

International Gas Union Research Conference 2011

**A ROUTE PLANNER FOR RELIABLE AND EFFICIENT
OPERATION OF THE GAS TRANSPORT SYSTEM
IN A CHANGING WORLD OF ENERGY**

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ABSTRACT

In this paper we demonstrate the use of the route planner for gas transport: in close collaboration with the network operators in the control room of Gastransport Services in the Netherlands, we have developed, implemented, tested, and embedded a fully autonomous model-based decision support tool that provides guidance to the operator in a similar way as a satellite navigation system in a car provides directions to the driver.

We show how the tool helps operators to face the challenges of gas transport in the changing world of energy of today, where greater dynamics and volatility of gas flows go hand-in-hand with increased pressure by tariff regulators on the operational cost of gas transport. As it turns out, the route planner is able to cope with the enormous complexity of the gas transport problem in a systematic way, proving itself as a reliable tool to assist operators in making reliable and efficient transport plans.

The route planner does not only help to reduce the operational cost of gas transport. Computer-aided transport planning provides new insight in the transport system and a much greater feeling of control over the network, assuring that our operators will be ready to deliver reliable and efficient gas transport in an even more complex, sustainable world of energy of tomorrow.

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1. GAS TRANSPORT IN TRANSITION

Liberalization of the gas market in countries around the world, most notably in the United States and Western Europe, has led to increased complexity and uncertainty for gas transport network operators. The liberalized market attracts new gas suppliers and traders and stimulates the construction of new gas infrastructure, such as interconnectors, LNG terminals, and storage. As a result, the direction and the composition of flows through the network changes structurally.

Example: liberalization of the gas market in the Netherlands

In the Netherlands gas was traditionally produced out of the giant Groningen field and exported to a large part of Western Europe. Liberalization of the Dutch gas market some six years ago formed the basis for the construction of new infrastructure, such as an interconnector to England, an LNG terminal in Rotterdam, and new salt caverns close to the market. Holland is gradually transforming into a huge transit hub for natural gas, known as the gas roundabout of Northwest Europe. As a result, the role of the Dutch gas transport network operator Gasunie has also changed significantly. Gas is now flowing into different directions than in the past.

Gas traders are discovering the benefits of the liberalized gas market, such as the flexibility of nomination and balancing regimes, and they show new, commercial behaviour, such as the inter-day and intra-day use of storage for commercial purposes. This results in greater variability of the gas flows at entry and exit points and requires faster response times by the gas transport network operator. The global focus on sustainability further adds to the uncertainty of market demand for gas, in particular for gas-to-power, as a consequence of the integration of intermittent, renewable energy sources such as wind. Increased complexity of gas transport is not just an issue in liberalized markets, but also in an integrated market such as Russia, where gas is expected to come from a greater variety of more remote production locations in the future, and in a country such as China, which is rapidly developing its sustainability agenda.

Inasmuch as gas transport is subject to tariff regulation, increased operational complexity goes hand-in-hand with efforts by the tariff regulator to cut the operational cost of gas transport. At the same time, the focus of governments around the world on sustainability forces gas transport network operators to improve their energy efficiency and to reduce harmful emissions, just like other industrial enterprises. Gas transport is a challenging business, and it will be harder and harder to keep a good balance between profit, people, and planet in a changing world, providing safe and reliable gas transport against minimal cost, in a way that spares the environment as much as possible.

2. ROUTE PLANNER FOR GAS TRANSPORT

In this paper we demonstrate how gas transport network operators can face the challenges of gas transport in a changing world with the use of the route planner for gas transport. The route planner is an autonomous tool that helps gas transport network operators to make transport plans in a similar way as a satellite navigation system in a car helps the driver to plan his route. The route planner was developed over a period of three years by Gasunie Engineering and Technology and has been implemented as a prototype in the control room of Gastransport Services B.V. (GTS) in the Netherlands. The tool is currently being maintained and brought to the market on a commercial basis by KEMA after KEMA took over the R&D activities of Gasunie in 2009.

The basic function of the route planner is to determine a cost-optimal gas transport plan for the upcoming twenty-four hours for a given set of nominations submitted by gas traders, combined with predictions of the gas demand for domestic use, mostly on the basis of weather forecasts. Such an optimal plan comprises all set points under the control of gas transport network operators, such as the set points of compressors, pressure reducing stations, and blending stations, and gas injection and send-out volumes into and from own and third-party, contractual storage.

