Project Deliverable

Project Number:	Project Acronym:	Project Title:
604068	MORE	Real-time Monitoring and Optimization of Resource Efficiency in Integrated Processing Plants

Instrument:	Thematic Priority
COLLABORATIVE PROJECT	NMP

Title
D6.11 Public Synthesis

Due Date:	Actual Submission Date:
Month 40 (February 2017)	March 24th, 2017

Start date of project:	Duration:
November 1st, 2013	40 months

Organisation name of lead contractor for this deliverable:	Document version:
inno	1.0

Dissemination level (Project co-funded by the European Commission within the Seventh Framework Programme)		
PU	**Public**	**x**
PP	Restricted to other programme participants (including the Commission)	
RE	Restricted to a group defined by the consortium (including the Commission)	
CO	Confidential, only for members of the consortium (including the Commission)	

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 604068.

Abstract:
This report summarises the activities and the results of the MORE project. This includes the technical development of methods and tools for real-time resource efficiency monitoring and decision support for managers and operators and their prototypical implementation in four industrial applications, and the assessment of their impact. In addition, exploitation, standardisation and outreach activities of the project are presented.

Authors (organisations): Eva Fadil, Svetlana Klessova, inno TSD

Revised and validated by: Sebastian Engell, TUDO

Keywords:

Resource Efficiency Indicators, industrial cases, exploitation, standardisation, dissemination, impact assessment

Disclaimer

Table of Contents

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 604068.

1. Introduction

MORE, a 40-month STREP project, was supported by the European Commission under the 7th Framework Programme in the field of 'Nanosciences, Nanotechnologies, Materials and new Production Technologies' (NMP). It aimed at identifying real-time **resource efficiency indicators** (REIs) that can **support operational decisions** in **process industries by visualisation of the indicators, computer-based decision support, and** control and real-time optimization.

In recent years, indicators for the environmental impact of products and production processes have been developed and are increasingly used by companies in the process industries in the communication with the public. Indicators have also been established and used in the internal evaluation process of alternative production processes and for the decision on investments into new production facilities or revamp measures.

In the MORE project, we significantly extended the definition and the use of such indicators by

- Defining real-time resource efficiency indicators that can be efficiently used in daily operations and are computed based upon the processing of real-time data that is available in the monitoring and control systems and from innovative analytical measurements
- Taking the step from monitoring to improving resource efficiency by providing model-based real-time decision support to plant operators and plant managers.

The MORE project dealt with resource efficiency as a multidimensional attribute with several indicators that measure different aspects of resource efficiency.

MORE was focused on large integrated chemical and petrochemical plants with many interconnected units. The real-time resource efficiency indicators and decision support tools were developed exemplarily for this domain and tested through the implementation in four industry use cases. Besides, impact of these applications was assessed and guidance was provided for the implementation of similar approaches in other companies and industries.

Public project documents have been published on the project web site www.more-nmp.eu . This summary provides a brief overview on the project results.

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 604068.

2. Main project activities and outcomes

2.1. Objectives and context

The goal of the MORE project was to provide Real-time Resource Efficiency Indicators (REI) to support operator and management decisions, leading to resource efficient operation of chemical processes. Main achievements of MORE are the identification of adequate REI that are transferable to diverse process industries, the development of decision making tools and real-time optimization and control solutions, and their implementation in four industrial applications.

The case studies that were considered in the MORE project cover a significant part of the value chain of the chemical industry: a refinery (Petronor, Spain), a petrochemical site (INEOS in Köln, Germany), a global supplier of specialty chemical products and nutritional ingredients based on renewable raw materials (BASF PCN, Germany) and a plant producing viscose fibers (Lenzing AG, Austria).

Raw materials of the companies providing the case studies are both fossil and renewable feedstock. The processes in place were equipped with standard measurements that can be used for the calculation of REI. In two of the case studies the flows of interest contained many chemical species so that the use of advanced online analytics to calculate the REI and to optimise the processes based on these additional measurements was investigated.

The MORE project team prototypically realized solutions for improving resource efficiency in the four cases and r demonstrated a large potential for the use and the exploitation of REI and real-time optimisation. In all cases the support of the plant personnel was gained. An analysis of the potential for generalization of the results to the process industries beyond the cases was performed and significant possible gains were quantified.

