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CARBON FOOTPRINT ASSESSMENT FOR COMPRESSOR STATIONS

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ABSTRACT

Natural gas is the most environmentally friendly fossil fuel. All forecasts indicate the leading role of natural gas in the effort to provide the world with energy, while reducing the environmental impact. While natural gas is abundant in some regions, the transport of natural gas is receiving scrutiny regarding its environmental impact. This paper discusses concepts to reduce the carbon footprint of gas compression operations.

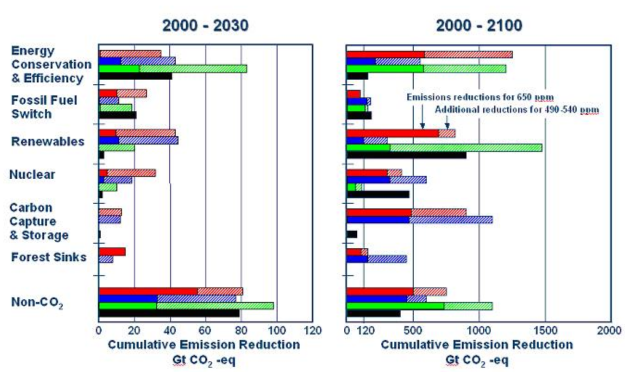
We will discuss methods to reduce the amount of CO2 emitted by increasing the efficiency drivers and driven equipment. Another key area for improvement is to make the overall operation more efficient. The operational effectiveness of a pipeline or a pipeline system will not be measured only by the cost of transporting a certain amount of gas to the end user, but also by the carbon footprint related to this effort.

One of the key theses of this paper is the requirement of a system level view, rather than the level of individual units. This is particularly true for operational issues to be considered, such as the discussion of the carbon footprint of electric motor driven compression versus gas turbine driven compression. Topics like this require an evaluation including the carbon footprint related to the generation and the transport of electric power.

BACKGROUND

The increasing population, together with the overall increasing wealth of the world population causes an ever-increasing demand for energy. On the other hand, the concern about global warming associated with the release of greenhouses gases such as CO_2 or methane into the atmosphere constrains the use of fossil energy to satisfy this increasing demand. Alternative forms of energy have been proposed, and are increasing their market share. However, even alternative energy sources can create environmental problems and have issues with cost and availability.

In the short and medium term, the biggest portion of CO_2 reduction measures are based on energy efficiency improvements, and fossil fuel switch (Figure 1, [1,2]). At the same time, some concepts that were hailed as solutions only a few years ago, now are questioned due to the side effects that only become apparent once they were used in a larger



Ref.: Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), 2007

Figure 1: CO_2 Emission Reduction Strategies [2]. The colors indicate the results from 4 different simulation models.

scale. One example is the impact of using corn to generate ethanol as a fuel, on water supply and food prices. Many technologies will not be available for large-scale production for many years. This leaves the smarter, more efficient use of existing technology, continuously improved, as the key contributor to a reduction in carbon emissions. The biggest impact on CO_2 stabilization comes from measures that are available immediately for large-scale deployment.

Therefore, fossil fuels will in the foreseeable future, provide the backbone of power generation, transportation and heating needs. Among fossil fuels, natural gas is by far the cleanest, most environmentally friendly fuel and provides reduced carbon emissions at a lower reduction cost far smaller than other concepts [3].

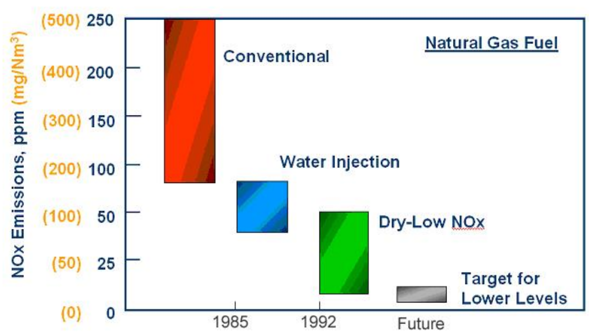


Figure 2: Reduction in Gas Turbine NO_x Emissions.