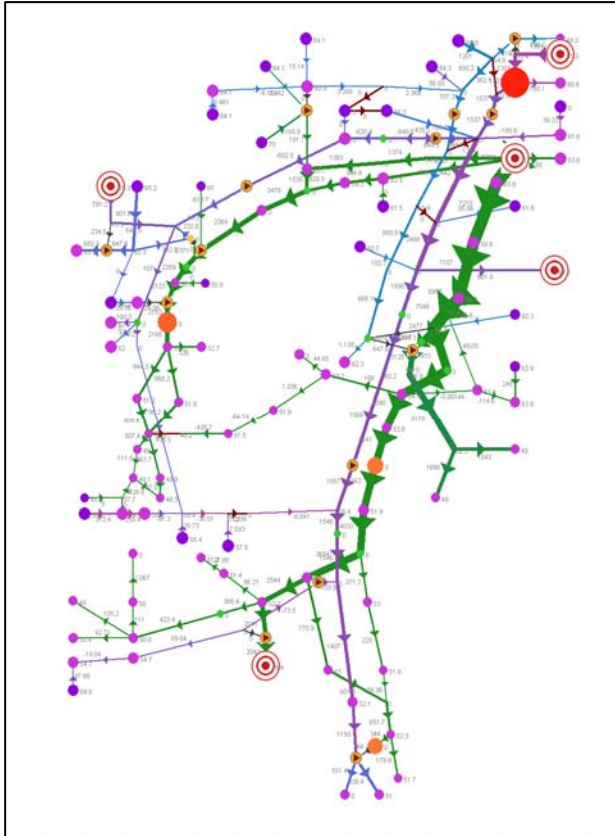
The route planner runs autonomously in the background, producing optimal gas transport plans every hour on the basis of the state of the network and the latest available nominations and demand predictions. The prototype at GTS receives information about the state of the network from the Gasunie simulator (GUS), nominations by gas market parties from the NIMBUS system, and predictions of gas demand in the public market from the Gasunie flow forecaster (GFF) model. GUS, NIMBUS, and GFF are parts of the existing SCADA system of GTS.

It is important to note that even though the route planner is a model-based tool, it is not a full simulator of the gas transport network, such as the GTS system GUS or a commercial gas network simulator like SIMONE. The route planner works side-by-side with a network simulator, using the simulator only as a data reconciliation tool to corroborate the current state of the network derived on the basis of field measurements, and only to the extent that that would be required in order to obtain an accurate enough initial position to start planning a route.

The route planner uses only empirical models of the behaviour of the gas transport network, based on recorded measurement data of the actual pressure drop over system parts and the actual performance of compressor units over the past twelve months. These data-driven models are updated monthly in order to accommodate for gradual changes of the physical performance of the equipment.

Last but not least, the route planner uses a bag of tricks from applied mathematics in order to solve the highly complex, nonlinear optimization problem of cost-optimal gas transport over a period of twenty-four hours ahead. This includes, but is not limited to, a technique for automatic model reduction, a technique for iterative linearization of the nonlinear system, multi-stage optimization with the use of a different strategy in each stage, and the use of penalties to make the optimizer believe what it should believe in order to converge to a solution. More details about the working of the route planner have been presented and discussed in the Pipeline Simulation Interest Group (PSIG), see Turkstra, Kiewiet, Blik, and Van der Geest (2009) and Turkstra and Van der Geest (2010).

The figure below shows a screenshot of a graphical presentation of a page of a gas transport plan generated by the route planner, in which the thickness of the lines represents the flows travelling through the network; the colours represent different gas qualities; the pressure in a great number of points may be found on the map. The target symbols in the map indicate pressures that run into minimum or maximum pressure boundaries and may require special attention from the operators.



3. BENEFITS OF COMPUTER-AIDED TRANSPORT PLANNING

Minimize operational cost

The route planner minimizes the total expected cost of fuel gas of the gas-fired compressors, including the cost of start-up, the cost of electricity of the electrical compressors, the cost of nitrogen for gas quality conversion, and the attributed cost for the use of gas storage. The cost structure of any gas transport network that is more complicated than a single compressor station is too complex for a human operator to oversee fully, and even a simple network with only one compressor station is difficult to optimize for a human operator over a period of twenty-four hours ahead as soon as the expected flow pattern is not trivial. This suggests that the route planner should be able to do better than a gas network operator who controls the network on the basis of intuition.