2.2. Methods and tools developed by MORE

The activities of MORE started with the development of general principles and methodologies for the definition and the evaluation of process specific resource efficiency indicators. A comprehensive study of real-time resource efficiency indicators for batch processes and mixed continuous-batch processes was performed. A list of generic indicators was developed for batch and continuously operated plants and specific indicators were chosen for the four industrial cases. A concept and algorithms for the aggregation of REI from the unit level to the site level and for the analysis of the contributions of the individual elements to the overall indicators was developed.

Current real-time measurements were assessed against the input structure of the REI calculations. Where required, additional process analytical techniques for complex process streams were developed. Additionally, data reconciliation methods with new robust estimation techniques were developed and applied. The MORE project developed a general visualisation concept for multi-dimensional resource efficiency indicators to support operators and plan managers. A neutral deployment platform for REI computation, visualisation and decision support was specified and realised. It consists of three functional components (topology editor,

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 604068.

calculation engine, HMI development studio) and interfaces to legacy systems. Prototypes of the deployment platform were installed at two plants and REI Dashboards were developed for the implementation of the MORE visualisation concept in the industrial case studies.

For the decision support, a What-If Analysis tool with simulation capability and a tool for multicriterial optimization of REI were developed and tested on industrial cases. Operating policies were optimised based on experimental data, process understanding and rigorous mathematical models. In two processes, new control solutions and operator support based on real-time optimization were developed.

After the definition of real-time resource efficiency indicators and their demonstration in the industrial sites, the project launched an impact assessment. All four industrial cases were analysed in a "before-after analysis" – prior to and after the implementation of the MORE developments in the industrial processes. The purpose was to evaluate the economic, environmental and managerial impact of using the real-time REI and the visualisation and decision support tools for the four MORE case studies. A generalisation analysis undertaken by MORE on the basis of the results for the industrial case studies estimated the potential impact of the broad application of the MORE approach in the European process industries. MORE presented its results at a Workshop on Resource Efficiency Monitoring, Assessment and Optimization, organised by A.SPIRE in January 2016, and in April 2016 in an Impact Workshop, organised by the European Commission and A.SPIRE. The project concluded in a final workshop at DECHEMA, Frankfurt in February 2017 with a strong external industrial participation.

2.3. Summary of the activities in the application cases

2.3.1. Petronor - Demonstration of MORE tools in a refinery

Refineries are at the beginning of the value chain and they use fossil feedstock. Typically, in refineries many standard measurements are already available and can be used for REI calculations and visualisation but data reconciliation may be required. Due to the large throughput of refineries, the improvement of the efficiencies of the processes even by relatively small amounts has a large economic and ecological impact. In the Petronor case study, the MORE partners analysed and optimised the efficiency of the distribution and the use of hydrogen as a raw material in an oil refinery.

Petronor achieved the following results:

- A long-term stable solution for resource efficiency monitoring and operator guidance for individual units and overall sites using data reconciliation and REIs.
- The implementation of efficient modes of operation in closed-loop control solutions employing the MPC technology.
- A decision support system that uses the computed REIs and generates recommendations to operate at better operating points using model based optimization.
- A roll out across the site integrating these functionalities into the refinery information system (PI).

The system that was implemented in the refinery during the MORE project provides a clear improvement in the efficiency of the use of hydrogen and represents a significant step forward to further integration with other advanced systems in the refinery and enhancements of their functionality.

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 604068.

2.3.2. INEOS - Demonstration of MORE tools in an integrated petrochemical plant

The next step in the value chain of the oil and gas-based production of chemicals are integrated petrochemical sites, the core of which are naphtha or gas crackers. INEOS in Köln operates such a typical integrated petrochemical complex. The Köln petrochemical site is based on naphtha as the main raw material. Standard measurements are in place throughout the plant but a real-time measurement of the properties of the raw material naphtha that consists of a large number of components and has a different composition depending on the source is not available.

INEOS in Köln developed an integrated REI aggregation and reporting framework for the whole site and REI calculations and visualisations for a number of production plants that show the potential for further improvements. Steps were made towards an optimal operation of the crackers based on a new online naphtha composition measurement that was developed in the MORE project. Additionally, a tool that supports optimal cooling tower operation and visualises the trade-off between optimal cooling tower operation and optimal operation of the "customer plants" of the cooling towers was installed.

For the petrochemical process, a composition analyser based on Raman spectroscopy was developed, predicting the substance classes and individual key components of the naphtha feed in excellent accuracy. From the complex training task of the prediction method for the hydrocarbon mix, a workflow and software tool for efficient calibration development was derived and will be finalised for commercial exploitation by a MORE partner.

