Project Description:

Optimal design and operation of natural gas processing plants

1. Objective

The objective of this project is to increase the value of natural gas produced offshore by more efficient operations and improved design of processing plants for natural gas. This will be achieved by:

- Improving production planning by advanced optimization and scheduling.
- Incorporate market information into production planning and thereby achieving market focus on process control
- Provide decision support tools to link process control and business operation for use in the new emerging control centers
- Provide a framework within the Gas Technology Centre at NTNU/SINTEF for exchange and reuse of Process System Technology

2. Measurable Goals

1. Develop an application that demonstrates the integration of optimization algorithms, process models and process control for two selected cases
2. Supervise 3 PhDs
3. Publish a tutorial paper that summarize the main contribution of new methodology
4. Develop a core software library for a generic model / optimizer interface
5. Acquire an industrial project based on this technology

3. Background

Optimal operation of processing plants is a challenging area where new dynamic markets for gas components lead to a need for stronger analytical capabilities of decision support tools. Also the supply situation becomes more variable, as the gas companies responds to market opportunities.

The result is a more rapidly changing environment and as a consequense processing plants needs to be reconfigured more often.. There is a need for better understanding on how to make plantwide production plans and implement these through process management.

Decision support tools have to combine both optimization and simulation capabilities in order to analyse the consequence of different scenarios. This is an area where little research has been done, and we wish to focus on developing new methodology for combining simulation and optimization.

Advanced modeling and optimization is needed in order to address the new challenges in plant control and optimization systems:

- Many of the processing plants are short of capacity. It is more important than before to maximize flow through the plants or the profit from final products.

- New opportunities exist because of recent advances in modern control technology. E.g. Model Predictive control lifts the level of automation and gives better opportunities for process optimization systems at higher levels.

- Integration of tasks and systems in operation support centers. E-fields give a new perspective on operation of the oil and gas production, and this mode of operation must be prepared for in the gas processing plants. (1)

- The MTO-perspective. (Man-Technology-Organisation). Provide relevant information for the personnel involved. (10)

- The use of models for planning and process control plays a central role.

- Modeling the dynamics of the markets and incorporate it in contingent plans. The plans should reflect capacities and production possibilities of the plant. This again depends on the design and operation of the plant control system

- Structuring of the information flow between layers and systems in the process in the process control hierarchy, the real time optimization level and the planning and scheduling levels.

- Self regulating and robust systems. Optimizing the other parameters

- Limitations imposed by process design. How do the above issues have impact on the optimal design of gas processing plants.

3.1 Industrial relevance

In the upcoming decade there will be large investments in gas production, and in facilities for transportation and processing. Optimal utilization of all these facilities is vital in order to maximise the value from produced natural gas.

Advanced process control and operation has raised the level of automation in the process industry significantly in the last decades. For example in the refinery industry methods like model based predictive control (MPC) and real time optimisation (RTO) have become widely used. (2) The focus on these technologies has given large benefits to the industry in form of increased throughput and more robust operation. The improvements obtained by the use of better control and decision support tools ends up directly on the bottom line for the operating companies. The substance of these tools is in fact software realization of process knowledge, control and optimization methods. MPC and RTO are now more or less off the shelf products, although for complex processes the adoption of this technology requires specialist competence.

However, there are significant potentials for further improvements in this area. One challenge for the gas processing plants is being able to quickly adapt the plant operation to dynamic changes in the markets, thus the plant flexibility and ability to perform rapid production changes becomes more important. It is also required to know accurately the plant production capability, both on very short term (today-tomorrow) and on weekly, monthly and even longer horizons. And this requires use of advanced optimisation tools and efficient process calculations. It is important to consider these issues related to dynamic operation also in the design of new processing plants, and for modification projects. Investments in this type of project have typically short payback time . (3)

Combination of individual units into an integrated plant gives a large scale control problem that is more than just the sum of the units. Cross-connections, bypasses and recycling of streams give more flexibility, but at the same time, the operation becomes significantly more complicated, and it is almost impossible to utilize the full potential of a complex plant without computer based decision support tools.