EMISSIONS

In addition to greenhouse gases, combustion of fossil fuels generates other pollutants. Some of them are generated as a result of high combustion temperatures (NOx), while others are the result of incomplete combustion (CO, unburned hydrocarbons, soot, ash), or constituents of some fuels (mercury, sulfur). Natural gas as a fuel avoids many of the issues that prove difficult for coal-fired and oil-fired power plants. The gas turbine industry has been at the forefront of pollutant reduction and in particular the reduction of smog forming NO_x [4]. Figure 2 shows the dramatic reduction of NO_x emissions from industrial gas turbines, using lean-premix technologies. Gas turbines also are capable of using gas that otherwise would be flared as fuel for a gas turbine – be it for power generation or to drive pumps or compressors.

The fuel capability now not only includes pipeline quality natural gas, but also associated gas and raw natural gas.

EFFICIENCY

Ultimately, energy efficiency for a compressor operation is framed by the question: "How much energy do I need to burn to pump a certain amount of energy within the system constraints[1]?" In terms of a carbon constrained world, this almost parallels the question: "How much CO_2 do I generate while doing this?" In economic terms, another question to be asked is: "What upside potential do I have to pump additional gas with the existing system?"

This translates into the requirement for turbomachinery systems to provide a higher efficiency over a wider range of operating conditions, while contributing to a constantly improved system availability.

Figure 3 outlines the efficiency improvements achieved by persistent improvements to the gas turbines and centrifugal compressors used. The chart shows the dramatic improvement in efficiency for power generation equipment (top curve) – the amount of CO_2/kW generated from today's state-of-the-art power generation equipment is at least 40% less than that of gas turbines of the 1960s.

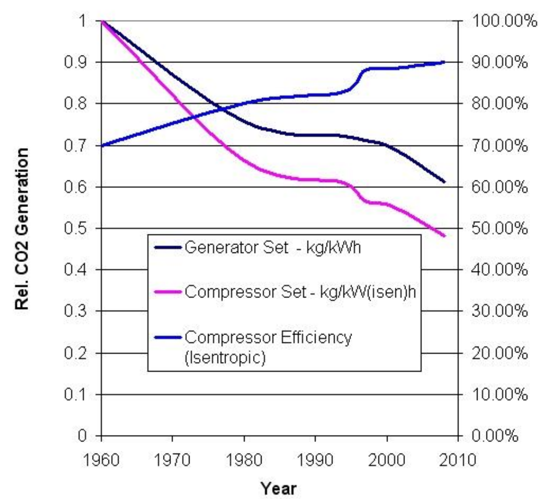


Figure 3: Reduction of Carbon Footprint and Increase in Gas Compressor Efficiency.

Reducing the carbon footprint of a gas turbine with a gas compressor in a pipeline system, a gas-gathering operation, or a gas re-injection system, either onshore or offshore not only requires efficiency improvements for gas turbines, but also for the driven compressors. Figure 3 demonstrates the improvements by showing the carbon generation per kW

[1]System Constraints are the characteristics of the system to resist the transportation. For a gas pipeline, where the pressure loss from the pipe friction has to be overcome by gas compression, the question would be, how much energy is needed to transport the energy contained in the gas over a certain given distance.

of isentropic compression. It shows that if we were to take a pipeline with machines built in 1960, and replace it with new engines and compressors, we could pump the same amount of gas while generating half the CO_2.

TECHNOLOGY

The operational effectiveness of a pipeline or a pipeline system will not be measured only by the cost of transporting a certain amount of gas to the end user, but also by the carbon footprint related to this effort. Gas turbine systems have seen a large reduction in the amount of CO_2 produced (Figure 3) per amount of gas transported, and have arguably the lowest carbon footprint of all land-based gas transportation methods. For a given type of fuel, CO_2 emission reduction can only be accomplished by increasing the efficiency of the system. The first step is to increase component efficiency.

