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ENERGY EFFICIENCY IN INDUSTRY
A main path for increased value creation and sustainable energy use

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ABSTRACT

Energy efficiency is identified as one of the most effective means for combating climate change as it contributes significantly to reducing the global greenhouse gas emissions. Further, more efficient energy use represents a significant opportunity for increased value creation. The paper identifies research topics critical to improve the energy performance in the industry and reviews some major Norwegian research initiatives to advance development and deployment of energy efficient solutions. Strategies for promoting innovation are discussed together with possible effects of future standards and regulations. A main conclusion is that the challenges regarding energy shortage and greenhouse gas emissions call for long-term and dedicated public-private efforts to bring forward and apply technology for energy efficient industry operation. Extensive knowledge building and international collaboration should be prioritised.

1. INTRODUCTION

According to IEA World Energy Outlook 2010, energy efficiency is the most important factor to reach the ambitious target of limiting the global CO_2 emissions to 21.7 Gt/y within 2035. Business as usual will result in CO_2 emissions amounting to 35.4 Gt/y. In the longer view, the CO_2 emissions must be limited to 14 Gt/y by 2050 to avoid temperature increase above 2°C and about 60% of this reduction depends on energy efficiency and fuel switch [1]. Due to expected economic growth in the developing countries it is foreseen that their share of the global CO_2 emissions will increase considerably. The world face a unique opportunity to enable these countries to move directly from inefficient technologies based on coal and wood to modern technology integrating efficient solutions for energy use and renewable energy.

In addition to limiting greenhouse gas emissions (GHG), more efficient energy use is also a prerequisite to ensure energy security [2] and even to reduce many countries' dependence on imported energy. Hence, energy efficiency is an important part of the solution to critical global challenges with extensive political, economical and environmental implications. An interesting aspect is that energy efficiency is uncontroversial and in many cases represents the most cost-efficient measure to make more energy available. Even the sceptics arguing the environmental impact of human-made GHG emissions can agree on taking actions to make the most of the available energy resources at the lowest possible cost.

In Norway, energy efficiency receives increasing attention due to higher energy costs and periodically, shortage of electricity in parts of the country. When it comes to the industry, there is basically one factor motivating the development and deployment of new technologies: profitability. The paper identifies new competence and innovative technology as key issues to enable the industry to improve energy efficiency and thereby, reducing their costs and increasing their competitive power. Examples from the aluminium industry are included for illustration, but other sectors such as fishery and food production, supermarkets, pulp and paper, and offshore oil and gas production are referred to. The paper describes technologies investigated to strengthen the overall energy performance of the industries, outlines possible application of research results and discusses strategies for promoting innovation and value creation based on the results.

The authors represent major Norwegian research and industry actors with extensive work on energy efficiency. A principle idea of the research being conducted is to establish research platforms promoting scientific progress in topics relevant for several industries and to verify the results in industry specific test facilities, demonstration sites or pilots. By organising the research as collaborative efforts, complementary expertise of energy users, equipment vendors and academia is included. This approach ensures that the scientific perspective is safeguarded and it allows the research to be directed and specialised to meet the particular challenges of each branch of the industry.

2. POTENTIALS FOR VALUE CREATION

In many industry sectors and in particular in the energy intensive industry, energy is a major input factor. By reducing the specific energy use of the production process, the costs are reduced and profitability increased. The profit will be proportional with energy performance of the available technologies and solutions, but in inverse ratio with the investment and operational costs. The energy made available through more efficient operation can be used to expand the existing business enabling increased production. In a recent strategy report, major Norwegian industry actors set forth an ambition to reduce specific energy use in the industry by 20 % within 2020, representing 10 % of the national stationary energy end use [3]. The estimated increase in value creation by using this energy for new industry production is 20 % (40 billion NOK). Hence, energy efficiency enables more optimal use of a significant part of the national energy resources releasing a potential of extensive value creation.