We have tested the route planner in the background as a kind of shadow cabinet for the network operators of GTS in the Netherlands over a period of twelve months. This extensive test has not only shown that the route planner is a very robust system that practically runs at all times, just as long as the required input data is available. As it turns out, it would have been possible to save at least two percent of the total operational cost of gas transport, if the operators would have consistently followed the advice of the route planner instead of choosing set points on the basis of intuition.

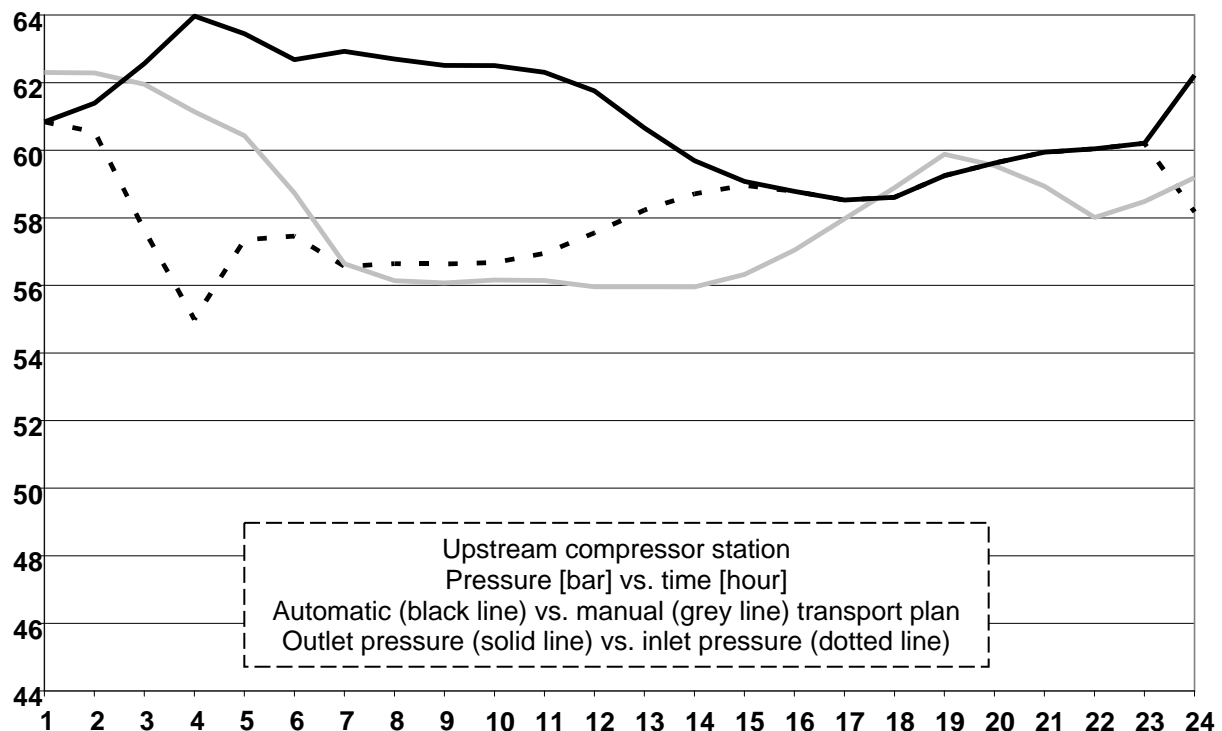
It is important to note that the exact cost savings that could be realized by a certain network operator with the use of the route planner are highly dependent of circumstances such as the complexity of the network and the complexity of the transport situations that occur during a certain period of time. The level of experience of the operator is also an important factor. On the other hand, for many gas network operators only two percent of savings on the total fuel bill would be more than enough to justify the construction of a route planner.

