Industrial Energy-Related Technologies and Systems
An Implementing Agreement established under the auspices of the International Energy Agency

IEA Expert Workshop in Berlin on April 4 – 5, 2017:

REPORT: THE ROLE OF PROCESS INTEGRATION FOR GREENHOUSE GAS MITIGATION IN INDUSTRY

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INTRODUCTION

Due to the urgent need for global GHG mitigation, process integration in industry will most probably play an even more important role than traditionally in the areas of industrial GHG mitigation, energy efficiency, industrial clustering and system aspects of innovative technologies. In order to increase the awareness of new developments in this key methodology, a two-day IEA workshop was arranged in Berlin, April 4-5, 2017, with attendance of the majority of the world's leading experts in this area.

This report summarizes the presentations and discussions in and the conclusions from this workshop. It highlights new developments in different types of industry, novel applications and the role of process integration in GHG mitigation and strategic decision-making in industry. It consists of a short description of process integration, a report on main findings and conclusions, and, linked, abstract and slides from all presentations. An Executive Summary is also available.

BACKGROUND AND AIMS

Process integration became a concept in the scientific literature and in industry R&D in the late 70's.

Its ability to identify more economic and sustainable system solutions than traditionally has made it an important tool globally in both research communities and in industry.

The first international workshop on process integration was held in Gothenburg 1992, organized partly by IEA. That led to a workshop in Berlin 1993 on opportunities for further international cooperation in this area. A suggestion for a new IEA implementing agreement was developed there and the implementing agreement started 1995. A second international process integration conference was held in Copenhagen 1999.

The implementing agreement was merged with the pulp &paper and separation systems (planned) ones into the IETS (Industrial Energy-Related Technologies and Systems) implementing agreement in 2005. In IETS one annex on process integration in the iron and steel industry has been performed.

In order to intensify and broaden activities in process integration in IETS, an International Process Integration Jubilee Conference was organized in Gothenburg in 2013.

This conference was followed up with the Berlin workshop 2017, reported here.

The main aims were:

- To give an overview of recent developments.
- To present success stories.
- To show how PI could be used to identify new future technical and system solutions.

- To discuss the role of PI for industrial GHG mitigation.

WHAT IS PROCESS INTEGRATION?

Process integration (PI) deals with system and interaction aspects of industrial technologies as well as process and energy streams for identifying more energy efficient and economically and environmentally more sustainable industrial systems.

There are several definitions of PI. The one developed in the former IEA Process Integration Implementing Agreement, and later used in IEA, IETS, is:

"Systematic and General Methods for Designing Integrated Production Systems, ranging from Individual Processes to Total Sites, with special emphasis on the Efficient Use of Energy and reducing Environmental Effects".

Process integration was developed as a scientific area in the late 70'. Since then, process integration has evolved from a heat recovery methodology in the 80's to become a major strategic design and planning technology. With this technology, it is possible to significantly reduce the operating cost and environmental impact of existing plants, while new processes and systems often can be designed with reductions in investment cost, operating cost, energy consumption and harmful emissions.The scope and emphasis of process integration has changed over the years. It is now also connected to the design, optimization, operational optimization and control of industrial processes

In this report, the breadth of this area and new developments are presented.

For more information about process integration, the reader is referred to e. g.:

Chen, Q. and I.E. Grossmann, "Recent Developments and Challenges in Optimization-based Process Synthesis," Annual Review of Chemical and Biomolecular Engineering, 8, 249-283 (2017).

El-Halwagi, M., "Sustainable Design Through Process Integration," Butterworth-Heinemann, Oxford (2012).

Linnhoff, B., "A User Guide on Process Integration for the Efficient Use of Energy," Institution of Chemica Engineers (1994).

Lutze P, Gani R,Woodley JM. "Process intensification: a perspective on process synthesis." Chem. Eng. Process. Process Intensif. 4, 547–58 (2010)

Smith, R., "Chemical Process Design and Integration," 2nd edition, Wiley (2016).

ORGANIZATION AND PROGRAMME OF THE WORKSHOP

A small organizing committee was appointed, consisting of:

Professor Robin Smith, University of Manchester

Professor Jeff Siirola, Carnegie Mellon and Purdue Universities
Professor Truls Gundersen, NTNU
Professor Thore Berntsson, Chalmers University (chair)

Around 20 internationally high level experts were identified and invited, of which the majority were able to attend. In addition, country experts, IETS delegates and IEA representatives participated, see list of participants in the Appendix. The total number of participants were around 30.