An alternative approach to expanding existing production is to utilise the excess energy as basis for developing new businesses. The increasing number of established industry clusters illustrates the value creating potentials of making alternative use of the energy made available through energy efficiency [4]. One option is to use excess heat for businesses depending on regular supply of heat, such as diaries, greenhouses or indoor swimming pools. A main challenge is to identify local actors that can utilise the available surplus heat and usually, the customers utilising this surplus heat do not exist near the heavy industry. Therefore, incentives for cooperation and technology for designing and operating industry clusters are needed in addition to governmental regulations stimulating industry clustering. In China, such aspects are already taken into account when new cities are designed. Also in smaller, developed countries like Norway there are examples of district heating based on surplus heat from industry and waste incineration, but in general more efforts are needed to redesign an existing industrial area than to design and build a new one. Nevertheless, industry clusters with integrated energy grids will be important parts of the future energy system.

Due to the steadily increasing energy costs, only the businesses with energy efficient operation can survive and the industry seeks optimal solutions. This can be illustrated by the aluminium industry, a more than 100 years old industry, with an annual global production approaching 35 million tonnes aluminium. Since 1990, the energy consumption has dropped from about 50 kWh/kg Al to below 13 kWh/kg Al. The worst performing (old) smelters operate at around 16-17 kWh/kg Al [5][6]. To reduce the energy consumption further, new technology for more energy efficient production is needed. As about 50% of the energy used is wasted as heat, energy recovery is attractive. To obtain maximum flexibility electricity production would be ideal, but the technologies for electricity production from low-temperature heat are still expensive compared with the potential gains from reduced production costs and excess energy trade. On the other hand, there are huge potentials for utilising surplus heat from the power plants for heating and cooling. At present, energy recovery from process gas is taking place at smelters like Hydro’s Norwegian smelters in Høyanger and Sunndalsøra where the heat captured from exhaust gas is used for district heating in the local community.

An additional perspective is the potentials for value creation based on equipment development and development of services related to implementation of energy efficient solutions in the industry. Novel technologies and solutions rely on components and systems covering a wide range of areas, representing opportunities to expand the businesses of existing vendors and to pave the way for new companies.

3. REQUIRED KNOWLEDGE AND TECHNOLOGY

New competence and innovative technology are key issues to enable the industry to improve energy efficiency and thereby, to reduce the costs and increase the competitive power. Research topics critical to meet the industrial challenges and strengthen the overall energy performance are described below:

Innovative refrigeration and heat-pumping technologies using natural work fluids: There is an extensive need for heating and cooling in the industry and design and assessment of concepts for optimal refrigeration and heat pumping technologies using natural working fluids industry are required. Together with other natural refrigerants, the non-toxic and inflammable CO_2 stands out as a working fluid for the future. Emissions cause no impact on the ozone layer and causes negligible contribution to greenhouse gas emissions. Moreover, CO_2 may represent more optimal solutions for electricity production from low temperature surplus heat in a Rankine cycle. An additional benefit of CO_2 based technology is the opportunity to design compact units, thus reducing costs and enabling alternative applications (i.a. off shore). Efficient components as well as refrigeration and heat pumping systems based on natural refrigerants for industrial purposes should therefore be designed and developed.

Efficient heat recovery and cold production from surplus heat: At present, large amounts of surplus heat are available in the industry. Efficient capture and utilization of low temperature heat within and among the industries are areas with substantial potentials for energy savings. The industry has a variety of heat and cold requirements and one opportunity for utilizing the low temperature surplus heat is to use it for producing heat and cold. For instance, cold may be provided by implementing sorption technology based on ammonia/water and by using ice slurry systems for cold accumulation.

Electricity production from surplus heat: There is an identified need to increase the efficiency of electricity production from low temperature surplus heat. CO_2 power production cycles operate close to the critical point of CO_2. In this region, ideal gas laws on which standard turbo machinery design is based, is not valid. Design of optimized CO_2 turbines for power production from low temperature heat is needed. Standard power cycle operates with constant evaporation of the working fluid at sub-critical pressures. A CO_2 power cycle will operate in the super-critical region where heat absorption by the working fluid takes place with a temperature glide. This important difference leads to divergent behavior when the power cycle operates with conditions deviating slightly from the conditions it has been designed for. These effects should be investigated. In addition, efficient and non-expensive solutions for heat capture and transport of captured heat from heat source to the energy converter unit are required.