INEOS achieved the following results:

- Theoretical foundation and prototype of a site-wide REI calculation, aggregation and evaluation scheme
- Implementation of REI calculations, visualisation dashboards and REI aggregation and contribution analysis for selected plants and for the site
- Initial implementation of past and live reporting using MORE REIs and MORE principles in the integrated deployment platform as decision support tool
- Prototypical implementation of cooling tower optimisation and multiobjective optimisation of the cooling tower and butadiene plant operation in a decision support tool
- Online naphtha analysis and cracker data reconciliation and optimization as a proof of concept – decision on full implementation expected in 2017.

2.3.3. Lenzing - Demonstration of MORE tools in a cellulose plant

Lenzing operates a world-wide reference factory for producing man-made cellulose fibres using both renewable sources (wood) and fossil resources (chemicals, natural gas). Lenzing optimized the specific steam consumption together with the overall cycle cost of the evaporator system for the spin baths. Optimal control schemes and a model-based decision support system for the choice of the evaporators and their loads have been implemented.

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 604068.

Lenzing achieved the following results:

- Development and implementation of a new evaporator control scheme in the Lenzing Decision Control System (DCS) generating 2,5 % savings in evaporator steam consumption, equivalent to around 1.0 Mio Nm³ natural gas per year
- Development and implementation of a new cooling tower control in the Lenzing DCS generating 0,5 % savings in evaporator steam consumption equivalent to around 0.25 Mio Nm³ natural gas per year
- Development and prototypical implementation of a decision support system for the evaporator selection and load allocation supporting the operators to achieve the most energy efficient load allocation
- Ongoing development of an optimisation tool to improve the evaporator cleaning cycles and prototypical decision support system for an optimal scheduling of cleaning

2.3.4. BASF - Demonstration of MORE tools in an integrated plant based on renewable feedstock

The BASF case is an example of a plant that consists of batch and continuous operations. Its feedstock is based on natural and renewable raw materials and advanced online-analytics were developed for this case. A UV-VIS spectroscopic quality measurement was successfully designed and is planned to be implemented in the plant as a substitute for manual sampling and analysis

BASF achieved these results:

- REI for the reaction, purification and post-processing steps were defined
- Real-time monitoring of REI for the purification and the post-processing steps were realized and indicate the actual efficiency of the process
- A prototype implementation of the REI dashboard for the BASF process was realized and displays the REI for the purification and the post-processing steps
- Implementation of a new PAT measurement of the product quality after the post-processing step in real-time
- Evaluation of the potential for further improvements of the process efficiency based upon new PAT measurements are in progress

2.3.5. Summary of the results of the four case studies

Overall, the results show very successful implementations of the MORE technologies in the case studies. Two partners, Petronor and Lenzing implemented control solutions that are in daily use and have a direct impact on the performance of the plant. Further, model-based decision support tools have been developed for these two cases and are in use (Petronor) or under field test (Lenzing). The technologies can be applied to other companies that operate the same type of plants. The two other partners, INEOS and BASF, installed prototypes of the MORE technology on a scale that matches the size of the case study. INEOS is committed

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 604068.

to follow through with the full installation of the MORE technology for REI visualisation, real-time reporting and decision support.

Overall, all technologies that were developed in MORE have been successfully applied in at least one of the industrial case studies and the implementation of the tools and methods is ongoing with high expectations and a strong commitment of the industrial partners. The SME partner Leikon has productized the MORE implementation platform and is involved in further projects that are part of the implementation and roll-out of the MORE technologies at INEOS. As far as possible for confidentiality reasons, the results of the industrial case studies have been published in scientific papers and are included in an upcoming book on "Resource Efficiency of Processing Plants -- Monitoring and Improvement" which is edited by leading members of the MORE consortium and which will be published by Wiley-VCH in 2017 [KE17].

2.4. Exploitation and standardisation of MORE results

The results of the project MORE are **exploitable** on different levels: scientifically, commercially and also pre-commercially. Therefore, an exploitation plan was initiated which included strategies to exploit the project results of MORE on the international market as well as a process on how to improve and follow-up the plan periodically during the project lifetime of the MORE project. The exploitation plan was specified for the consortium as a whole and for each partner individually. The exploitation activities were closely coupled with the MORE communication strategy and communication tools as well with the standardisation activities, Industrial Stakeholder Panel activities and the impact assessment.