For programme, with sessions and presentations, see Appendix.

PRESENTATIONS

In this section, all presentations are summarized briefly. For more detailed information about the contents of the presentations, please visit the IETS website:

http://www.iea-industry.org/activities/105-iea-iets-pi-ws.html

THE ROLE OF PI IN IEA

Main PI activities within the IEA are presented above.

Gudrun Maass identified the workshop as very timely. In the IEA, there is now a strong emphasis on identifying gaps, barriers, opportunities and possible potentials for energy efficiency and GHG mitigation in different sectors. The industry has been identified as a key sector that needs more attention than it has received previously.

Kira West presented the IEA secretariat work on large-scale modelling of industry as a whole globally and of different sectors. In order to reach 2C or even well below 2C, a drastic change and many combinations of industrial technologies and systems will be required. She concluded that PI is difficult to include in large-scale modelling due to regional differences, access to data (including confidentiality) and e. g. temperature levels for different processes. However, some examples of use were given, e. g. for excess heat and integrated pulp and paper mills where some data are available. She looked forward to more knowledge and inputs from the experts.

NEED FOR GHG MITIGATION IN INDUSTRY

Thore Berntsson showed, based on knowledge from e. g. IEA and UN, IPCC, that there is an urgent need for drastic reductions of GHG emissions globally. Within 25 years or probably less, the world must reach zero net emissions. This means an enormous challenge also for the industrial sector. Some different scenarios were shown, in which all available low-emission technologies and systems must be combined. There is, however, uncertainty to what extent PI has been included in that modelling.

RECENT USE IN PROCESS INDUSTRY

Robin Smith gave an overview of the ongoing development in the oil refinery industry. There has been a huge development of methods and applications for system optimization using PI. However, most real applications are in retrofitting and most methods are for grass-root systems. There is still a need for new development of methods for retrofit situations. The big potential for energy recovery by combining heat exchanger networks and process models was exemplified by case studies.

Les Bolton discussed PI opportunities in the petrochemical industries. He concluded that the chemical and petrochemical industries contain a very diverse range of different processes. There are many mature and well-integrated technologies, but opportunities still exist for technology vendors and operators to make improvements in energy efficiency by process integration. In addition, very large exergy losses remain, requiring different technological breakthroughs, as well as process integration analysis, to address. Chemical and petrochemical processes will continue to be very large producers of lower grade heat. Applying conventional heat integration approaches (e.g. heat exchanger sequencing) will achieve only marginal energy consumption (and hence GHG emission) reductions. More radical reductions are likely only to be achieved by applying more radical approaches, such as large-scale waste heat recovery: these have not yet been widely applied because the financial returns on investing in them have been too low.

Philippe Navarri presented the Canadian experience of using PI in the pulp and paper industry. He pointed out the close connection between energy and water systems in this type of industry. A large number of case studies have been performed (84), which have resulted in many lessons learned. 10-20 % reductions of steam and water usage are possible. PI for strategic long-term decisions is important as well as developing more knowledge about data mining and evaluation for better energy efficiency.

Lawrence Hooey presented opportunities in the iron and steel industry, based partly on the IETS Annex 14 work. He concluded that PI is essential in understanding design and operational aspects both of energy and overall resource efficiency. A broadening of integration from metallurgical operations together with chemical and energy engineering in finding optimum CCU or alternate steel production paths will be vital for drastic reductions in CO2. Although there are several good examples from industrial applications, there is still a lack, or insufficient reporting, of success stories. Hence, a lack of awareness of the benefits results in low probability to launch PI projects. This is important in order to overcome the hurdles of acceptance and understanding the potential and role of the techniques.

PI AND NOVEL TECHNOLOGIES AND SYSTEMS

Paul Stuart presented a survey about PI for industrial biorefineries. He pointed out that PI is essential in finding the right system solutions but most projects must be performed by experts knowledgeable in both methods and practical aspects. Key factors for success are timing, combination of expertises in processes, business and PI methods. He also presented a new methodology, the Bridge method, aimed at optimizing energy efficiency in retrofit situations.

