turbines may provide a viable opportunity for reducing CO_2 emissions without taking up precious space and adding weight on the platform, and it is an important factor in the design of future platforms or during the remodeling of current platforms. The cost of this scenario is not significant because a smaller turbine may cost less than a larger turbine. It may also be a relevant option for a retrofit because turbines are taken out for off site service every few years. During such service, the turbine can be exchanged for a smaller one.

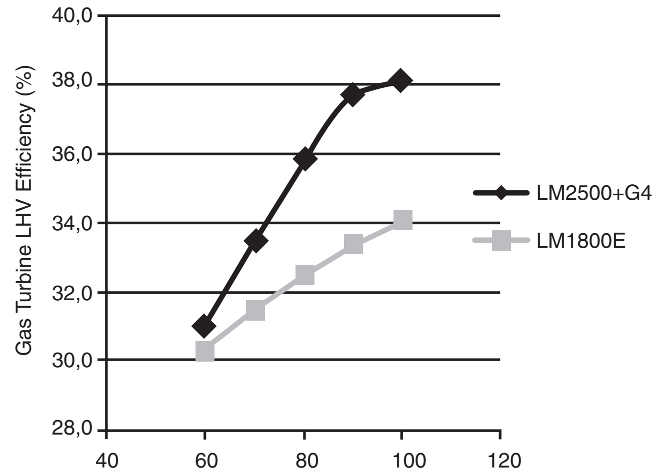

Fig. 5—Gross LHV efficiency vs. load for an LM2500+G4 (32.5 MW) gas turbine and an LM1800E (14.9 MW) gas turbine (Calculated by GT Pro.)

Scenario 2: One Turbine Can Be Removed and a Bottoming Cycle Can Be Added to an Existing Turbine. In Scenario 2, one gas turbine is removed and replaced with a CO_2 bottoming cycle by use of the the exhaust heat from one of the remaining gas turbines. This turbine is upgraded from a GE LM2500+ (30 MW) to a GE LM2500+G4 (32.5 MW). This would not increase the weight on the platform because the crate containing the one gas turbine to be removed has weight similar to that of the crate that contains the CO_2 bottoming cycle, weighing approximately 200 t each. The substitution would not affect the ability to cover the heat demand on the platform because a WHRU is installed on the other platform gas turbine.

This substitution would reduce the CO_2 emitted from the platform by 1.1 Mt of CO_2 over the lifetime of the platform or by 62 000 to 66 000 t/a of CO_2 (i.e, an average of 63 000 t/a), which is a 22% reduction, as can be seen from the right bar of **Fig. 6**, which shows a comparison with the reduction in CO_2 emissions from Scenario 1.

The average annual fuel consumption for the original platform is 180 MW-hr. If running as in Scenario 2, it is reduced by 39 MW-hr. The price of natural gas varies greatly throughout the world. For the purpose of this paper, the savings in fuel cost will be calculated for the US and for the NCS. The price of natural gas as of December 2012 was €28/MW-hr in Norway and Europe (Gaspoint Nordic A/S 2012). This is the equivalent of USD 10.9/million Btu [i.e., 3.6 times more than the cost of natural gas in the US, which was USD 3/million Btu in December 2012 (EIA 2012)]. This is partly because of the much-less-expensive shale gas available currently in the US.

The total fuel cost for the platform if located on the NCS is USD 59 million. For Scenario 2, the cost is reduced by USD 12 million. For platforms on the NCS, there is a tax on emitting CO_2. This tax will increase to USD 73/t CO_2 starting 1 January 2013 (Carell 2012). The platform will be paying approximately USD 21 million in Norwegian CO_2 taxes. The annual savings in CO_2 tax under Scenario 2 would be USD 5 million (**Fig. 7**). If the platform were

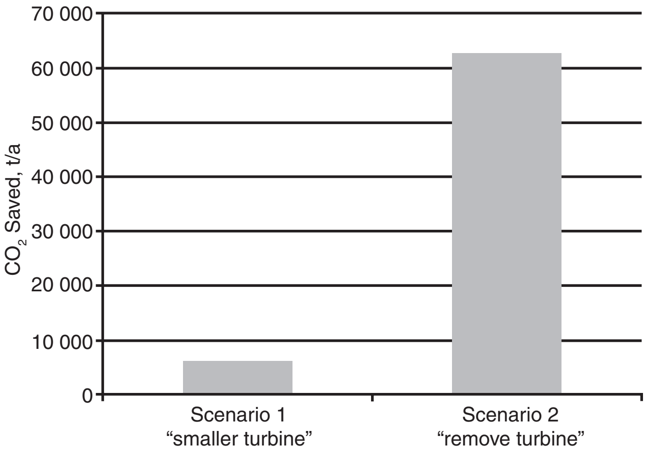

Fig. 6—Reduction in emitted CO_2 for different energy-efficiency scenarios.

