The future of global oil and gas production is uncertain. After the surprising statements made by the International Energy Agency (IEA), that oil production has peaked already and world energy consumption increases by more than 59% until 2020, oil and gas companies will have to reassess their current and future production strategies even more.

The end of easy oil was already proclaimed before, but due to increased geopolitical and financial issues, the latter has now become obvious to all. To counterpart this growing demand-supply discrepancy, NOC’s and IOC’s will have to give more attention to their mature fields to sustain current production levels. It should be realized that most operators have not exploited the full capacity of mature fields to their potential. In addition to this they face the challenge of developing green fields in such a way that they can be produced to their maximum potential in the future. With a mean recovery factor of about 36%, there is an immense opportunity for production optimization.

TNO addresses the challenges by delivering pragmatic results and is willing to transfer its technology and knowledge (see Examples). TNO does this by combining:
- A thorough understanding of the key processes
- The use of (real time) production data to improve the predictability of processes
- The ability to develop new measurement & control technologies
- Model-based production control & recovery optimization strategies
- Experience in successfully implementing innovations & new ways of working in organizations.

TNO assists operating companies with the development of production optimization strategies in two ways:
- Independent advise on the optimal utilization of production optimization technologies that are available today by taking an overall approach that covers crucial aspects of people, processes and technology (e.g. completion design, digital oil field architecture)
- Technology development projects to fill technology gaps, support in-house development within companies, or investigate new concepts that can have a major impact on future production.
New developments in drilling and completion technology, as well as in improved oil recovery techniques are expected, in combination with ever increasing computing and simulation capacity, to enable significantly increased recovery from hydrocarbon reserves. At the same time, the complexity of huge and unconventional data streams that accompanies these developments is posing challenges to existing workflows. TNO is on the forefront of research and new developments that aim to facilitate the move to the intelligent, digital or integrated field. Part of this development is the concept of closed-loop production and reservoir management, which provides the framework to integrate advanced semi-automated workflows that are required to realize the full potential that such fields offer. TNO is active both in realizing this framework as well as the individual advanced workflows themselves.

**ABOUT TNO**

TNO is one of Europe’s largest independent companies in the areas of technology development and technical consultancy. The last 30 years TNO has been active in the oil and gas industry. With around 4,500 engineers and scientists, TNO is working in a wide range of economical sectors, including energy, mobility, industrial innovation, information society, health and defense. TNO has more than 70 years of experience in advisory, in which independent from commercial interest, during innovative technologies in close collaboration with major industrial parties and universities have developed and knowledge transfer programs have been implemented.

TNO distinguishes itself by its independent position and capability to address challenging technological issues with multi-disciplinary teams of highly qualified engineers throughout the entire oil and gas chain; upstream to downstream. TNO develops technology on the basis of fundamental scientific knowledge into practical applications with industrial use.

In the oil & gas sector we hold over 30 years of experience in working with operators and service companies around the world. Among our customers are major international oil companies like Statoil, Shell, and Lukoil; as well as large independents such as Wintershall and Maersk Oil. TNO has been active in the Middle East for several decades, mainly working with or for national oil companies such as Saudi Aramco, ADNOC, PDO and KOC.

**IMPROVED RESERVOIR CHARACTERIZATION**

While the industry has realized the need to incorporate uncertainty in the description of reservoirs, existing workflows for reservoir characterization based on dynamic data (history matching) often pose practical limitations on the number of parameters that can be estimated. Furthermore, such workflows are usually limited to production type data only. TNO is active in developing algorithms and tools that will enable full use of all available data and estimation of all uncertain parameters within practical computational constraints. These activities are supported by a strong knowledge position in the area of reservoir simulation and hydrocarbon-recovery processes.

TNO assists companies with:
- Development of company-oriented tools and workflows for advanced history matching
- Application of advanced history matching tools to provide improved reservoir models
- Use of unconventional data types, such as e.g. time-lapse seismic and subsidence, to improve reservoir understanding and characterization;
- Performing complex reservoir and process studies
- Physics-consistent interpretation of special core analysis experiments
- Transferring knowledge through joint-industry research projects;
- Transferring knowledge on a B2B basis.