The use of PI in another new application, production of shale gas, which is regarded as "bridge" fuel as it emits 50% of CO2 compared to coal, was presented by Ignacio Grossmann. PI has been used for designing and planning of infrastructures for shale gas production, to study water management through recycle and reuse in this production, and to study optimization of new processes based on C1 and C2 chemistries from the liquid natural gases in shale gas. He demonstrated how MINLP and MILP mathematical programming can be used for identifying efficient and economic solutions that also minimize environmental impact. He also showed how PI and mathematical programming can be used for another new application of future high importance, the optimal planning of electric power infrastructures. This area will be of increasing importance as it will help to optimize and better integrate the use of intermittent power production sources such as wind and solar.

Truls Gundersen talked about a new PI application in sub-ambient processes. When combining Work and Heat Integration, the classical Heat Exchanger Network (HEN) problem is extended to Work and Heat Exchange Networks (WHENs). He described how the recent developments in WHENs can increase the use of Process Integration in sub-ambient processes, and thereby enable the design of significantly more energy efficient low temperature processes. Savings of up to 10% can be obtained even in classical well-designed systems. e. g. Linde process in ASU. He also showed how large savings could be obtained in different CO2 capture systems as well as through new insights about where compressors and expanders should be placed in different systems.

Thokozani Majozi presented opportunities for energy efficiency by using PI in combined water and energy optimization. The increasing awareness of environmental regulations has heightened the need for process integration techniques that are environmentally benign and economically feasible. Process integration techniques within water network synthesis require a holistic approach for the sustainable use of water through reuse and recycle and regeneration reuse and recycle. In two examples, considerable amounts of water, energy and costs could be saved through optimization with the aid MINLP models.

PI AND PROCESS INTENSIFICATION

Jeff Siirola (presented by Rafiqul Gani) and Rafiqul Gani discussed the importance of PI in process intensification studies. Systematic chemical process synthesis methods have been under investigation for more than forty years with several techniques now developed to the point of industrial applicability. One such method is the hierarchical task-based systematic generation approach to process synthesis based on the goal-oriented means-ends analysis paradigm with particular emphasis on task integration and process intensification. Process intensification is classically related to altering process rate and equipment size determining mechanism, but is being expanded to several other PI-related design problems. Also, a computer-aided, multi-level, multi-scale framework for synthesis, design and intensification of processes, for identifying more sustainable alternatives was presented (Rafiqul Gani), with three stages (synthesis, design and innovation). Examples of applications are in distillation systems, heat exchanger networks, chemical and biorefrinery concepts with integrated task functionality, etc. Potential computer-aided tools that have been used for performing process intensification in the open literature were also presented. Finally, suggestions were proposed for future research and development for process intensification related to process design.

PI IN INDUSTRIAL CLUSTERS AND ENERGY CONVERSION

Diane Hildebrandt presented a PI methodology called the GH – space (G for Gibbs energy and H for enthalpy) which represents processes as vectors and uses vector geometry to consider the thermodynamic interactions of unit processes from the very earliest stages of design. The GH-space is a dynamic and flexible synthesis technique that allows designers to apply sound judgment and innovation from the very outset of a design project. She applied this on a small-scale system for gasification of biomass and showed that such systems, given local conditions, can be economic even in this small scale.

Francois Marechal discussed the importance of PI in industrial symbiosis/industrial clusters. Methods developed in process systems engineering and process integration have a large potential to identify symbiosis solutions and define ways of implementing them. Combining heat recovery with energy conversion can save typically 30% in energy use, in certain cases much more. Integration between existing plants and new processes have potentials of 20-40 % saving in energy or water usage. Huge savings can be achieved with combined solar cell/heat pump systems. The use of optimization techniques and PI will be necessary to generate in a systematic way different options and to propose the implementation of resilient solutions.

PI AS A TOOL FOR FUTURE RADICAL GHG MITIGATION IN INDUSTRIAL SYSTEMS

David Miller discussed different opportunities for GHG mitigation industry, mainly different carbon capture technologies (CCS). Applying PI in conjunction with GHG mitigation technologies will be essential for reducing the energy penalty, especially as more advanced, large-scale, energy conversion technology gets deployed and consideration of CCS expands beyond power production into industrial applications. In an example from CCS in power production, the use of PI was shown to increase the power efficiency by 4 % units, which is of high importance in such systems. Significant challenges will be different technology developers for different parts and operational flexibility, process optimization and integration. A concerted effort will be required to develop the computational tools for PI and process optimization to show the potential savings as well as to address the technical barriers.