Since gas turbines inherently deliver exhaust gas at high temperatures, another important way to improve efficiency is the use of this exhaust heat in a combined-cycle application [5]. Combined Cycles use the exhaust heat from the gas turbine, that is lost in simple cycle operations, in a steam turbine cycle or an organic Rankine cycle (ORC). This uses technologies established in the power market. The impact can be further increased if ways are found to even use low quality heat in processes. Examples are residential heating, drying processes, amine or glycol reheating in CO_2 or water removal processes, respectively. A variety of other hybrid gas turbine concepts are under study.

Incorporating technological advancements are key for realizing the full potential of the gas turbine for reducing pollutant emissions and lowering the carbon footprint. Increasing the turbine inlet temperature is a major route to increasing gas turbine efficiency. This in turn requires careful air management in the combustor and turbine sections of the engine. The ability to strategically utilize advanced alloys, coatings, ceramics, composites and air management in the hot section is critical for operating at the increasingly higher firing temperatures (Figures 4 and 5).

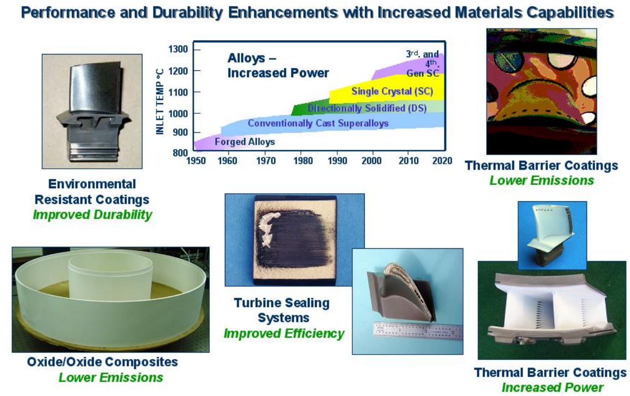


Figure 4: Materials and Process Technologies for Gas Turbines

OPERATIONAL EFFICIENCY

With natural gas as a fuel for gas turbines, the fossil fuel with the lowest possible carbon footprint is already in use. Therefore, a reduction in carbon footprint is mainly possible by increasing the efficiency of operation. Operational efficiency requires the full integration of a gas turbine and gas compressor into a pipeline system operation. The resulting savings in carbon footprint, fuel and maintenance costs, are discussed here.

With the worldwide demand for gas rising, new pipelines are required to bring gas over longer distances to the market. For long distance pipelines, the cost of gas transportation will make up an increasing portion of the delivery cost to the customer, and can reach 30 to 50% of the total cost at the receiving terminal [6]. This transport cost can be influenced by optimizing fuel consumption, equipment first cost, equipment operating cost, as well as equipment reliability and availability. The pressure and flow characteristics of pipelines and other factors influence the arrangement of compressors in a station. Also, pipelines often operate under non-steady state conditions. The question about number of units, spare concepts, the spacing of stations, standby requirements or the use of series or parallel arrangements in a station arises, together with the type of driver, and the type of compressor ([7],[8],[9],[10],[11],[12],[13]).

The use of information technology to better monitor health and decide on maintenance intervention is becoming an integral aspect of operation. This leverages turbine package controls and web-based technology for equipment monitoring, diagnostic reports, operational statistics, technical decision support, information management and project management. The result is an increase in availability and the prevention of unnecessary shutdowns [14].

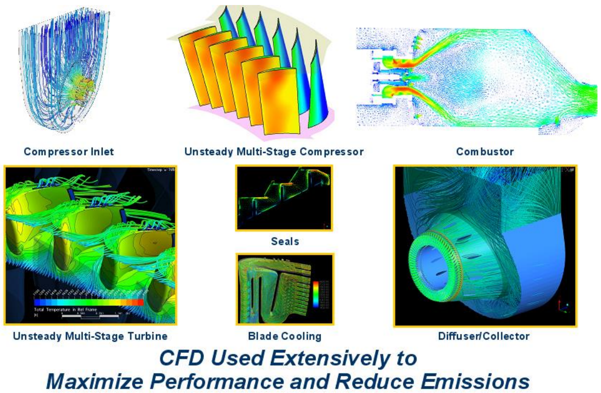


Figure 5: Computational Fluid Dynamics Used in Gas Turbine Design.