Thus there is a need for development of new decision support tools that combines optimization technology, realize process calculation models at a suitable level of speed and accuracy, and structure the information flow, both from the process measurements and deduced variables, and from the support tool down to the manipulated variables in the control system. It is also needed to develop further the methodology related to Plantwide control (4) in this context.

3.2 The Technology Integration Challenge

This requires contribution and integration of several technical disciplines:

- Control engineering – process control, control structuring, model interfacing
- Industrial Economy - Description of economic mechanisms and environment, planning and scheduling
- Process engineering – Process knowledge, models, process design
- Applied mathematics –Optimization methods, efficient numerical methods, basic supplier to the above disciplines
- System integration – Framework/interface standards for system components

There is an obvious potential in combining the multidisciplinary knowledge into a working solution in form of a decision support tool. However, different disciplines have normally different focus on their research, and develop their own terminology and tools, so bridging the gap and to join forces towards a common goal is a challenge that must not be underestimated.

Thus for every research group there must be an incentive to adapt their approaches to fit into a wider context. For example, the compressor experts normally have their focus on making better compressors, but in a plant operation context the focus is on providing models of compressor behavior in a format and at a complexity level that are suited for the overall system. Nobody else than the compressor experts are better qualified to do this right but it requires a system focus in stead of a unit focus. If the compressor expert does not contribute, who can, and how do we integrate the required technology then? Thus, the vital question for an expert within every discipline is: How can I best provide my knowledge and tools into a common system for optimization of natural gas processing plants.

It is not an issue whether the Gas technology Centre at NTNU/SINTEF has resources within each of the required disciplines, but how the knowledge and available methods can be integrated into a working system. This requires development of new methodology.

4. Scientific Approach

Optimal operation of gas processing plants is a challenging multidisciplinary task. Large-scale process optimization is challenging in itself. Thus, when we also will consider dynamic conditions in the market and on the supply side the operation will most certainly run into problems that must be solved. Some will arise from the size of the problem, some from complex process behavior and from requirements to solution of complex optimization problems.

The starting point in this project is the need for decision support as seen from the personnel in a plant operating company. This defines a set of tasks that requires optimization calculations, process calculations and measurement data handling.
The personnel in question can be plant operators, production planners, sales personnel, maintenance planners, process engineers, managements, etc. Experience from other applications like gas transportation will be utilized (5).

The inclusion of market factors, capacity planning and scheduling shall be focused, as this sets new requirements to vertical integration of process control and the optimization layers. We may in fact have several such layers, where for example the classical real time optimization is just one element. In planning and capacity assessment, the RTO-layer may be accessed by superior layers in order to compute the optimal process targets over a certain horizon.

The requirements to process calculations for each type of task shall be classified. This may result in a set of optimization problems with different properties and requirements to solution approach and to the underlying process calculations and data handling. E.g. one approach from the planning side is to start with empty or extremely simple process models, and to refine the models based on the requirements to the planning.

Segmentation into suitable process sections and control hierarchies are central issues. Here we can apply methods from Plantwide control (4) in order to structure the control of the plant units in a way so that the influence from unknown disturbances and model uncertainties are minimized. A very important output in the first phase is to define high level targets for the process control. The next important issue is to develop methods to select the variables that should be exchanged between the optimization and the process control layers. This is a control structure design task where the focus is on selecting the variables that are best suited for setpoint control in order to fulfill the process optimization targets in presence of unknown disturbances and model parameters and measurement errors. Segmentation of the control into suitable sections and layers is also a part of this task.

Recent advances in process control technology also give a new perspective. For example, with an active MPC controller, information about active and inactive process constraints is high level information that can be exchanged with the optimization layer, in stead of representing the constraint equations at the optimization layer.