Dominic Foo (on behalf of Raymond Tan) presented the use of PI for carbon management networks, focusing on carbon-constrained energy planning (or carbon emission pinch analysis – "CEPA" in short) and also the planning of carbon capture, utilization and storage (CCUS) using PI techniques. For CEPA, the allocation of various fossil fuel and renewable sources are optimized in order not to exceed the CO2 emission limit. A case study based on China was presented to show how PI tool is utilized for the planning of biomass resources for power generation sector. For CCUS, various recent developed tools on pinch analysis and mathematical optimization techniques were presented to show how CO2 may be utilized and/or sent for storage once it is captured.

Simon Harvey discussed the importance of an approach for identifying opportunities to achieve substantially increased energy efficiency and reduced GHG emissions in future industrial processes. Future energy market conditions are, however, subject to significant uncertainty. One way to handle decision-making subject to such uncertainty is to evaluate candidate PI investments using different scenarios that include future fuel prices, energy carrier prices, as well as indicative values of GHG emissions associated with important energy flows related to industrial plant operations. By assessing profitability for different cornerstones of energy market conditions, robust PI investment options can hopefully be identified, i.e. investment decisions that perform acceptably for a variety of different energy market scenarios. He presented the ENPAC tool, aimed at making ex-ante assessments of e. g. process integration measures, and showed one case study for a biorefinery concept.

NATIONAL PRESENTATIONS FROM GERMANY AND PORTUGAL

Germany

Carsten Ernst presented improved predictive methods in energy efficiency. The focus is on a consistent methodology for establishing energy performance indicators based on measured values including a regression model with all relevant variables. Typically one can only measure the actual energy consumption and not the energy saved due to the implementation of energy efficiency measures. The presented methodology focusses on clearly distinguished systems with all relevant variables included. A baseline needs to be established before implementing the energy efficiency measures resulting in a more or less complex statistical model. After implementing the measure the regression model of the baseline forecasts the effort based on current combination of relevant variables at each point in time. The difference between the forecast and current effort values determines the actual saving. The presented methodology can be applied in both monitoring (maintaining the efficiency of an existing system) and benchmarking (improving the system, identifying saving potentials) situations.

Portugal

Henrique Matos presented four GHG mitigation projects from the Portuguese National Group for Process Integration (GNIP), established in 1995 for PI development. These were i) PI inside a Biodiesel plant; ii) Hydrogen network at Sines Refinery; iii) Heat Pinch Analysis of Sines Refinery and iv) Biomass-based Power Plant. In each one of the studies a deep process gathering data was carried out and from applying methodologies and models a set of proposals of modifications were presented trying to improve the global energy efficiency and therefore mitigate the GHG effect. They are a part of the Portfolio of Success Case Studies for promoting PI.

RESULTS FROM THE GENERAL DISCUSSION AND CONCLUSIONS

There is an imminent need for radical reduction of GHG emissions globally, including industry. The global emissions must be reduced to zero net emissions in a very short time period, 6-25 years, according to international studies in e. g. UN, IPCC. This means that novel technologies, systems, feed-stocks, products, circular economy development and interactions industry-society must be introduced in a size- and time-scale hitherto never experienced. A main reason for the workshop was to discuss the role of PI in the huge transition of the industry sector. Another reason was to discuss experiences with PI, possible potentials for more sustainable industrial systems and the broadening of the RD&D area towards new types of application. The findings are discussed below.

Since the start of the concept in the late 70's, PI has been developed strongly and implemented in all major types of industry. However, there is still a big potential for further use, both in traditional types of projects and for meeting the new challenge of a radical transition of the industrial sector. Therefore, as has been shown in the presentations, PI method and application areas have been broadened considerably recently into several new areas (see also below).