More energy efficient production methods: In ongoing projects, industry actors have defined their specific challenges to achieve more efficient production methods and cost-effective solutions are needed for industries such as aluminium, pulp and paper, food and fishery products. Generic concepts for reduced heat losses in the production processes will be a part of these solutions. For instance, new membrane concepts for separation processes, new technology for increased furnace efficiency and energy efficient drying processes are pinpointed by the industry as critical issues for efficiency improvement. The environmental impact due to emissions of CO_2, NOx and HF, as well as discharge of heat and waste to the nature should be minimised.

Optimal energy use among several businesses in industry clusters: Development of energy optimal industry clusters with thermal exchange between processes, manufacturers and companies is a crucial challenge in order to succeed with an energy efficient industry. In addition to thermal exchange the industry clusters could utilize waste flows from one industry as raw materials in another industry. Energy and cost analyses are needed to pursue possible cases for industry clusters. Development of adequate energy policies is also relevant to release the potentials of industry clusters.

Energy efficient buildings: Up to 40 % of the European energy consumption takes place in buildings. Ventilation, refrigeration and air condition systems accounts for most of the energy use in energy intensive buildings. Increased heat recovery from the exhaust air in ventilation systems requires more efficient air-to-air exchangers and/or heat pumping solutions with coupling to freezing-/refrigeration plants. Integration of commercial refrigeration and air conditioning in energy intensive buildings is complex and the complexity increases further when the ventilation system is included. Quantitative comparisons between alternative solutions for integrated ventilation, refrigeration and air condition taking the building envelope and ambient conditions into account is needed. Aluminum is a necessary component in the advanced facade technologies that will cut emissions from heating, cooling, ventilation and lighting of buildings.

4. ONGOING RESEARCH PROJECTS AND POSSIBLE INDUSTRY APPLICATION

Over the last years several research projects focusing on energy use in the industry are initiated. New major Norwegian initiatives addressing critical research topics are reviewed in the following. So far, the work has revealed a significant need for more knowledge both on the actual potentials for more efficient energy use in industry processes and how excess energy can be made available for alternative use. Further, there is an identified need for new technologies and solutions that enable improved utilisation of energy. On the other hand, it is to a large extent confirmed that knowledge and technology for energy efficiency is applicable across several industry sectors. Hence, the potentials for synergy effects are considerable and serve as incentives for interaction across traditional discipline borders.

CREATIV [7] is a research project focusing on utilisation of surplus heat and efficient heating and cooling in the industry. In the project, international research groups work together with key vendors of energy efficiency equipment and an industry consortium including the areas metallurgy, pulp and paper, food and fishery, and supermarkets. The ambition of CREATIV is to bring forward technology and solutions enabling 25 % reduction of both energy consumption and greenhouse gas emissions. The main research topics are electricity production from low temperature heat sources in supercritical CO_2 cycles, energy efficient end-user technology for heating and cooling based on natural working fluids and system optimisation, and efficient utilisation of low temperature heat by developing new sorption systems and compact compressor-expander units [8][9]. To support the project SINTEF Energy Research is currently developing a laboratory to build and test compact systems for waste heat utilisation based on CO_2 as working fluid. The main contributions of CREATIV are to develop new knowledge and solutions related to surplus heat capture and utilisation, and also to contribute to the development and testing of new equipment such as oil free turbo compressors, integrated units for commercial refrigeration and air conditioning and an absorption type heat pump based on ammonia and water for heat and cold production. An additional perspective of CREATIV is through case studies to evaluate potentials of industry clusters to improve energy efficiency.

Recently, the project **EFFORT** was launched with the objective to promote and accelerate the uptake of energy efficient solutions in offshore oil- and gas production. EFFORT will develop knowledge and tools for offshore-accommodated compact bottoming cycles and surplus heat recovery. The project consortium includes four oil companies in addition to the research institutions. Energy efficiency improvements will be realised either through utilisation of surplus heat for electricity production or through heat recovery for process purposes. A main concern is to enable implementation of new technology through research focused on the offshore-specific requirements, i.e.