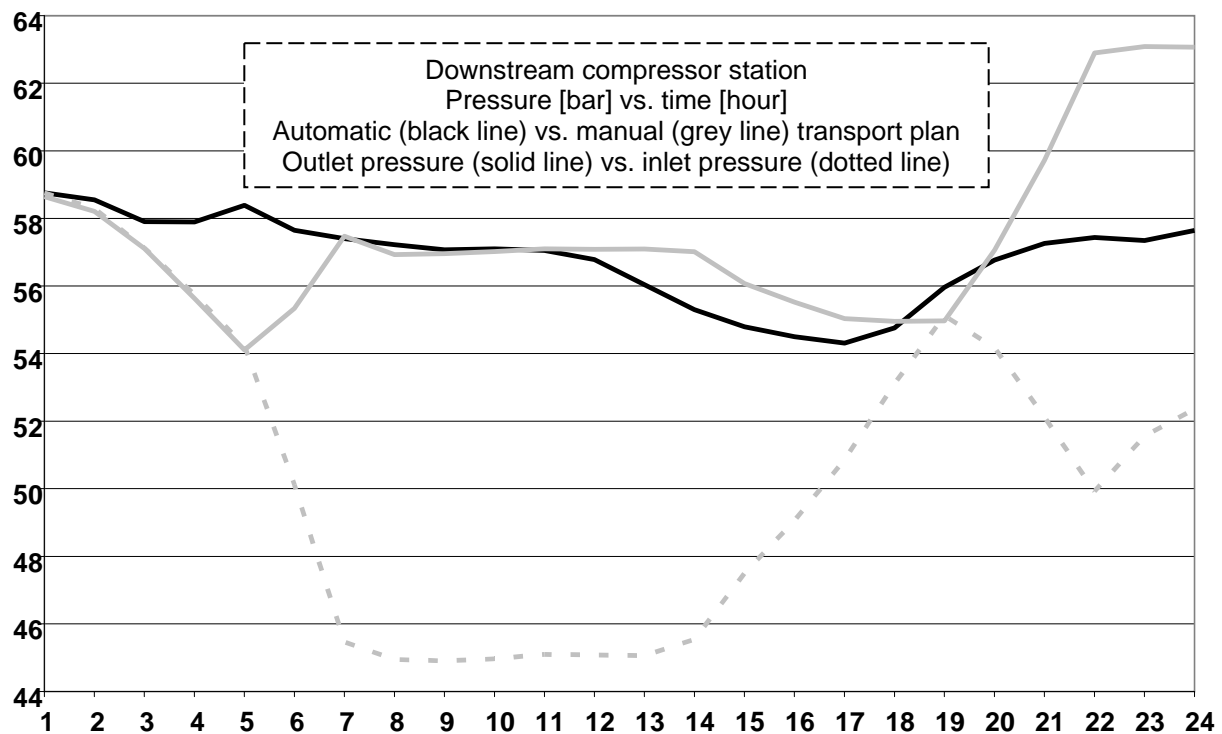
Develop new insight

Rather than focussing on the exact cost savings that could have been obtained when you look back upon a certain period of time, we have investigated thoroughly whether the advice of the route planner makes sense, in a similar way as a driver would expect his satellite navigation system to propose logical itineraries, and a chess player would like his chess computer to play like a real opponent. Apparent intelligence of the route planner would allow network operators to derive new best practices for new transport situations. Developing new insight in the structure of the gas transport problem is a benefit of its own that may be used to train new operators and to prepare experienced operators for new transport situations expected in the future. An apparently intelligent system could also be used as a benchmark for the performance of a gas network operator both for internal use and for the purpose of external reporting.