Efficient use of models is a so wide area that this issue can be subject to extended research in separate programs. For example, in process design it is industrial practice to use quite detailed process models, including rigorous thermodynamics and representation of detailed phenomena within each process unit. In operator training simulators, detailed dynamic models are used, but these are rarely the same models as used in design, and the built in process knowledge in form of model configurations and parameters is usually *not* interchangeable because of different modeling approaches and different model data representation. The models used in MPCs are normally captured from experiments on the process itself, and are not connected to the other two types of models. For Real time optimization (RTO), steady state models are normally used, and in some cases model tools with rigorous models are used there too. For capacity assessment, correct representation of potential bottlenecks is important.

In this project the focus shall be on model representation at an accuracy level and format that is required from the optimization level for the different optimization tasks.

In a system realization, the system architecture and formats for interchange of data between must be unified. As far as possible, available standards should be applied. This is a central issue within the Gas Technology centre in order to be able to combine newly developed models and optimization procedures for analysis and performance evaluation.

5. Activities

5.1 Project Management

Coordination activities by the project manager, and disipline leaders.
Refer to project organization.

5.2 Developing new methodology

5.2.1 Modelling for optimization purposes

The focus in this activity is to address any special requirements for process calculations that arise from a set of relevant optimization problems. The requirements may be different dependant on the type of the requested decision support information that is needed. E.g. the assessment of spare capacity over a planning horizon may require more rapid, but less accurate process calculations than solution of the current real time optimum.

- Model requirements for various optimization problems
- Representation and extraction of process knowledge

- Use of commercial process simulation tools
- Standards for interchange of model data
- Model development methods
- Handling of uncertainties: model, measurements, prices, etc.
- Use of steady-state and dynamic models
- Fitting models to measurement data
- Representation of constraints
- Representation of the control system
- Relation to Control Structure design
- Analysis of the process system regularity

5.2.2 Applied optimization technologies

The resulting optimization problems are highly complex, and no general effective global methods exist for such problems. There are a large number of problem areas where different solution approaches are required. A set of problem areas shall be selected from the relevant cases. Issues to be addressed are:

- Classify optimization problems
- Non-convex problems
- Large Scale problems
- Search algorithms tailored to the properties of the underlying cases
- Use of Real Time Optimization based on steady state models in a time-varying dynamic plant
- Analysis of requirements to the underlying process computations
- Updating process constraints and other parameters from measurement data

5.2.3 Plantwide Control

Explore the issues related to control structure design and structuring of the process control hierarchy in the perspective of market focus on process operation.

5.3 System integration of a demonstrator system

A versatile decision support tool will consist of a several complex functional modules. The integration of simulators, optimizing functions, real time data, planning input data, economic data etc. requires that system integration issues must not be underestimated. Thus, the selection of methods/standards for communication interface, computing platforms, system architecture and other system development issues are vital for realization of an integrated system. Interface to commercial packages both for optimization and simulation.

Phases:

1. Requirement specifications
2. System functional analysis
3. System architecture
4. Interface specifications
5. Production
6. Demonstrator testing

5.4 Adaptation and testing on relevant cases

5.4.1 Case: Natural gas processing plant optimization

A typical area of use would be decision support tools for the plantwide optimization of a processing plant like the Kårstø gas processing facility:

- Optimization of export gas specification: For example, to meet delivery contract requirements as well as possible, under the circumstances of limited feed-streams or technical problems within the plant

- Capacity assessment: Optimization of available capacity for a given set of conditions. Examples of this function include:
- Optimization based on constraints on gas specification, liquids production or feed-streams
- Optimization based on constraints on individual components within the plant
- Optimization based on shutdown of equipment items or trains
- Maximization of liquids recovery: For example, to take advantage of a short-term increase in specific product prices.
- Optimization of liquids specification: For example, during reduced effectiveness of a related piece of equipment
- Minimization of energy use: For example, due to limited steam generation capacity
- Minimization of emissions (or financial impact)
- Minimization of operating cost.