- Processes and equipment allowing low weight, compact size and flexible layout
- Robust operation; reliable and with low maintenance requirements
- Working fluids that are safe and associated with a minimum environmental impact
- Systems requiring minimum modifications and shut-down time for retrofit and installation.

EFFORT builds on CREATIV and the main contributions of the project are to develop equipment (heat exchangers and expanders) suited for off-shore use, compact bottoming cycles, methods for capturing heat and process integration, and to define and assess overall concepts for off-shore oil and gas production with minimum energy use.

ROMA is a competence building research program related to resource optimization and recovery in the materials industry. SINTEF and NTNU are research partners with industrial partners from the aluminium, titanium and FeSi industry. The project is divided in three parts, two of them concentrating on increased process efficiency and improved material quality and utilisation. The last one is concentrating on energy recovery, mainly towards utilization of surplus heat for electricity production or for direct use e.g. in industry clusters. ROMA aims to utilise CO_2 as working fluid in a Rankine cycle for electricity production from low temperature heat sources and to develop heat exchangers for heat capture from dirty gas streams.

Hydro Aluminium Ultra Performing Cell (HAL UP) is a research program run by Hydro Aluminium aiming for more energy efficient electrolysis for aluminium production. New technology for energy recovery is developed and the results will affect the design of the production units (electrolysis cells) and the choice of materials. Heat recovery from the electrolysis cells is demanding due to corrosion, manufacturing and operational challenges and due to the distributed design of the process. By introducing a new more efficient ventilation system, Hydro obtains less ingress of ambient air into the off-gas stream increasing gas temperature (more suitable for energy recovery), increases the process gas concentrations (mainly CO_2, i.e. potential for more efficient CO_2 capture) and reduced energy used on fans used to suck the gas from the cells through the gas scrubbers.

CO_2 capture and storage (CCS) is also considered to be important for reducing the global CO_2 emissions. A main challenge is the energy penalty introduced by the systems for CO_2 management. Depending on the technology, fuel and power cycle, the CO_2 capture process from power production accounts to typically 5-8 %-points and the compression train typically accounts for 4 % points or more [10]. Similar challenges are faced if CCS is introduced in the manufacturing industry. In the research centre **BIGCCS,** CO_2 management in power production is a main focus, but research is also initiated to develop solutions for CCS in industry [11]. There are significant potentials for improving the energy performance in such systems by process integration enabling more efficient energy use in the process and increased utilisation of surplus heat. For instance, in post combustion CO_2 capture plants considerable amounts of energy is used to provide steam for releasing CO_2 from the adsorption media and this steam may be produced from industry waste heat [12]. Hence, energy efficiency is crucial to enable large scale implementation of CCS and the opportunities for industrial synergy effects are considerable. This is reflected in the recent call for a Nordic CCS competence centre [13] where waste heat utilisation in CCS is emphasized.

5. STRATEGIES FOR PROMOTING INNOVATION AND VALUE CREATION

The innovation process can be characterised by defined steps, but the process is usually complex, time consuming and iterative. Further, the costs increase significantly as the process evolves. To achieve successful development and deployment of commercial technology several challenges must be overcome at all stages and it is essential that relevant stakeholders are involved at the appropriate stage. The research programs referred to in the current paper are organised as collaborative efforts including R&D actors, user industry and to some extent equipment vendors to ensure that all relevant perspectives are taken into account when forming the research initiatives, in the course of the programs and in the technology development, demonstration and implementation. The approach is based on experience from several comprehensive research programmes where international consortiums, work processes and means for identifying and pursuing opportunities for innovation are designed to maximise the outcome of the programmes [14].