Example: upstream vs. downstream compression

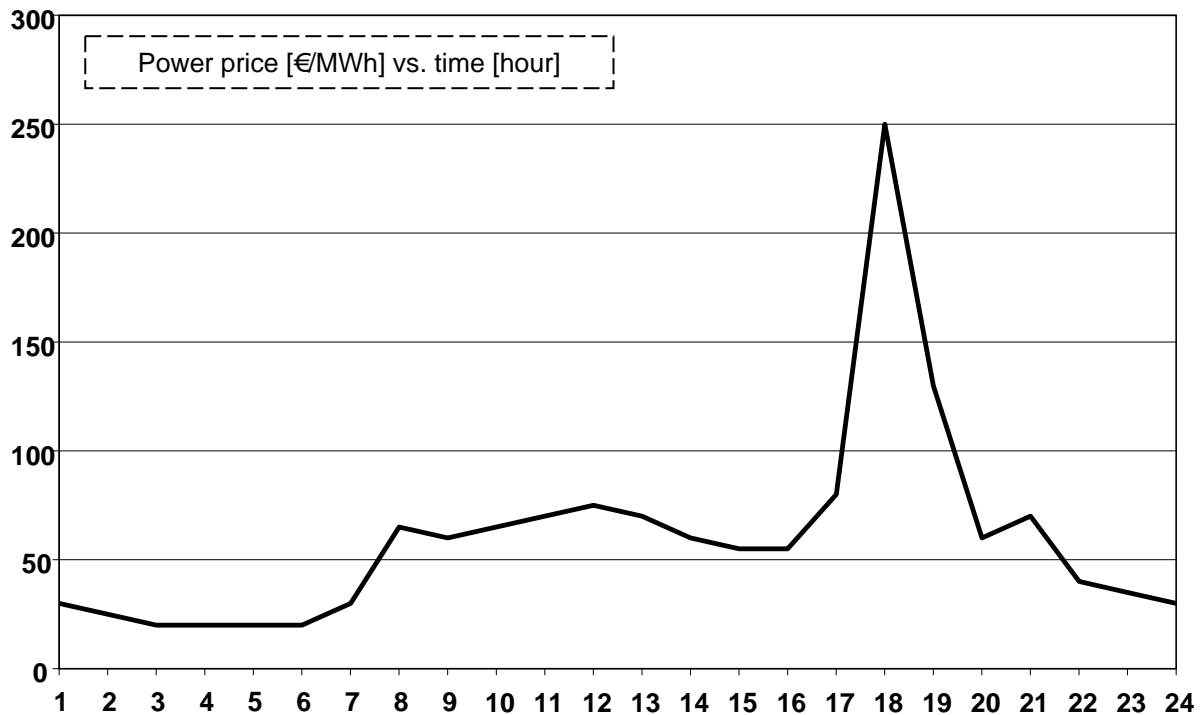
The figures below show the pressure at an upstream and a downstream compressor station on the same transport line. As a rule-of-thumb, it will be cheaper to pack a transport line upstream, because you will benefit from a higher average line pressure. On the other hand, it will be easier for a network operator to follow the variations in gas demand in the market with a downstream compressor. In this example the route planner proposes the use of the upstream compressor station to pack the line, whereas the manual transport plan relies on the downstream compressor station. The area between the dotted and the solid line is indicative for the amount of work done on the gas. Since the flows through both stations are practically equal, the difference between the areas in between the lines in the two graphs is indicative of the compressor fuel spent on this particular day. The example clearly shows that the automatic plan is cheaper than the manual plan.





Energy management system for electric compression

In case a gas transport company has electrical compressors in use, the route planner may be used as an energy management system for playing on the highly volatile market for electricity imbalances. Liberalized electricity markets are much more volatile than liberalized gas markets because imbalances between supply and demand in the electricity grid need to be balanced instantaneously. This can easily lead to huge variations of the spot price for electricity over a day; see the graph below for an example of the development of power prices on an arbitrary day on the Amsterdam Power Exchange (APX). This means that you could make a lot of money if you would have the flexibility to take power off the grid when it is needed rather than when you need it. A gas transport network operator with electrical compressors may just have that flexibility available, using the possibilities to buffer up and drain the network. The route planner has built-in capabilities to deal with fluctuating power prices over the upcoming twenty-four hours so as to make maximum use of such opportunities.



Enhance security of supply

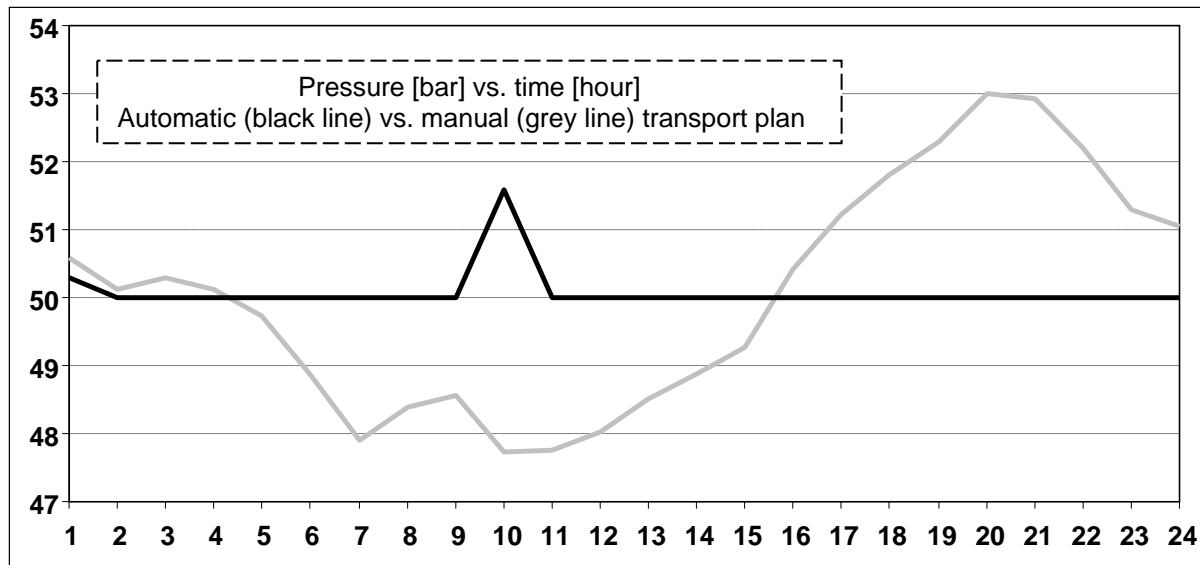
We believe that the main benefit of the route planner is not to find optimal gas transport plans, but to find a feasible solution to the gas transport problem at all times. Notwithstanding incessant efforts by gas transport companies to reduce their cost, most operators will consider the uninterrupted supply of gas to the market to be more important than the efficiency of their operations. Along with safety of the operation, security of the gas supply defines your reputation as a gas transport company. Even though an interruption of gas supply to an end-user could in theory be handled by referring to a force majeure clause under the conditions of the connection agreement, we believe that gas transport companies ought to pay for the damage suffered by the end-user, or face the consequences of losing the customer to a competing gas transport company or to a competing fuel. A gas-fired power plant in particular may be inclined to switch to alternative fuel if an interruption of the gas supply has resulted in a power outage and has affected its reputation as a power supplier.