Gassco, who is the operator at Kårstø, is probably going to start a project in this area during 2004 and this project fits together. A supporting letter from Gassco is enclosed with this proposal.

5.4.2 LNG

The Snøhvit LNG plant is a very interesting case. It is of great importance to study the operation of this plant in view of dynamic markets. Process modeling and market modeling are uncertain and selection of optimal operational parameters and storage utilization in presence of this uncertainty is challenging. The interfaces to the transportation systems on the supply and product sides are also important.

5.4.3 Other areas

- Offshore processing
- CO2 handling
- Other types of process industry

As the second case is scheduled to be selected in 2006, detailed specification can be made with better information during the work with case 1.

5.5 PhD subjects

Several issues are also suited for PhD studies and three particular areas are outlined below.

There are needs for better understanding and new methodology in modeling for optimization purposes. The properties of the model will influence the nature of the optimization problem, and it is important to understand how model properties fit together with optimization solving techniques. The numerical properties and solution times are strongly affected and it is important to develop good methods that can make more efficient solutions. For example, the tradeoff between the level of accuracy of a model with respect to the accuracy of the final solution, representation of physical limitations in the model, or as constraint equations, etc.

Plantwide Control with market focus on process control. Vertical integration between business systems, planning systems and process control systems sets new requirements to how the process control best should be configured.

Operational analysis and study of the optimization problems that will appear in the context of market focus on process control

Allocation of PhD subjects shall be coordinated with the NTNU partners and the other ongoing activities within the Gas Technology Centre.

5.6 Dissemination and exploitation

The results form the basic methodology studies through the Ph.D studies will be published at conferences and appropriate scientific journals.

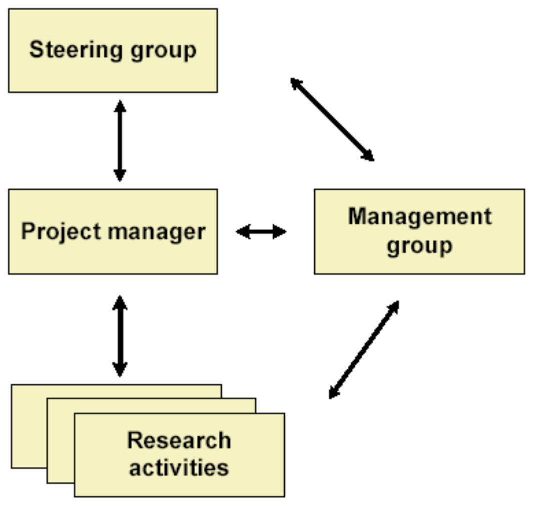
SINTEF is in an ideal position to distribute results to industry. Gassco, Statoil and Norsk Hydro are the main end users in Norway. SINTEF also carry out development projects for system industry. Relevant companies are Kongsberg Simrad, Cybernetica, Predictor, FMC.

6. Project organization

6.1 Organization of the project

The project contractual partner is SINTEF ICT. The Project Manager is Senior Scientist Ivar J. Halvorsen Dr.ing.