In addition to the organisational and operational framework for the research endeavours, there are other aspects that should influence the R&D strategies forming the innovation process. [15] investigates to what extent Japanese public R&D projects for energy efficiency have succeeded in providing innovative technologies enabling commercialisation and describes how hard it can be to commercialise research results. The paper points out a set of critical factors that can increase the probability of successful development and commercialisation of R&D results and the conclusions are in line with the experience from Norwegian R&D. First, the long-term (> 10 years) public funding is a prerequisite for enabling high-risk R&D projects that otherwise would not be initiated and that stimulate industry to contribute both within other public projects and within related private R&D project. In the long run the industry's investments into new technology exceeds the public subsidy, one Japanese example mentioned indicates a ratio of three to one. In Norway, the ratio is expected to be higher, due to the limited options so far for public support for demonstration and pilot activities but actual figures remain to be mapped. Second, when forming new research initiatives it is imperative to assess realistically the performance and cost of the technology and the potential market for the technology. This knowledge ensures relevance of the initiatives and serves as a basis for developing strategies for creating and expanding a niche market. It is also important for identifying opportunities for considerable cost reductions that may affect energy performance but within acceptable limits. Finally, when R&D projects approach the commercialisation phase they should be complemented by a deployment policy. One measure may be investment subsidy contributing to creating the niche market and stimulating technology learning and diffusion of technology. Another measure is regulations, as discussed in section 6.

As pointed out by [15] there are benefits from R&D projects additional to the commercialisation and deployment of novel technology and solutions. Most importantly, increased competence in participating organisations enables further development and implementation of energy efficient technology. In Norway, lack of competence is pointed out as a main obstacle for implementing already existing technology for energy efficiency [16]. There is an identified need to strengthen knowledge on opportunities for reduced energy consumption in the industry companies, and to emphasise topics relevant for energy efficiency in the education of technicians, engineers and researchers. The ongoing research projects contribute to the recruitment of competent personnel to industry and academia by educating PhD and post doc candidates and several MSc students. Another benefit is the international networks facilitated by the projects. Knowledge exchange through seminars, collaboration and personnel mobility is valuable for utilising complementary competence and research infrastructure, creating synergy effects and thereby accelerating the development and demonstration of new technology. The projects referred to in this paper comprise consortiums where the number of partners varies from 3-4 to more than 20 research and industry actors representing several European countries, Japan, China, USA and Brazil.

6. POSSIBLE EFFECTS OF FUTURE STANDARDS AND REGULATIONS

Over the years, large efforts have been put into reducing the specific energy use but the potentials are still not fully released. Spring 2011 EU will launch an action plan on energy efficiency putting energy efficiency at the centre of the EU energy policy as a main measure of achieving the EU 20-20-20 target [17]. It is expected to include binding targets and actions to meet the underachievement of the energy-efficiency potential. The plan will supplement and replace the current fragmented framework including the Energy Services Directive (ESD) and the Directive on CO-generation (CHP) and will provide a more unified legislative framework contributing to the fulfilment of emission reduction and reduced energy use targets.

Previously, it is demonstrated that regulations can promote development and implementation of new technology. One example is the introduction of CO_2 tax in Norway which led to Statoil's pioneer project on capturing CO_2 from the natural gas produced at Sleipner and injecting it into a saline aquifer [18]. Not only is 1 million tons of CO_2 sequestrated annually since 1996, but the project and related R&D activities have been key factors in enabling the research community at SINTEF/NTNU to take an international leading role in the research and development regarding CO_2 management. It is reason to believe that restrictions such as saving obligations and emission targets can stimulate research, development and demonstration of new technology and thereby accelerate the progress towards more sustainable energy use in the industry.

On the other hand, such measures must be supplemented by framework conditions and financing tools to avoid unintended effects. One example is the danger of creating carbon leakages as a result of moving industry to countries with lower energy costs and/or few restrictions on GHG emissions. At present, several industries in Europe operate in an international market with global competition and PVC and aluminium production are two examples. Production based on the an European energy mix and in particular based on Nordic hydro power, provide industry products with low carbon footprint compared with products manufactured in other parts of the world. However, if the European tax policy and/or energy costs obstruct the international competition with actors not facing such limitations, the risk is high that the industry will close down in Europe and move to locations with fewer regulations and lower priced energy. In [3] it is indicated that Chinese PVC production based on coal emit 3-20 times more CO_2 than PVC production in the Nordic countries based on hydro power and the example illustrates the possible consequences of carbon leakages. Equally important to consider is the impact on European economy by investing in industry elsewhere and thereby, drain technology and competence out of Europe. The 50/50 joint venture Hydro/Qatar Petroleum aluminium smelter in Qatar is completed in 2011, based on Hydro's best technology and the cost is nearly 6 billion USD (incl. gas power plant). The main reasons for building the smelter in Qatar are the long term power contracts and vicinity to a growing Asian market. Without the prospects of predictable long-term framework conditions like energy supply and prices (incl. CO_2 taxation), it is not likely that a modern smelter like the one in Qatar will be built in Norway in the near future.