Five levels of general application areas were identified:

- **Measures for improved energy efficiency in existing industrial plants**

In spite of its wide use, there is still a big potential for PI in this area. System approach is typically missing leading to a poor understanding of the system integration while individual technologies are optimised. Some barriers for its use are lack of competence, awareness or, mainly, personnel resources. In addition, most PI methods have been developed for grass-root situations whereas most real projects are performed in retrofit situations. New methods explicitly aimed at retrofitting, however, exist and are being developed, but there is still a scope for improvement for such applications. To use of PI techniques as a necessary step of the energy audits can be of major importance to identify energy and resource efficiency targets and identify CO2 mitigation roadmaps and their conditions of implementation. With existing conditions for fuel prices, investment costs, policy instruments, etc, typical energy saving potentials through proper PI studies are in the range of 10-20 %, much depending on type of industry, age of equipment, regional differences in energy prices etc.

- **Strategies for long-term development of industrial plants for increased energy efficiency**

Many technically possible measures identified in PI studies are not implemented due to insufficient short-term profitability. However, with increasing need for more radical changes, the economic incentives for energy efficiency and GHG mitigation measures will most probably increase considerably. It must be borne in mind that future incentives for facilitating new equipment and processes will also mean that many more energy system efficiency measures will become profitable. The potential for this depends of course on the future magnitude of the incentives, but could well be on the order of additionally 10-20%. There is a need for closer communication with decision makers with high level workshops to demonstrate the strategic importance of process integration in increasing profitability and decreasing emissions.

- **New technologies and systems**

In order to meet GHG mitigation targets, industry will most probably implement several new types of technologies and processes. Hence, many new concepts are studied and developed in the R,D&D international community. Some major novel solutions for industrial GHG mitigation being discussed generally and at the workshop include biorefineries, CCUS (carbon capture and storage/utilization), process intensification, membrane technologies, heat pumping and cogeneration and electrification (including power-to-heat, power-to-chemicals, power-to-hydrogen, etc). For all these concepts, a combination of high efficiency equipment and system optimisation will lead to considerable GHG mitigation opportunities. As there is no experience or rules of thumb for integration of these concepts, systematic PI measures for identifying optimal system solutions will be crucial.

As has been shown in the workshop presentations, PI methods for these new types of concepts have been developed/are under development.

- **New energy resources**

CO2 mitigation can also be realised by using natural gas as “bridge” fuel, and in the longer term by replacing fossil resources by renewable energy resources. This on the one hand implies electrification of the processes by integrating for example heat pumps or new efficient electricity driven technologies (e.g. electrochemical processes) or on the other hand the use of bio-based resources like biomass or biofuels. PI will play an important role in this context as integrated solutions that consider the management of the intermittent energy resources and the optimal integration of the renewable energy resource conversion processes will be needed. PI will even be more important in this context with the possible role of the process industries to contribute to the electrical grid stability by offering both the short term and the long-term peak shaving capacities. Process integration will therefore also have an important role to play in the development of a circular economy.

- **Industrial clusters and integration with regional energy systems**

In several studies and applications, the huge potential for energy saving and GHG mitigation by clustering between industries or improved integration in regional energy systems has been demonstrated and exemplified. Clustering can mean common or shared energy and/or material streams and integration with regional energy systems is often in the form of usage of industrial excess heat for heating or cooling in large commercial and office buildings or district heating/cooling systems. It is a very complicated task to identify possible and/or optimal solutions. For this purpose, newly developed PI methods will probably play an important role for optimisation/maximisation of system GHG mitigation at various conditions. Process integration has a major role to play in increasing energy efficiency and raw materials efficiency, and decreasing emissions. To achieve the full potential, even industrially, restricting the scope to consider only the envelope of manufacturing must change. The scope must be widened to consider interactions between manufacturing and society at large.

All these levels or application areas are necessary to reach the GHG mitigation targets. Results from all large modelling activities within e. g. IEA, UN, EU about possible scenarios for radical GHG mitigation show that there are no “silver bullets”, i. e. all known measures must be used in different combinations (at least with today’s knowledge of existing and upcoming concepts). Due to the time perspective, short term evaluations and assessments with more long-term solutions (10-20 years, i. e. ex-ante assessments) are necessary to identify “robust” concepts, i. e. both economically and climate-wise sustainable solutions given different future energy market scenarios. PI methods can therefore be of high importance in industrial strategic decision-making and in developing road maps for an individual plant or an industry sector.