A modern centrifugal gas compressor is undoubtedly the compression device with the highest availability of all alternatives, and therefore will be the compression device of choice for the foreseeable future in any application where its characteristics and established ranges make it a fit. Gas turbine designs become increasingly optimized regarding their capability to operate with larger maintenance intervals, fewer shutdowns, and maintenance friendly layouts. Modular approaches, both for gas turbines and for gas compressors are important to meet these requirements. Customized maintenance concepts involve not just the gas turbine package, but also the environment and process systems around it, intelligent condition monitoring, as well as optimized maintenance and spare parts planning together with the best possible logistic concepts to cover all areas around the globe [14].

High availability of the system components is a key ingredient to high operational effectiveness. This may seem surprising in an efficiency and carbon footprint discussion, but high availability can reduce unnecessary redundancy and related ineffectiveness. High availability also reduces the need for frequent shutdowns, and thus avoids the release of methane into the atmosphere.

What does this all mean? Fundamentally, improving the operating efficiency requires a look into both the details and the big picture. Details include improvements in efficiency and operating range for the driven compressor, improvements in efficiency, power, and availability for the gas turbine.

The big picture side is all about integration, and it requires trusted interaction between the operator, the engineering/design firm, and the turbomachinery supplier. This begins with the determination of the supply commitments for the pipeline project, including firm supply, variable supply, and upsides. This, among other things, influences pipeline size, number of stations, pressure ratings, but also redundancy requirements for the turbomachinery. To fully understand the performance of turbomachinery, the impact of ambient conditions needs to be considered (for example, the fact that a gas turbine provides more power when it gets colder), together with the fact that gas turbines come in discrete sizes. Via basic aero-thermal relationships relate the power turbine speed for a given gas turbine size and optimal compressor sizes.

Further, very few, if any, pipelines operate under steady-state conditions, so off-design compressor and part-load gas turbine performance need to be considered ([7],[11]). For the availability of a gas turbine, which is a function of spare parts logistic, maintenance philosophy, as well as engine, package and compressor design, play an important role. This also drives the discussion on the installation of spare units. Here, he transient behavior of the pipeline when one unit is lost has to be considered, and the storage capacity of the pipeline itself often helps to ride through outages [8].

Similar thoughts, as put forward here for pipeline operations, apply to all other installations in the gas industry, be it gas gathering, gas storage, or gas plant compression. Differences arise from the cost of outages, the relative value of the fuel burned in a gas turbine, and the remoteness of the installation. In this context, the capability of gas turbines to use a wider range of fuel compositions with low emissions combustion systems has been an important factor. Significant efforts have been made to use natural gas that would otherwise have been flared, to enhance oil recovery, to gather it for use in power plants, or to liquefy it and transport it as LNG.

SYSTEM LEVEL VIEW

One of the key theses of this paper is the requirement of a system level view, rather than the level of individual units. This is particularly true for operational issues to be considered, such as the discussion of the carbon footprint of electric motor driven compression versus gas turbine driven compression. Topics like this require an evaluation including the carbon footprint related to the generation and the transport of electric power.

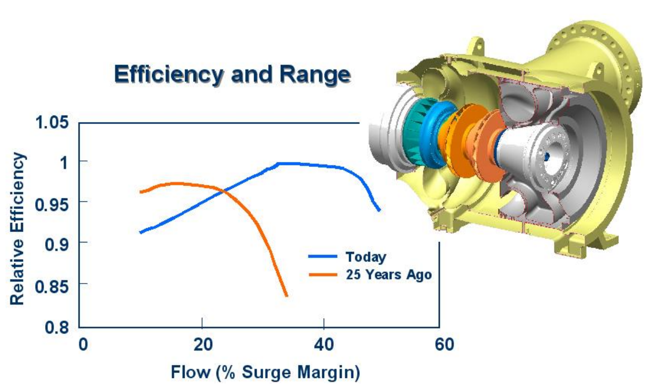


Figure 6: Improvements in Gas Compressor Efficiency and Range.