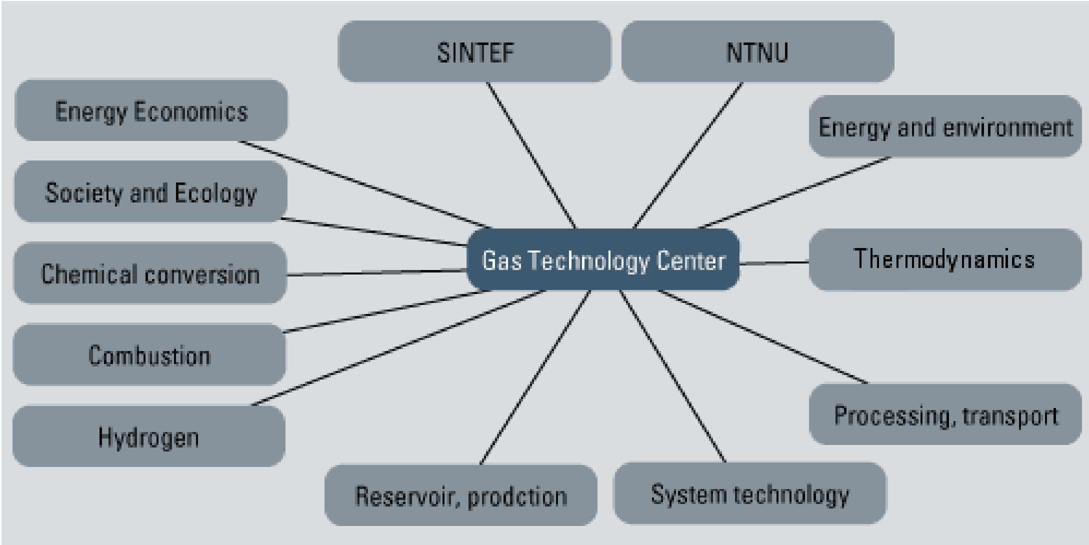
We will establish a steering group. This group will be appointed by the board of The Gas Technology centre and will consist of 1-2 representatives from each of NTNU and SINTEF and also from one of the industrial companies that supply case data (Gassco or Statoil).



For each of the research activities we will establish a work group and an activity leader responsible for the deliverables of the activity. The activity leaders are responsible for the daily operation of the activities, the operational management of these and their budget. Work groups will consist of NTNU professors, SINTEF researchers, PhD students and industry people (when the industry finds it adequate). This kind of co-operation is challenging and we will therefore establish a management group consisting of the project manager, the activity leaders and senior persons from SINTEF and NTNU, representing different disciplines. The main purpose of this group is to co-ordinate the activities among all the partners in the project and to make operational decisions for the project guided by the priorities of the steering group. The project manager is responsible for the overall project budget, the deliverables of the project and the co-ordination of the research activities. He reports to the steering group and leads the management group.

6.2 Partners and roles

The partners in this project already cooperate within the Gas Technology Centre at NTNU-SINTEF. (See web page at http://www.ntnu.no/gass/).



SINTEF	NTNU
Industrial Management	Industrial Economics and Technology Management
ICT, Applied Cybernetics, Applied Mathematics	Engineering Cybernetics
Energy Research	Chemical Engineering

SINTEF
SINTEF Industrial management (IM): Has competence in optimization, mathematical modeling and energy markets. Previous experience within optimization models for the natural gas value chain includes:

- VENOGA: NFR project finishing in 2004. Modeling the value chain for natural gas including production, transportation, processing and contract management (in cooperation with Statoil and NTNU).
- GassOptTKL: industrial project in co-operation with Statoil and Gassco modeling transport optimization using steady-state models (ongoing since 1997).
- Omega: EU-project finished in 2000. Supply chain optimization models for European energy companies (NTNU, Iberdrola and Enel main partners).
- SARA: Optimization tool for portfolio investment analysis. Developed together with NTNU in the 80's for Norwegian petroleum Directorate and several oil companies. Statoil is still using a modified version.

Key personnel: Senior scientist dr. ing. Asgeir Tomasgard, Senior Scientist Frode Rømo, Dr. Matthias Nowak.

SINTEF Energy research (SEfAS): Has competence in modeling energy processes and knowledge of new technology development. Related projects are:

- NFR project finished in Dec. 2003. Ship based transport of CO_2.
- CCP: NFR project finished in Dec. 2003. CO_2 conditioning and transportation (In cooperation with industrial partner)

- NFR project started in 2003 (going for 4 years) Next generation LNG heat exchangers
- Industry project finished in 2003, LNG technology status
- ACMAR, NFR-project ended in 2003. Multiphase flow modeling
- Coil, Modeling of spiral wound heat exchangers (in cooperation with industrial partner)
- Mini-LNG, Development of small scale LNG production technology
- General development of in-house tools for dynamic pipeline transport, including thermodynamic properties for CO2 and hydrocarbon mixtures, within various industrial projects

Key personnel: Dr.ing. Maria Barrio, Dr.ing Hanne Kvamsdal

SINTEF Information and communication technology (ICT):
Applied Cybernetics (Former department Automatic Control). Process control and system integration.