All MORE project work was oriented towards industrial applications. Consequently, industrial exploitation of the MORE results assumed a major role in the exploitation strategy. All end users plan to use the tools developed in MORE in order to enable a resource efficient and an environmentally friendly production. Project results are further developed and rolled out to other technologies and production sites. The tool providers exploit their MORE results for new business strategies based on licence fees as well as on consulting and engineering services.

The **standardisation activities** of MORE project consisted of a comprehensive review of the relevant existing standards, an active dialogue with some key players in the field at national and international levels, and a concrete way forward with NAMUR. The definitions of REI, as well as the methodology to identify and to realise REI applications were identified as main issues worth to standardise. The relevance of these topics in relation to the aspects of ongoing ISO and IEC standardisation activities was agreed among standardisation experts. It was agreed with the NAMUR managing board to build a new NAMUR ad hoc standardization group "Resource Efficiency Indicators". A NAMUR recommendation describing the state-of-the-art and best demonstrated available technologies is planned for 2017. This will serve as an input for further national and international standardisation activities. Additionally, the German DIN DKE K931 agreed to support a new work item proposal for an international standard in terms of an IEC Technical Report (IEC TR) based on the NAMUR recommendation.

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 604068.

2.5. MORE awareness raising and transfer of results

In parallel to the implementation of new developments and tools into the case studies, a methodological framework to investigate the transferability of technical developments to other industries was developed. More specifically, the transferability of the resource efficiency indicators to different sectors with similar production systems was investigated, e.g. the sugar production and the pulp and paper industry.

Based on the experience gained, a **guidebook** for defining resource efficiency indicators that can measure the effect of technical improvements and of operational policies and derive actions for real-time or near real-time plant performance improvements was prepared. A clear step-by-step procedure was designed that includes twelve steps for selecting and defining the process units for consideration, identifying and selecting REI, and implementing and evaluating them. The guidebook provides a technical introduction to the methods that should be used and a detailed step-by-step procedure that can be followed to successfully implement the core ideas of real-time resource efficiency monitoring and improvement.

In general, the technical developments in MORE were accompanied by targeted dissemination activities and engagement with relevant stakeholders. A number of scientific publications and presentations at international conferences resulted from the project. An **Industrial Stakeholder Panel** (ISP) with experts from several sectors of the EU process industries was created as a consulting body to provide feedback on and suggestions for the technical work and to discuss how MORE project outcomes can serve other industrial sectors as well. The ISP members gathered at several workshops and were consulted on an ad-hoc basis. At the **Final Event**, “Real-time Monitoring and Optimization of Resource Efficiency – From Measurements to Optimal Operation”, held on 15-16 February 2017 at DECHEMA in Frankfurt, Germany, the MORE project presented its results and discussed with a large audience of experts from the process industries. The workshop was concluded by a panel discussion on the opportunities and challenges for the roll-out of the MORE results to the process industries. All industrial representatives on the panel rated the MORE results as highly relevant and applicable to their companies and sectors.

This project has received funding from the European Union’s Seventh Framework Programme for research, technological development and demonstration under grant agreement no 604068.

3. Conclusion

MORE has built upon existing processes and brought the use of resource efficiency indicators to a new level, integrating the real-time or close to real-time aspect into the development and implementing decision making and visualisation tools that allow for direct adjustments in daily operations instead of evaluation in the aftermath.

Results of MORE have been discussed and analysed by diverse stakeholders and MORE has been considered a success case by the European Commission.

Indeed, *MORE contributes to the European 20-20-20 Targets:*

European policy makers introduced goals for the year 2020 in a number of different sectors. In the energy sector the 2020 goals were based on the three pillars leading European energy policy: Security of supply, competitive markets and sustainability.

The 2020 energy goals seek having a 20% (or even 30%) reduction in CO2 emissions compared to 1990 levels, 20% of the energy, on the basis of consumption, coming from renewables and a 20% increase in energy efficiency.

A newly funded project, CoPro – Improved energy and resource efficiency by better coordination of production in the process industries – is now building on the achievements to widen the implementation of results, thus contributing to even higher impact. A number of MORE partners contribute to the implementation of this SPIRE project.

For further details:

www.more-nmp.eu

Project Management Team:

Svetlana Klessova, MORE Project Coordinator – inno TSD, France
Prof. Sebastian Engell, MORE Scientific Leader – Technische Universität Dortmund, Germany
Dr.-Ing. Stefan Krämer, MORE Industrial Application Coordinator – INEOS in Köln, Germany

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 604068.