One of the new buzzwords is the smart grid (Totty,[15]). While the public focus is on electricity grids and transportation, there is equal potential in the transportation of gas, using essentially the same concepts. The gas transmission network has actually a greater flexibility than the electric grid due to its inherent capability for storage. But, in order to accomplish this flexibility at a high efficiency, the machinery, in particular the gas compressors and gas turbines, have to able to operate at a high efficiency over a wide operating range. This requirement is far more challenging than simply improving the efficiency of the compressor at a single operating condition [16]. Modern design methodologies have led to significant improvements in this area (Figure 6).

Furthermore, the system integration between turbomachines, plants and pipelines has to be accomplished in cooperation between manufacturers and operators. In particular, we find many installations where the power installed far exceeds the requirements, and the equipment therefore often runs at low efficiency [17].

CARBON FOOTPRINT

Natural gas is the most environmentally friendly fossil fuel. All forecasts indicate the leading role of natural gas in the effort to provide the world with energy, while reducing the environmental impact. While natural gas is abundant in some regions, the transport of natural gas is receiving scrutiny regarding its environmental impact. To bring natural gas to power plants and other industrial or private users, it is transported from the gas well through pipelines. Along the pipeline, the gas is pumped through the pipe using gas compressors. It may also be pumped in and out of storage facilities. And here is where an interesting argument starts: Any of these compressors conceptually can be driven either by drivers burning natural gas as a fuel (such as gas engines and gas turbines), or by electric motors of various configurations.

Legislation and regulation on CO_2 and other emissions are affecting the decision making process for building new natural gas compression stations. To minimize CO_2 emissions some pipeline companies have decided to install electric motor drivers rather than gas turbines to power their centrifugal compressors. This approach may not yield the desired results, if some fundamental concepts regarding the true carbon footprint are neglected.

If one just looks at the compressor station the argument is clear: The electric motor does not generate any carbon dioxide, while the drivers that use natural gas as a fuel do. However, the argument becomes less clear once we consider that the electricity to drive the motor has to be generated somewhere, and has to be transported to the compression site using transmission lines.

However, one of the key issues is that neither CO_2 nor NO_x emissions can be seen as localized emissions. In other words, the impact of CO_2 is not localized to the area where it is emitted, but it is rather a global issue. Once we have established this thought, it becomes clear that the capability of electric drives to avoid local emissions is immaterial. Instead, we should ask the question about the emissions of the system involved. In the case of the electric motor drive, we have to account for the emissions generated in the generation and transport of said electricity.

In most parts of the world, a large portion of the electricity is not generated in modern, gas-fired, combined-cycle power plants, nor exclusively in coal-fired plants. Usually we find a mix of coal-fired, oil-fired and natural gas-fired plants together with nuclear or hydro power plants, as well as an increasing number of plants using renewable energy. With this mix, a compressor station using a modern, gas-fired gas turbine to drive an efficient centrifugal compressor, will actually generate less carbon dioxide than an electric motor driven station.

The emissions budget of different types of power generation is vastly different (Figure 7 and 8). While hydro power plants, wind power and other renewables, or nuclear power plants don't generate any emissions, a coal-fired power plant produces 1000 kg of CO_2 for each megawatt-hour it generates, depending on the plant efficiency and coal type [19]. Nuclear power plants also don't generate CO_2 emissions, but face increased public scrutiny. Because of their superior thermal efficiency and high hydrogen-to-carbon ratio of natural gas, modern, natural gas fired combined cycle gas turbine power plants generate one megawatt-hour of electricity producing only about 400 kg of CO_2. Natural gas is the fossil fuel with the lowest carbon production. This is due to the high hydrogen to carbon ratio of natural gas. Methane, its main ingredient, has one carbon atom and four hydrogen atoms. Consequently, burning one Methane molecule generates two water molecules and only one CO_2 molecule.

In the United States, over 40% of electricity is generated by coal fired power plants. Many of these plants were built in the 1950's and 1960's and have relatively low efficiencies. The average efficiency of fossil power plants in the US is only about 33% [18].