7. PUBLIC-PRIVATE COOPERATION TO PAVE THE WAY

In light of the horizon of the EU 2020 strategy, it is obvious that actions must be taken immediately to reach the ambitions set forth in the strategy. Like many European nations Norway has defined national goals for reducing CO_2 emissions in line with the EU targets and the ambition is to overachieve the EU target for reducing CO_2 emissions within 2020. When it comes to reduced energy use in the industry, the targets were not specified by the government. Consequently, the Norwegian industry in 2010 defined its ambitions: The Norwegian on-shore industry shall reduce the specific energy use by 20 % within 2020 and a path for achieving this is outlined [3]. As the industry has worked continuously with reducing energy use for the last 10-20 years, this goal is very ambitious and depends on close public-private cooperation with respect to providing the necessary knowledge and technology, and for putting it to use in the industry sites.

The most important starting point for rapid improvement and implementation of more energy efficient solutions is to make them economically viable and aligned with national laws and regulations. The current paper does not investigate relevant initiatives to change the regulatory framework, but it is obvious that the development and diffusion of energy efficient technologies depend on strong government action. Therefore, some public measures should be mentioned. First and foremost, public funding is required to support the industrial uptake of new technology within the short timeframe we are facing. One element may be subsidies to support audit programs to identify opportunities for improving the efficiency, financial support for accompanying investment assessments and to some extent investment support for implementing new or immature technology for demonstration purposes. Such public funding both promotes adoption of energy saving solutions and stimulates the development of a market. The market development may be further stimulated by imposing energy saving obligations and directing the public sector to take a leading role in applying innovative solutions for reduced energy use. Another element may be to support the building and maintenance of energy infrastructures required to implement new solutions for excess energy utilisation, enabling industry clusters to emerge and creating additional demand for efficient technologies. For instance, heat must be transported from electricity refiners (like an aluminium plant) to heat consumers (like pulp and paper industry, food industry, vegetable and fish farming etc.). Finally, it may be an option to form regulatory frameworks where taxes and financial support reflect the environmental impact and energy use of the whole the value chains. For instance, new technology enabling use and reuse of aluminium in energy efficient cars and buildings illustrates that the metal can be a important part of a future sustainable society and therefore should still be produced despite the energy intensive process of producing primary aluminium.

However, to form the future framework regulating industry production there must be a balanced approach based on a dialogue between the government/policy makers and the industry. In cooperation, the actors must develop solutions where the national goals regarding energy efficiency and emissions can be met over time, still making it economically attractive for the industry to operate within the requirements and hence, enabling profitable and sustainable industry production. The national legislation comprises national law and regulations which must be leveraged with the international framework. Therefore, it is important for the nations to participate actively in the arenas in Europe and beyond Europe where the international legislation is shaped. This is a challenge for Norway having decided to stay outside EU but to a high degree will be affected by European standards and regulations.

Regarding research and technology development, public-private joint efforts are needed, as well. Sections 3-4 show that progress is needed within a range of scientific areas to develop an energy efficient industry. Important topics relevant across industry sectors are to reduce costs of existing technologies, to develop and verify novel technologies and solutions, and to demonstrate the technologies in large scale implementations. Some topics will require years of high-risk research and only a few of the technologies will be commercialised and generate profits based on the R&D investments. On the other hand, the industry is exposed to international competition and face pay-off times in the range of 1 to 3 years. Hence, there is a huge gap between the industry's time scale and risk aversion and the inherent uncertainty and long-term perspective of R&D. Public funding can contribute to close this gap and enable a fruitful interplay between the stakeholders where new knowledge is developed and shared. [3] points out a well-functioning public support system as a major means for releasing the energy efficiency potentials of the Norwegian industry. The existing public bodies should be coordinated and to some extent integrated to a seamless unit providing adequate support at all stages along the innovation process. It is proposed that the public budgets allocated to improve energy performance are increased to support a national strategy for a sustainable industry. In particular, it is proposed that more efforts should be put into pilot and demonstration activities. But make no mistake about it; in the long run it will be the industry bearing the majority of the costs related to the efficiency improvement.