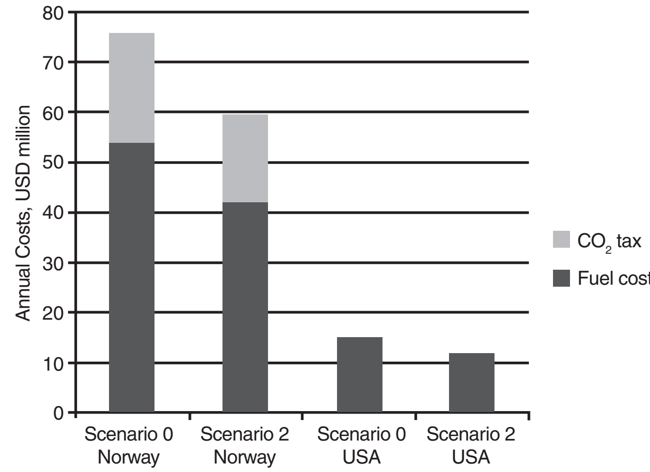

Fig. 7—Annual costs of fuel and CO2 tax in Norway and the US for different scenarios.

located in the US, the annual savings in fuel cost would be USD 3 million. There is no CO_2 tax in the US.

There is great difference in incentivizing energy-efficiency technologies in Norway vs. many other parts of the world. In Norway, the annual savings in operational costs from implementing Scenario 2 would be USD 17 million vs. only USD 3 million saved if the platform was located in the US, as can be seen from Fig. 7. The energy efficiency of oil production on the NCS is the second best in the world, only recently slightly bypassed by the Middle East (OLF 2011). This indicates that the taxes applied in Norway since introduced in 1991 have had a positive influence on improving energy efficiency on the NCS (Hansen and Rasen 2012).

Scenario 2 should be promising for implementation because it indicates significant reduction in CO_2 emissions of 22%, and does not involve adding additional weight or volume to the platform. It must be noted that this scenario may not be possible on all platforms, depending on production and load profiles. There is often a need for redundancy so that a certain number of turbines must be on the platform in case one goes down for repair, which has to be taken into consideration.

An alternative to removing the extra turbine is to keep the turbine on the platform and combine its exhaust stack with that of the bottoming cycle turbine so that if one turbine is down, the other one can run with the bottoming cycle, and it will not affect the operation of the platform. In such a scenario, there will be an additional weight increase of approximately 200 t to the platform as a result of the installation of the bottoming cycle. The advantage is a 22% reduction in CO_2 emmissions, but reduced risk of platform production stops because of the redundancy in the number of turbines.

The cost analysis of this scenario is quite promising. It is not possible to obtain accurate numbers for these through a direct quote. However, approximate numbers have been obtained through a private communication with a vendor. For a steam cycle of less than 15 MW, the price, weight, and cost will be approximately equal to that of a 20- to 25-MW gas turbine. Further, the price of the bottoming cycle will be dependent on how many drums are needed to produce the steam and will depend on how many other turbines are available for heat recovery.

For a 30-MW steam-turbine skid in an offshore package as a single-lift skid, which includes the condenser and condensate pumps, the cost is between USD 25 and 33 million. Four OTSGs (or heat-recovery steam generators) packaged for offshore are approximately the same cost. The total cost for a complete bottoming cycle delivered at the harbor is therefore between USD 50 and 67 million. There will be additional expenses for installation, commissioning, and startup costs.

Scenario 3. Another scenario that will be investigated is to add smaller gas turbines, such as an LM1800, with bottoming cycles. This will allow running at a more optimal load on each of the gas turbines. At the same time, the number of turbines on the platform remains the same, providing redundancy in the event that one turbine has to go out of production for repair. This will reduce the risk of implementing the alternative energy-efficiency technology. Yet another scenario will be to combine the exhaust from several turbines to run one bottoming cycle.

Scenario 4. For certain platforms that produce and export gas at high pressure, heat recovery from the compressed gas is an interesting option to increase energy efficiency. We estimate a potential improvement in energy efficiency of up to 6% of power to the export-gas compressor. There is a possibility of saving up to 3 MW from the export-gas compressor, assuming a production of 15 000 std m3/d of compressed gas to 180 bar at 125°C. The corresponding reduction in CO_2 released is 6000 t/a.

Summary and Conclusions

The most effective means of improving energy efficiency on offshore oil and gas platforms is by applying compact bottoming cycles to the waste heat from the platform's gas turbines with potential CO_2 reductions of up to 25%.