**STATOIL: ‘IMPRESSED WITH THE SWIFTNESS AND THE QUALITY’**
WINTERSHALL: ‘WHAT TNO ALSO OFFERED WAS A NICE COMBINATION OF THOROUGH THEORETICAL KNOWLEDGE AND A VERY PRAGMATIC APPROACH, AN URGE TO SOLVE PRACTICAL PROBLEMS’

PRODUCTION AND FIELD DEVELOPMENT OPTIMIZATION PLANS
The primary objective within reservoir management is to provide optimal production scenarios, accompanied by estimates of expected hydrocarbon recovery, ultimately resulting in an optimized field development plan. Elements of such a plan include recovery techniques, well types and position or pattern designs, completion types, and production scheduling. In fields with significant complexity automated workflows based on numerical algorithms will need to be used to find optimal choices for all these variables. TNO has in-depth knowledge and experience in the area of numerical optimization. The latter has been integrated into tools that enable robust optimization of time-dependent ICV settings, or injection and production rates and pressures, taking into account any remaining uncertainty in reservoir properties.

TNO assist companies by:
− Developing and incorporating advanced optimization tools into company workflows
− Applying advanced robust optimization techniques to explore improved field development plans for new or existing fields
− Providing optimal production strategies based on both field life-time objectives and short-term production constraints and targets
− Transferring knowledge through joint-industry research projects.

REDUCING DOWNTIME AND CONTROLLING FLOW INSTABILITIES
Mature and more challenging fields are becoming the main feature of present and future operations. One of the key challenges operators are facing is to minimize downtime and have a controlled stable flow that can be handled by the topside facilities. TNO assists national and international companies in understanding, controlling and mitigating phenomena that stand in the way of optimal production. The focus is on phenomena like flow instabilities (severe slugging, gas coning, liquid loading) on both oil and depositions in well and near-well reservoir (salt, asphaltene, wax).

TNO assists companies by:
− Performing root-cause-analysis by analyzing & diagnosing production data
− Develop forecasting tools, to assist operators in deciding optimal response strategy
− Building dedicated dynamic flow & deposition models, to understand (field specific) behavior
− Determining optimal production & control strategies to prevent & postpone production upsets
− Transfer of developed knowledge to prevent similar challenges in the future.

REAL TIME PRODUCTION DIAGNOSTICS & OPTIMIZATION
Many assets at present have monitoring and data acquisition in real-time in place. These systems generate large amounts of real-time production data, sometimes resulting in the well known ‘Data Tsunami’. The key challenge is to realize direct added value to operations with this data, for example by detecting events earlier, prevent down-time, and doing predictive maintenance. TNO helps operating companies to achieve this by giving independent advice, in full collaboration with the operator, on the design of production diagnostics systems or developing case-specific diagnostics applications, if required.

The success of a real-time monitoring diagnostics and optimization system depends on its ability to combine production technology functionality with an IT system that is supported in and by the organization. TNO is specialized in assisting the integrated development of such system through three unique roles:
− Working together with the end-user to design a fit for purpose monitoring system design, taking into account: production technology (what the end user needs), IT (making data available) and organization (implementation)
− Develop real-time diagnostic and optimization application that extract information from functional production data. Our core strength lies in the development of dedicated applications that utilize models for the diagnoses and optimization of specific production issues on an asset. These diagnostic modules run in real time to optimally assist operators and make sure they can focus all their energy on optimizing production, instead of only analyzing large amounts of data.
− Training the different end users of the diagnostics and optimization system in a company and helping them expand its functionality.

TNO teams that work on the development of real-time diagnostics and optimization solutions exist of a mix of production and reservoir engineers, IT experts and specialist in real-time optimization of production plants. Especially in real-time optimization, TNO strongly leverages on its experience in other industries (downstream, food, cement, glass) where many of the real-time paradigms already have been developed years ago, tested and successfully implemented. On specific request TNO also works with its own partners in the IT industry to develop monitoring systems for customers.
The last decade has seen an uptake in the deployment of a broad range of production optimization technologies, like intelligent well-completions and the digital oil field. Experience shows that the successful deployment of production optimization technologies asks for vision and leadership of management and a deep understanding of the technology, because people and processes involved could also be a main source for improvement. TNO recognizes Integrated Operations as the road to be taken. This means not only putting in place new technologies, instruments and IT-systems, but also making sure that the different working processes and stakeholders within the companies are taken into account to ensure successful implementation and integration. TNO’s overall approach has proven effective on operations in the North Sea, Africa and the Middle East in close cooperation with the respective operators.