The route planner takes into account all physical and contractual, operational constraints of the gas transport network, such as maximum allowable operating pressure, minimum delivery pressure, and gas quality constraints. Use of the route planner greatly reduces the risk of gas supply interruption, because the tool plans ahead to make sure that there is always enough line pack in the right place in the right time to deliver gas exactly according to the orders of market parties.

Example: export station with a minimum delivery pressure

The figure below shows the pressure at an export station with a minimum delivery pressure of 50 bar. The automatic transport plan generated by the route planner takes the pressure constraint into account. Further analysis of the automatic transport plan reveals that the route planner deploys a compressor upstream in order to build up enough line pack in this part of the network to meet the pressure constraint over the upcoming twenty-four hours. The manual transport plan obviously does not meet the minimum pressure constraint. What actually happened on this day is that the network operator got an alarm after four hours to signal that the pressure had dropped below 50 bar. A compressor was started especially to avoid the pressure to drop below 49 bar, which is the hard constraint for this export station. 50 bar is just a soft constraint that includes a safety margin of 1 bar. This example shows how the route planner proposes a graceful solution for a situation that resulted in an alarm for the operator and additional cost for the company. It also shows that safety margins, such

as the safety margin of 1 bar in this example, may not be necessary if you rely on the route planner. This is an additional opportunity for operational cost savings.



Early warning system of gas supply interruptions

In the unfortunate event of an infeasible gas transport situation, that is, a combination of nominations by gas traders and predictions of market demand for which it is not possible to find a feasible gas transport plan, the route planner will detect and signal that the problem is infeasible. Even though this is an undesirable situation, it is far better for a network operator to be informed about such problems before they become critical and the gas supply is interrupted automatically, for example because the pressure at some point in the network crosses a limit value. Timely warning of a network congestion problem opens up possibilities to find collaborative solutions together with market parties. In some countries, there is an auction system in place that may be used by the gas transport network operator to bid for more gas to be supplied into the system or for additional gas to be taken out of the system by market parties on a commercial basis. With the help of such auctions, many infeasible gas transport situations could probably be avoided before they occur in the first place. Another option for a network operator may be to shut off the gas supply to selected customers in a controlled way, giving customers the time to shut off their equipment in an orderly manner or to switch to alternative fuels. We believe that such collaborative solutions are always cheaper than uncontrolled shutdowns.

4. CONCLUDING REMARKS

Gas transport network operators face challenges to deliver reliable and efficient gas transport in gas markets in transition around the world today. We believe that these challenges will only get bigger as the share of renewables in the energy mix will become more significant in transition towards a sustainable energy system in the future. The route planner for gas transport has proven itself in the control room of a major gas transport network operator as a reliable tool to assist operators in making reliable and efficient transport plans. We have demonstrated that the route planner provides valuable advice to operators because it is able to cope with the enormous complexity of gas transport problems in a systematic way. This opens up possibilities to make full use of the flexibility within the gas transport network, securing the position of the gas industry as the main supplier of capacity and the back bone of the sustainable world of energy of tomorrow.

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