It was concluded at the workshop that strong new policy instruments as incentives for radical GHG mitigation measures will be necessary. As in all sectors, the configuration of such instruments will be crucial for creating a fair and globally valid system. However, regardless of how future policy instruments and incentives will be introduced, PI methods and applications will always be important for identifying the most optimal solutions for future conditions. With increasing levels of incentives, they will be an increasingly more important tool for industry in creating the most economic solutions and a competitive advantage and at the same time meeting the GHG mitigation targets.

In order for industry to take new PI methods and system studies on board, a good cooperation between in-house competence and resources, expert consultants and research organisations will be necessary. At the workshop, as well as in the Jubilee Process Integration Conference in 2013, concerns from many participants about the quantity and quality of chemical engineering university education, including PI, were expressed. Chemical engineering programs are increasingly emphasizing chemistry and chemical engineering science at the expense of chemical engineering design. High quality chemical engineering educational training is a necessity, if the high targets for industrial GHG mitigation shall be met.

Due to the short time horizon, there is an urgent need for improved knowledge, more method developments, success stories in different applications, training of industry engineers, education and international cooperation. Several possible areas for international cooperation were discussed at the workshop, see next section.

MAIN MESSAGES

- Due to the imminent need for radical reduction of GHG emissions in industry, novel technologies, systems, feed-stocks, products, as well as circular economy and cooperation solutions must be introduced in a size- and time-scale hitherto never experienced in industry and in industry-society cooperation.
- Process integration methods and tools are crucial in identifying sustainable and economically viable new process and system solutions.

POSSIBLE AREAS FOR INTERNATIONAL COOPERATION WITHIN IEA, IETS

SHARING OF DATA FOR INDUSTRIAL ENERGY SYSTEMS

Results from different research studies and real-world projects in the PI area are in many cases difficult to compare. However, data for energy and material flows and/or their graphical representations generated using pinch analysis tools are available in many R&D groups for typical existing plants or for future BAT (best available technology) plants. By sharing such information and using standardized data, results can be compared and be of more general interest and, at the same time, show opportunities in existing specific industries. A cooperation area could therefore be sharing of input data and sharing of project results. Collaboration with IETS projects (called Annexes) that focus on technologies (heat pumps, cogeneration, bio-energy) are also needed to incorporate system integration in the agenda of the technology development roadmaps.

PI TRAINING AND IMPLEMENTATION IN INDUSTRY

As discussed in the conclusion section, there is a need for improved training in PI. However, PI is taught at different levels and depth in many universities, not the least connected to the experts at the workshop. Hence, a first step in an international cooperation in this area could be to perform a survey about where, how and what PI is taught in different universities (including professional development activities). Based on that, opportunities for sharing experience or teaching material and/or for teacher exchange between universities can be explored.

Further to education aimed at university students, there is also a clear need for education of industry professionals to anchor PI approaches into today’s industry, and improve the acceptance and speed implementation of solutions. This should be considered a collaboration in bringing academia and industry together to find optimum practical solutions. Experiences from these programmes would be valuable to exchange. Industry executives is an important target group in improving implementation of PI in industry.

PI METHODS FOR RETROFITTING AND FOR NOVEL INDUSTRIAL CONCEPTS

As discussed in the Conclusions section, there is a need for new PI methods for retrofitting, for new concepts in an industry or cluster formations. Several such developments are ongoing in different R&D groups globally. One cooperation possibility could therefore be to share the progress in those groups and jointly identify barriers and opportunities with new developments.

SHARING EXPERIENCES FROM DEMO PROJECTS AND SUCCESS STORIES IN DIFFERENT TYPES OF INDUSTRY

A compilation of finalized and ongoing PI demo projects and success stories could mean an increased awareness in industry about methods and applications of PI.

GHG MITIGATION OPPORTUNITIES IN DIFFERENT TYPES OF INDUSTRY

Many projects about radical changes in different types of industry or in clustering situations are ongoing or planned. By sharing results from such projects, different groups could learn from each other and an overall picture about opportunities in different types could be built up. Quantifying the CO2 mitigation potential of process integration approaches is quite difficult. It is however important to try to measure this impact. For doing this it will be important to create for the different industrial sectors data bases of typical process models including process integration options that could then be applied to generate CO2 mitigation roadmaps for the industry. This would imply a strong collaboration between IEA-IETS, research initiatives like SPIRE in the EU, industrial branches and authorities.