TNO has a special role as an independent company to advise management of international and national oil companies on production optimization technologies. We leverage our broad experience into a practical management advise about e.g. production optimization deployment strategies.

ROADMAPPING
For the successful deployment of production optimization technologies the needs of various stakeholder groups (production, reservoir, IT, management, ...) and issues relevant to the operation of a field (KPIs, HSE and bottlenecks) need to be addressed.

Based on discussion with these stakeholders TNO develops a roadmap:
− An independent overview of the state-of-the-art in the deployment of intelligent field technology at various national and international operating companies
− Identify the level of alignment between stakeholder views, and possible gaps that need attention in technology deployment
− Added values
− Propose a stepwise approach for the deployment of technologies.

Based on this high level strategy, a management approach and specific production optimization technology deployment projects can be defined, in collaboration with engineering contractors.

SURVEYS
Production optimization technologies are often discussed in the industry. Yet little information is available about its actual deployment rate. For examples: how many intelligent wells have been installed to date?

In order to finding an answer to this question TNO works together with suppliers and operating companies to perform independent surveys in order to obtain representative numbers for the uptake of technology. Examples of available data:
− Uptake of flow control and intelligent production control technologies
− Regional spread
− Breakdown by types of end-users: international (IOC), national (NOC) and independent operating companies
− Best practices
− Added value.

Example of a free report: TNO.NL/OILFIELDIQ

DEVELOPMENT OF INNOVATIVE SENSORS, MATERIALS & METHODS
Besides extracting valuable information out of production data, to improve production & reservoir management, TNO also develops new technologies that unlock currently unavailable valuable information about well and reservoir as well as technologies that enable new ways of controlling well & reservoir flows, adding value to ‘closed loop well-reservoir management’.

TNO has a strong track record as an innovator of breakthrough technologies in various relevant markets for the upstream sector. At the same time, with regards to the Oil & Gas market, TNO develops step-change technologies either on its own initiative or on request by customers.

For optimizing production/recovery TNO focuses on new measurement technologies & instruments and functionalized materials.
REAL-TIME MONITORING OF NORTH SEA GAS ASSET

HANS REIJN, PRODUCTION ENGINEERING SUPERINTENDENT, WINTERSHALL NOORDZEE B.V.

German oil and gas company Wintershall, which is a subsidiary of chemical giant BASF, asked TNO to assist in the development of an intelligent production monitoring system for its North Sea gas assets. Such a system continuously acquired measurement data from the off-shore asset in order to optimize production by offering real-time decision support to operators and engineers. ‘With good results’, says Hans Reijn, Production Engineering Superintendent at Wintershall. ‘We will be able to recover the costs of this project very quickly.’

In October 2008 Wintershall and TNO started a pilot project in section F16A (offshore North Sea). This has given much better insight into all kinds of operational issues. One of them is the difficult to predict gradual decline in production capacity due to salt build-up in some well of the asset. ‘By constantly checking the ideal situation against the real situation, we can more precisely plan the right moment for maintenance’.

The development of production monitoring systems asked for combining commercially available monitoring systems, with in-house production models of Wintershall and real-time monitoring methods that were developed by TNO. ‘What TNO also offered was a nice combination of thorough theoretical knowledge and a very pragmatic approach, an urge to solve practical problems’ says Hans Reijn. ‘We had several options available to hire in IT knowledge but TNO has the distinction of having much more in house, a wide spectrum of knowledge, including gas production, which was a must in this case.’

‘TNO’s flexibility in this project has been a real strong point. Interim adjustments were never a problem. Our team’s priority is day-today gas production. Projects, no matter how vital, always take second place. TNO constantly displayed the flexibility and understanding that took account of our priorities’.

‘URGE TO SOLVE PRACTICAL PROBLEMS’

Courtesy Wintershall
BRUGGE BENCHMARK MODEL
Leading universities as well as research consortia all over the world make extensive use of the ‘Brugge’ benchmark model to test their innovative tools in the area of closed-loop reservoir management. The Brugge benchmark case, build by TNO, consist of a complete geological model and reservoir simulation model including different realizations of the reservoir properties. From the model, synthetic data is generated, such as well log data, production data as well as synthetic seismic data. At an SPE Applied Technology Workshop in Bruges 2008, co-organized by TNO, the model was first presented to the industry and academia. Since then, numerous studies on the Brugge case have been published, also by TNO. In these studies, the potential of innovative methods for history matching and optimization has been demonstrated.