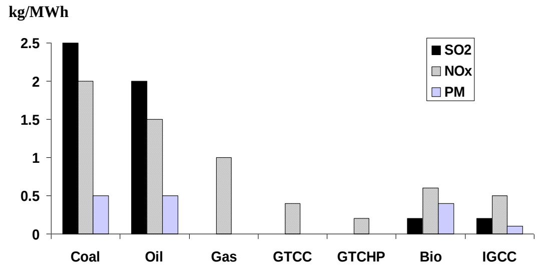


Figure 7: Comparison of Air Polluting Emissions from Power plants per MWh of Electricity generated[20].

Actually, in most parts of the world, a large portion of the electricity is not generated in modern, gas-fired combined cycle power plants, nor exclusively in coal fired plants. Typically, we find a mix of coal fired, oil fired and natural gas fired plants together with nuclear and hydro power plants, as well as an increasing, but still very small, number of plants using renewable energy. China, for example (Table 1), uses coal to generate 65% of their electricity. The remaining contributors are 30% nuclear and hydropower, which are carbon neutral, 3% natural gas, and 2% oil [19].

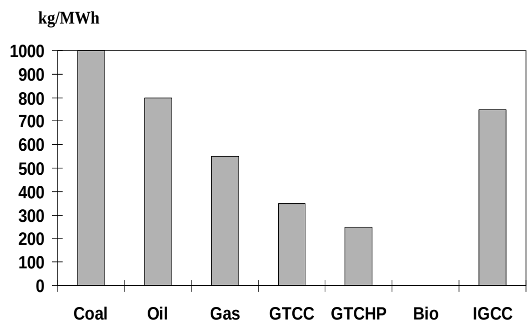


Figure 8: Comparison of CO_2 Emissions from various Power plants per MWh of Electricity generated [20].

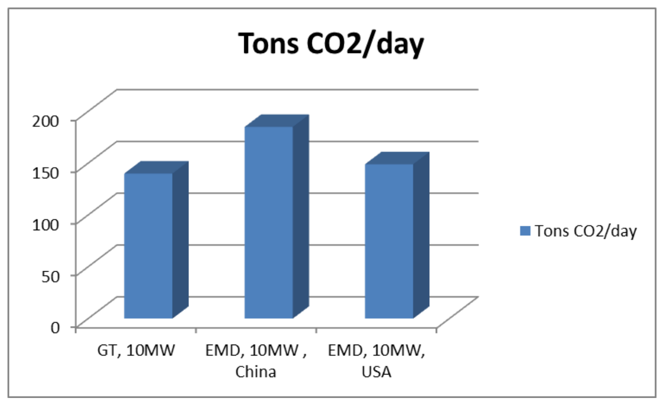
The authors often get involved in discussions about the carbon footprint of pipeline compressor stations. Based on the knowledge of how the electricity is generated, it is relatively straight forward to calculate the emissions generated by a compressor station that allows comparing gas turbine drives and electric drives for the compressors.

Power Plant Type	Contribution
Coal	65%
Gas	3%
Oil	2%
Nuclear and Hydro	30%

Table 1: Power Generation Mix in China (2006)

Power Plant Type	Contribution
Coal	41.7%
Gas	24.4%
Oil	0.5%
Nuclear and Renewables	33.4%

Table 2: Power Generation Mix in the USA (2012)



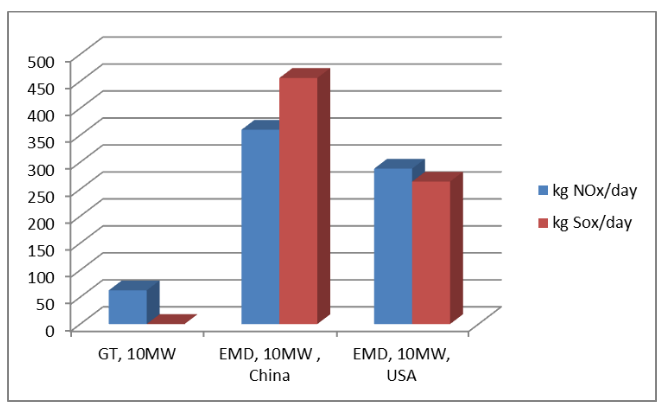


Figure 9: System Emissions for a 10MW compressor Assumptions: Lean Premix Gas Turbine; ,Power plant Emissions per Klein and Kurz [19]; Efficiency for Electric Drive train: 93%,; Transmission Efficiency for Electric power: 95%; Power Plant Mix per Tables 1 and 2 .