- Intelligent wells (SINTEF Strategic Institute Project) focused on some related issues concerning enhanced oil and production based on active use of models and control technology. (11)
- CORD – Optimal operation of offshore plants.2002-4 (10). Joint project betweek SINTEF, MARINTEK and IFE.
- REPP – "Reaktorteknologi i petrokjemi- og plastindustrien". Development of nonlinear modle based control for polymer reactors.
- Kybernetisk Lab- REPP-Kyb-lab is the base for the establishment of Cybernetica AS. (www.cybernetica.no)
- HOPE – Heidrun Operational Experience. Development of a training simulator and procedure handling system for Heidrun (92-95)
- MIP – Methodology program In the Process industry (88-92). Development of methodology within process control and instrumentation. Basis for Statoils inhouse MPC technology
- CADAS – Computer Aided Design Analysis and Simulations – (88-92) Life Cycle process simulator development. The design is now adopted in ASSETT from Kongsberg Simrad.

Key personnel: Senior scientist,
Dr.ing. Ivar Halvorsen, Dr ing Ingrid Schølberg, M.Sc Mary Ann Lundteigen

Applied Mathematics: Contribution in optimization methodology

Key personnel: Research Manager Trond Kvamsdal

The Norwegian University of science and technology (NTNU)

The main roles of the NTNU departments listed here will be in PhD student supervision and advising SINTEF.

NTNU Department of Industrial economics and technology management (IE): Has competence in energy economics and optimization, and is co-operating with SINTEF and advise SINTEF in the same areas. PhD student in optimization.
Key personnel: Associate professor Asgeir Tomasgard

NTNU Department of engineering cybernetics (EC): This department will advise SINTEF in the same areas. Will supervise PhD students in Modeling for optimisation and will advise SINTEF in the modeling.
Key personnel: Professor Bjarne Foss, Professor Morten Hovd

NTNU Department of chemical engineering (EP): Will supervise PhD students in Plantwide control and will advise SINTEF in this field.
Key personnel: Professor Sigurd Skogestad

7. Progress plan – Milestones

Kickoff	January 2005
Methodology	
Definition document for Methodology studies	June 2005
Recruitment of PhD* students	June 2005
Methodology studies (PhD basic research, SINTEF application)	June 2005-June 2008
Scientific articles	Each 6 months
Demonstrator	
Demonstrator requirement document	October 2005
Demonstrator system analysis document	April 2006
Demonstrator interface specification	June 2006
Demonstrator productionand testing	November 2006
Updated interface standard/library	November 2007
Case	
Selection of Case 1	August 2005
Demonstrator on Case 1	April 2007
Selection of Case 2	November 2006
Demonstrator on Case 2	December 2007
Dissemination	
Adoption of new results from the methodology Within the demonstrator	June 2008
Tutorial paper	January 2008

*PhD studies June 2005 – June 2008

8. Strategic relevance for NTNU-SINTEF

Joining forces in gas technology research is one of the backgrounds for establishment of the Gas Technology Centre at NTNU/SINTEF. Thus, this project fits right into that strategy. Some of the issues are also generic and demanded for other types of process industry than natural gas processing.

Note that this initiative shall not replace detailed research within each discipline. Such research is required for maintaining the deep knowledge within each discipline that is the base for contribution to a common system.

This project shall enhance SINTEFs position as provider of technology both directly to the operators of the gas production, processing and transportation systems and to vendors and engineering companies that deliver products and services to the industry.