FIELD REDEVELOPMENT PLANNING IN KAZAKHSTAN
An optimized well placement plan for a fractured carbonate oil field in Kazakhstan resulted in 33% more additional oil recovery compared to the existing development plan of the operator. In addition, the new infill drilling scheme requires 30% less wells. A combined geological/reservoir simulation study resulted in a new field development plan, based on the analysis of the natural fracture system, the construction of a discrete fracture network model and of a dual porosity/dual permeability dynamic model and the results of history matching.

PRODUCTION OPTIMIZATION IN QATAR
Maersk Oil and TNO have established a long-term collaboration to develop new technologies for increased oil recovery (IOR). Focus will be on long horizontal wells and increasing oil recovery through integrated operations and production optimization. The joint research project will be located at the Qatar Science and Technology Park in Doha where both Maersk Oil and TNO have research centers.

‘Maersk Oil has an ambition to become a leading oil and gas company within increased and enhanced oil recovery. By bringing together our and TNO’s experienced people, we create a research environment that will develop ground-breaking IOR technologies taking our oil recovery to a new level’, said Lewis Affleck, Managing Director, Maersk Oil Qatar.
MITIGATING LIQUID LOADING
Liquid loading is a major problem in mature gas fields. Virtually all gas fields produce varying quantities of liquids together with the natural gas. As a reservoir is depleted, this water can no longer be produced to the surface in the gas stream, and builds up in the wellbore. TNO multiphase flow experts have carried out many R&D projects for clients to investigate the liquid loading process. One of the findings from these projects is that the liquid loading process starts when the liquid film on the wall of the wellbore can no longer be produced upward. Previously it was assumed that liquid in droplets is the first to stay behind in the wellbore. With this new insight came the realization that an extremely hydrophobic coating developed previously as part of TNO’s Innovative Materials research program might be used to influence the properties of the wall. A test program was performed at TNO’s Flow Lab on behalf of Shell to investigate the feasibility of postponing liquid loading by coating the inside of the wellbore. This test indicated the onset of liquid loading could be significantly postponed. Following this positive result, Shell and TNO are now looking to further mature this technology.

INTEGRATED SYSTEM APPROACH PETROLEUM PRODUCTION (ISAPP)
The Integrated System Approach Petroleum Production (ISAPP) program was established in 2004 by Shell, TNO and TU Delft. Inspired by the systems and control theory used in meteorology and the process industry, a program was started to develop methods for reservoir model updating and production optimization based on data from various sources, such as production sensors and time-lapse seismic.

The project has run for four years (2005-2009) and consisted of fundamental knowledge development by 30 PhD students & research staff at the Technical University of Delft, knowledge & tool development by TNO and application of developed knowledge in projects & demonstrators by TNO. The main objectives of this program were:
− To generate significant innovations in the Exploration and Production (E&P) process through the application of system-dynamic thinking and model-based control concepts
− To generate the intellectual framework, concepts, models and algorithms to enable real time model based closed loop reservoir management, and to test these on virtual and real assets
− To develop tools and techniques for ‘smart’ production systems where measurement and control functionality adds significant value, and to test these on virtual and real assets
− To perform research beyond the state-of-the-art in the E&P industry and to introduce innovative elements from other industries.

Following the success of ISAPP-1, TNO and the Technical University of Delft are starting up a new ISAPP program with multiple sponsors.

The ISAPP-2 program offers three main ways of participation in R&D activities:
− Research: investigation of specific research topics in collaboration with researchers from TU Delft and TNO
− Development: partner-specific (B2B) proprietary innovations
− Cases: Integrated Field Studies, Production Systems.

The knowledge developed through Research, Development and Cases will feed each R&D area. For example Research and Development may be applied in Cases and the application of Research in Development may result in additional research questions that need to be resolved. It is this interaction between applied research, development of
tools and application in cases that will lead to constant progress in applied integrated closed-loop solutions. Figure below depicts this interaction.

Partners in ISAPP-2 can opt to participate in one or more R&D targets. In addition they:
- have access to ISAPP-1 legacy;
- are part of the Steering Committee: control over selection of R&D topics and part of R&D network working toward an integrated closed-loop concept;
- have access to ISAPP technology;
- have access to workshops, symposiums and in-company training.

For more up to date information about the program, look at the dedicated website: [www.isapp2.com](http://www.isapp2.com).

The interdependency of Research, Development and Cases