A strengthened dialogue with decision makers in industry and politics is crucial for achieving the necessary changes, considering the short time perspective available. Workshops dedicated to each important industry type should therefore be performed, in which experts in industry and academia can meet with decision makers to discuss strategic measures. Such workshops could be done in the form of a new annex within IEA, IETS.

COLLABORATION WITH IEA SECRETARIAT

At the workshop, opportunities for a closer collaboration with the IEA Secretariat was discussed, especially in their modelling work on future opportunities for e. g. GHG mitigation in different types of industry. In that work, PI measures for improved energy efficiency has not been incorporated to full extent, due to lack of knowledge about such opportunities in different types of industry and at different conditions. Through international cooperation in the areas above, especially the two last ones, a considerable improved knowledge can be achieved, which can be transferred to the secretariat and included in the modelling.

As the applicability and impact on energy savings of process integration techniques are highly site-specific, it is challenging to capture the full potential of process integration strategies in this type of scenario modelling. IETS TCP could have a leading role in developing techno-economic studies that explore energy savings and equipment/economic implications of implementing process integration techniques in main process technologies/arrangements within each of the energy-intensive industrial sectors in support of IEA technology modelling, and in general of the energy research community. From these studies, regional/national level techno-economic PI potentials could be derived by considering regional specific industrial production contexts.

MAJOR CONCLUSIONS

- Process integration is a major strategic design and planning technology, with which considerable improvements in energy efficiency and investment costs can be achieved and new processes and systems can be optimally designed in terms of efficiency, economy and environmental aspects
- There is an imminent need for radical reduction of GHG emissions in industry. The global emissions must be reduced to zero net emissions in a very short time period, 6-25 years.
- This means that novel technologies, systems, feed-stocks, products, and cooperation solutions must be introduced in a size- and time-scale hitherto never experienced.
- Due to the need for a radical transition of industrial systems, process integration will play a more important role than it traditionally has towards GHG mitigation measures
- Potentials for energy efficiency and GHG mitigation in industry through process integration are partly included in large-scale modelling of future industry developments within e. g. IEA. However, methods for transferring R&D and case-study results from researchers and industry to modellers should be developed.
- There is a great need for improved education and training in academia as well as in industry about opportunities for designing significantly more sustainable industrial processes and energy systems
- The international RD&D cooperation in process integration should be strengthened in order to develop and disseminate knowledge about opportunities for e. g. GHG mitigation in industry.

POSSIBLE AREAS FOR INTERNATIONAL COOPERATION WITHIN IEA, IETS

- Sharing of data for industrial energy systems.
- PI training and implementation in industry.
- PI methods for retrofitting and for novel industrial concepts.
- Sharing experiences from demo projects and success stories in different types of industry.
- GHG mitigation opportunities in different types of industry.

- Collaboration with the IEA Secretariat.

APPENDIX

PROGRAMME

Tuesday April 4

9.00-9.30	**Welcome and Introduction** Gudrun Maass, chair of IEA, EUWP Thore Berntsson, chair of IEA, IETS
9.30-10.15	**GHG Mitigation in Industry** The role of industry in meeting the GHG mitigation targets: Thore Berntsson Industrial energy use and CO2 emissions in IEA modelling - Key challenges and tools for modelling process integration: Kira West, IEA Secretariat, Paris, France
10.15-10.35	**Coffee/tea**
10.35-12.15	**PI in Grassroot or Revamping Situations in Process Industry** Process integration in petroleum refining – a perspective and future trends: Robin Smith, University of Manchester, UK Process integration in the chemical and petrochemical industries: Les Bolton, BP plc, UK Pulp and paper industry: Philippe Navarri, NRCan, Canada Process integration in iron and steel: Lawrence Hooey, Swerea MEFOS, Sweden
12.15-13.15	**Lunch**
13.15-13.55	**Discussion**
13.55-16.10	**PI and Novel Technologies and Systems (incl. coffee)** Biorefineries: Paul Stuart, École Polytechnique Montréal, Canada Shale gas production: infrastructure design, water management, and impact on electric power generation and new chemical processes: Ignacio Grossmann, Carnegie Mellon University, Pittsburgh, USA Work and heat exchange networks (WHENs) for PI in sub-ambient processes: Truls Gundersen, Norwegian University of Science and Technology (NTNU), Trondheim, Norway Simultaneous water and energy optimization in large scale systems: Thokozani Majozi, Wits University, South Africa Refinery of the future - from modular design to connected plants: Frank Zhu, UOP LLC, A Honeywell Company, USA
16.10-17.00	**Discussion**
17.00-17.15	**National Presentation** Improved predictive methods in energy efficiency: Carsten Ernst, Ökotec, Germany