The results show that applying a steam bottoming cycle to the gas turbine increases the efficiency of the power-production process from 0.38 to 0.51, a 33% increase in energy efficiency. This corresponds to a 25% reduction in fuel consumption and CO_2 release from 517 g CO_2/kW-hr for a gas turbine to only 388 g CO_2/kW-hr for a steam cycle.

Corresponding reduction for a CO_2 dual-cycle bottoming cycle is 24% and 397 g CO_2/kW-hr. The alternative working fluids, such as CO_2, are very interesting because they, like steam, are highly effective natural fluids, but have the additional potential of allowing construction of more-compact bottoming cycles.

One scenario that represents low-hanging fruit among the potential energy-efficiency improvements offshore is simply to replace gas turbines that run at low loads with slightly smaller turbines that will run at a higher load, and, therefore, a higher efficiency. The change in CO_2 emissions as a result of reducing the turbine size is relatively small, at an average reduction of 2%. However, by looking more closely at the production profile, it is apparent that the effect of reducing turbine size is much greater toward the end of the life of the platform when the power demand is reduced. This is because, at low loads, the less-efficient turbine may become relatively more efficient than the larger turbine. The effectiveness of Scenario 1 will therefore vary with production rate and load profiles on the platform. Under the right circumstances, it may provide a viable opportunity for reducing CO_2 emissions without taking up precious space and adding weight on the platform, and it is an important factor in the design of future platforms and during the remodeling of current platforms.

The most interesting scenario investigated was that in which the production profiles on the platform allowed one gas turbine to be replaced with a bottoming cycle. This resulted in 22% CO_2 reductions of 1.1 Mt over the remaining life of the platform. This is equal to average reductions of 63 000 t/a for the 18 years investigated. If located on the NCS, the annual savings in operational costs would be USD 17 million from the reduced fuel cost and CO_2 tax.

Adding the bottoming cycle would not affect the heat production for use on the platform because a WHRU could be installed on a different gas turbine than the one being replaced. Most importantly, this scenario does not involve adding weight or volume to the platform. A risk evaluation would have to be performed for potential platforms to determine whether the platform would meet the requirement for turbine redundancy.

An alternative to removing the extra turbine is to keep the turbine on the platform and combine its exhaust stack with that of the turbine with the bottoming cycle so that if one turbine is down, the other can run with the bottoming cycle, and the operation of the platform will not be affected. In such a scenario, there will be an additional weight increase of approximately 200 t to the platform as a result of the installation of the bottoming cycle. The advantage is a 22% reduction in CO_2 emmissions, but reduced risk of production stops because of the redundancy in the number of turbines available, although not in operations causing CO_2 emissions.

The potential for energy savings can be reduced somewhat, depending on the energy needs of the platform. Certain platform processes use heat, which then cannot be used for power production. It is also important to realize that challenges associated with weight, volume, and space limitations on offshore platforms can be a barrier to implementation of bottoming cycles. This barrier is especially large on platforms already in operation.

Another interesting scenario for future work is that in which larger gas turbines are replaced by smaller turbines with bottoming cycles. This allows the operator to keep the sa2me amount of gas turbines on the platform for redundancy in the event that a turbine goes down. It allows for operating at a high load, and if optimized, can result in CO_2 reductions of up to 30%.

The total release of CO_2 from the gas turbines on the NCS was 10.2 Mt in 2010 (Gaspoint Nordic A/S 2012). If steam bottoming cycles are implemented on all gas turbines on the NCS, then one can estimate 2.65 Mt of reduced CO_2 emissions per year. However, complete implementation is probably not realistic, so a more-accurate estimate should be developed. Possible implementation will depend on both technical and political factors, which makes the task quite challenging. The energy-efficiency technologies discussed represent a highly effective and not overly costly path toward reducing emissions of climate gases. The work in EFFORT in close collaboration with four major oil and gas companies will hopefully contribute to the implementation of new energy-efficiency measures.

Nomenclature

LHV = lower heating value of the fuel
$\dot{m}_{CO_2}$ = mass flow of CO_2 emitted from the plant, g/kW-hr
$\dot{m}_{\mathrm{fuel}}$ = mass flow of fuel
$\dot{W}_{\mathrm{aux}}$ = auxiliary power requirement
$\dot{W}_{bc}$ = steam or CO_2-bottoming-cycle gross electrical-power output
$\dot{W}_{\mathrm{shaft}}$ = shaft power
η_{gen} = generator efficiency
$\eta_{\mathrm{net,\ plant}}$ = net plant efficiency

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