Only in Norway, there are great challenges in optimal design and operation of gas processing plants e.g. at Kårstø, Kollsnes, Averøya and Melkeøya. Recent newspaper articles about some of these projects exceeding their budgets call for improvements in engineering and planning.

SINTEF, being an independent research foundation can play an active role in reducing the uncertainties related to new technology in gas processing plants, and thereby improve both design and operations. Both vendors and operators can benefit from this, and just by the size of the processing plants, optimal operation and design is also of National importance.

Thus, it is of strategic important that SINTEF develops and maintains knowledge, methodology and tools. Both within each discipline and in the wider process system technology context. The gas technology centre at NTNU/SINTEF is well suited to accumulate promising results from several basic programs and to make this technology available to the industry in form of system development projects, process studies and system evaluations etc.

9. Relation to other programs and projects at NTNU-SINTEF

This project proposal fits into a suite of projects aimed at added value in the production, processing and transportation of natural gas within the Gas Technology centre at NTNU/SINTEF.

This project shall bring together knowledge from different disciplines within SINTEF and NTNU in order to solve problems where the combined knowledge is required.

It is closely related to the NTNU proposal (SFP Forskerprosjekt): *Model Based Decision–Making for Large Scale systems*, and the SINTEF/NTNU/GASSCO proposal (KMB) *GasTrans-Optimization of natural gas transportation systems* (submitted to NFR June 2004). The NTNU proposal focuses on the fundamental issues for several parts of this quite wide problem area. The NTNU researchers typically consist of Ph.D students and their supervisors and some post-docs and will normally address basic research issues and methodology.

This SINTEF project shall focus on combining existing knowledge and new results from the basic research at NTNU in order to provide solutions and tools for actual problems as found in the natural gas production chain. Some of the Ph.D subjects are defined to fit into this context.

We expect two-way interaction between SINTEF and NTNU researchers that gives a potential for better overall results than each of the programs can provide separately.

GasTrans focuses on transportation. It is expected that some of the problem areas and methodology developed in GasTrans also will be relevant in gas processing too. The interface between transportation and processing systems is of particular interest.

In addition to the NFR proposals the EU-proposal PROMATCH (Promoting and structuring Multidisciplinary Academic - industrial collaboration in research & Training through SME teCHnology developers) are also closely related to these issues. NTNU and Cybernetica are the Norwegian partners. It is a Marie Curie project.

In sum, the partners in Gas Technology Centre will be better prepared to supply the natural gas industry with vital required new technology.

The NTNU and SINTEF departments have cooperated on several programs in the past. PROST, PETRONICS, REPP, MIP are just a few examples (see web links below).

10.References

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3 Ø. Moen; Machine Means for Design, Control and Economic Optimisation of Polyolefine Production Processes and their Products. Keynote at Escape-14 May 16-19, 2004, Lisbon, Portugal

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5 Rømo, F., Tomasgard, A.., Røvang, L.B. and Pedersen, B. (2003), Optimal routing of natural gas in pipeline networks, SINTEF Report, SINTEF Industrial Management, Trondheim, Norway.

6 Bjørnar Lund, Øyvind Kolnes, Finn A. Michelsen, Ivar J. Halvorsen, Fridtjof Nyhavn. A New Planning Tool for Smart Fields Evaluation, SPE 84223 ATCE 2003.

Web links:

7 The Gas Technology Centre at NTNU-SINTEF: http://www.ntnu.no/gass/

8 SINTEF: http://www.sintef.no

9 NTNU: http://www.ntnu.no

10 CORD : http://prosjekt.marintek.sintef.no/cord/

11 Intelligent wells: http://www.iku.sintef.no/sips/intwell/

12 Petronics: http://www.petronics.ntnu.no/

13 PROST: http://www.chemeng.ntnu.no/research/PROST/

14 REPP: http://program.forskningsradet.no/prosbio/prosjekter/prosmat_reaktorteknologi.pdf