Once we know the source of the electricity used in the compressor station, we can determine the emissions

contribution of the electricity and further apply factors for transmission efficiency. If we assume the power generation mix in China, the average CO_2 production for electricity becomes about 680kg of CO_2 per MW/hr. Including average electric transmission and motor losses, for each driver MW available for compression, an electric motor drive "produces" about 770kg of CO_2 per hour, together with 1.5 kg nitrogen oxides (NO_x) and 1.9 kg of sulfur oxides (SO_x). For a typical pipeline compression station of about 10MW, that results in about 185 tons of CO_2 produced per day.
Using the power generation mix for the United States (Table 2), and after applying the transmission and motor losses, we get 620 kg CO_2 per hour for each MW electric power available at the compressor shaft. In addition , we get 1.2 kg of NO_x and 1.1 kg of SO_x. The compressor station for a 10MW compressor thus produces 149 tons of CO_2 per day.

On the other hand, a gas turbine driver in a pipeline compression station utilizes natural gas as a fuel (from the same pipeline). A simple cycle gas turbine operating at nominal 35% efficiency, produces about 575 kg of CO_2 per MW per hour, together with 0.26 kg of NO_x, and, in general, less than one gram of SO_x. The NO_x emissions are based on the use of a state of the art lean premix combustion system. For the same average 10MW pipeline compression station operating with gas turbines as drivers, less than 140 tons of CO_2 are generated, which is less than by the electric motor drive under the conditions assumed above. The NO_x and SO_x emisions are significantly lower for the Gas turbine than for the EMDs.

The results of the comparison of the system emissions are shown in Figure 9. The basis for this comparison was the mix of power generation in China (Table 1) and the USA (Table 2), and an assumed realistic transmission efficiency (95%) and electric drive efficiency (93%). The energy mix in power generation is the key factor, and it will change depending on the average amount of CO_2 that is produced in the generation of electric power. In this scenario, a compressor station using a modern, gas-fired gas turbine to drive an efficient centrifugal compressor, will actually generate less carbon dioxide than an electric motor driven station (Figure 9). At the same time, other emission contributions, such as NO_x, are also lower for the gas turbine driven compressor station.

Thus, utilizing electric motors in compression stations rather than gas turbines can actually result in a greater net CO_2 production when most of the electricity comes from coal fired power plants, as is the case in North America, China, and many other developed countries. To be very clear: We are not trying to evaluate the commercial and operational advantages or disadvantages of different driver concepts. We simply point out that on the issue of carbon footprint, the system boundaries have to be drawn wider than just the compression station itself.

CONCLUSIONS

Natural gas is the most environmentally friendly fossil fuel. Replacing other fossil fuels with natural gas is a key strategy in the reduction of carbon emissions. We have discussed concepts to reduce the carbon footprint of gas compression operations.

By assessing the carbon footprint of compressor stations, we identify areas to reduce their carbon footprint: Reducing the amount of fuel that is consumed for compressing natural gas requires a high efficiency of gas turbine drivers and compressors over the life of their operation. Another key area for improvement is to make the overall operation more efficient. The operational effectiveness of a pipeline or a pipeline system will not be measured only by the cost of transporting a certain amount of gas to the end user, but also by the carbon footprint related to this effort.

We particularly highlighted that the requirement of a system level view, rather than the level of individual units is necessary. This is particularly true for operational issues to be considered, such as the discussion of the carbon footprint of electric motor driven compression versus gas turbine driven compression. Topics like this require an evaluation including the carbon footprint related to the generation and the transport of electric power.

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