Wednesday April 5

8.30-10.10 **PI and Process Intensification**

Process Integration within the broader context of process intensification supporting greenhouse gas mitigation: Jeffrey Siirola, US (via link or given by Rafiqul Gani)

Sustainable Process Synthesis–Intensification: Rafiqul Gani, DTU, Denmark

PI in Industrial Clusters and Energy conversion

Growing fuel, fuelling growth: Diane Hildebrandt, University of South Africa, South Africa

Industrial symbiosis: from energy requirements to large scale integration: François Marechal, École Polytechnique Fédérale de Lausanne, Switzerland

10.10-10.30 **Coffee/tea**

10.30-11.20 **Discussion**

11.20-11.35 **National Presentation**

Henrique Matos, Instituto Superior Technico, Portugal

11.35-14.15 **PI as a Tool for Future Radical GHG Mitigation in Industrial Systems**

Systems aspects of GHG mitigation: opportunities and challenges: David C. Miller, National Energy Technology Laboratory, U.S. Department of Energy, USA

Lunch

Process integration for the synthesis of carbon management networks:

Part 1: Carbon constrained energy planning and extensions

Part 2: Carbon sequestration and negative emissions systems,

Dominic Foo, University of Nottingham Malaysia Campus, Malaysia &Raymond Tan, De La Salle University, the Philippines

Assessing the long-term impact of PI measures in industrial systems: Simon Harvey, Chalmers University of Technology, Gothenburg, Sweden

14.15.14.35 **Coffee/tea**

14.35-15.20 **Discussion**

15.20-16.45 **General Discussion**

e. g.:

- Opportunities for GHG mitigation in different industrial sectors- assessments
- Need for information about opportunities, from success stories, etc
- Who shall use methods and tools available and under development?
- Need for education and training
- How to promote PI in revamping logistics
- How to include PI in novel technology and systems developments in industry
- How to include PI in large studies on potentials for industrial GHG mitigation (e. g. in IEA)

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ABOUT IEA, TCP IETS AND ANNEXES

The International Energy Agency (IEA) is an autonomous organisation which works to ensure reliable, affordable and clean energy for its 29 member countries and beyond. The IEA has four main areas of focus: energy security, economic development, environmental awareness and engagement worldwide

There are no quick fixes to long-term energy challenges. To find solutions, governments and industry benefit from sharing resources and accelerating results. For this reason the IEA enables independent groups of experts - the IEA Technology Collaboration Programmes, or IEA TCPs (formerly known as Implementing Agreements).

Through the Technology Collaboration Programme, the IEA provides a framework for more than 40 international collaborative energy research, development and demonstration projects. It enables experts from different countries to work collectively and share results, which are usually published. The programme deals with technologies for fossil fuels, renewable energy, efficient energy end-use and fusion power, as well as electric power technologies and technology assessment methodologies.

The IEA TCP on Industrial Energy-Related Technologies and Systems (IETS), founded in 2005, is dealing with new industrial energy technologies and systems.

The mission of IETS is to foster international cooperation among OECD and non-OECD countries for accelerated research and technology development of industrial energy-related technologies and systems. In doing so, IETS seeks to enhance knowledge and facilitate deployment of cost-effective new industrial technologies and system layouts that enable increased productivity and better product quality while improving energy efficiency and sustainability.

Through its activities, IETS will increase awareness of technology and energy efficiency opportunities in industry, contribute to synergy between different systems and technologies, and enhance international cooperation related to sustainable development.

The principal work of IETS is about identifying, observing, following and sharing work among countries and their organisations and industry clusters. This is done through defined projects, so called Annexes, in which experts from countries who choose to take part form a working group with an Annex Manager in charge of coordinating. For more information, please refer to the IETS website.

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