8. CONCLUSION

The world is facing high standards for reducing energy consumptions and urgent actions must be taken. Several scientific topics should be pursued to bring about technology and solutions relevant across several industries and there are identified potentials for value creation from introducing more efficient energy use in the industry. The inherent uncertain and long-term nature of research and immature/unpredictable framework conditions make it hard for the industry exposed to international competition to make the priorities required to boost the development and deployment of efficiency improvement actions. The challenges regarding energy shortage and greenhouse gas emissions call for long-term and dedicated public-private joint efforts to bring forward and apply technology for energy efficient industry operation. Extensive knowledge building, education and training of competent personnel and international collaboration should be a prioritised. In this way energy efficiency can be a main path for sustainable energy use and for increased value creation.

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10. REFERENCES

[1] IEA *Energy Technology Perspectives 2010: Scenarios and strategies to 2050* (www.iea.org/techno/etp/index.asp)

[2] European Commission (2008) *Securing your energy future: Commission presents energy security, solidarity and efficiency proposals* (http://europa.eu/rapid/pressReleasesAction.do?reference=IP/08/1696)

[3] Energi21 - A collective R&D strategy for the energy sector in Norway. *Report on energy efficiency in the industry* (2010) (In Norwegian) (http://www.energi21.no/servlet/Satellite?c=Page&cid=1253955410657&pagename=energi21%2FHovedsidemal)

[4] Nordtvedt T.S. 2010, Sustainable energy management in an industry park. *9th International Conference on Sustainable Energy Technologies* (SET 2010).

[5] IAI, International Aluminium Institute (http://www.world-aluminium.org) 2011-03-21.

[6] Prepared for DOE by BCS, U.S. *Energy Requirements for Aluminium Production. Historical Perspective, Theoretical Limits and Current Practices*, February 2007, (http://www1.eere.energy.gov/industry/aluminum/pdfs/al_theoretical.pdf)

[7] Tangen, G, Hemmingsen, A. K.T., Nekså, P. 2010, CREATIV: Research-based innovation for industry energy efficiency. To be published in the *Journal of Applied Thermal Engineering, spring 2011*.

[8] Nekså P., Walnum H.T., Hafner A., CO_2-a refrigerant from the past withprospects of being one of the main refrigerants in the future, 9th IIR Gustav Lorentzen Conference 2010, Sydney, April 12e14, ISBN 978-2-913149-74-8, ISSN 0151e1637; 2010.

[9] Harald Taxt Walnum, Yves Ladam, Petter Nekså and Trond Andresen, 2010 Evaluation of Rankine cycles for power production from surplus heat at off-design conditions. *9th International Conference on Sustainable Energy Technologies* (SET 2010).

[10] Teir, S. et al, 2010 *Potential for carbon capture and storage (CCS) in the Nordic region*. VTT Research Notes 2556.

[11] Mølnvik M.J, Tangen G, Røkke N.A. 2010, BIGCCS Centre - Boosting CCS research and innovation. *International Conference on Greenhouse Gas Technologies 2010 (GHGT-10).*

[12] Lorentsen, O.-A., Dyrøy, A. and Karlsen, M, 2009 *Handling CO_2eq from an Aluminium Electrolysis Cell*, TMS, Light Metals 2009, pp. 263-268.

[13] NORDEN – *Top-level research initiative*. Call for proposals: Nordic User Driven Competence Centre for realisation of Carbon Capture and Storage, 2011 (http://www.nordicinnovation.net/article.cfm?id=1-834-972)

[14] Aasen T.M, Amundsen O, Mølnvik M, Tangen G. 2010, Innovation in transdisciplinary and heterogeneous collaborations: exploring new ways of organizing environment-friendly energy research. *COMBI2010* conference, Finland 2010.

[15] Kimura O, 2010, Public R&D and commercialization of energy-efficient technology: A case study of Japanese projects. *Energy Policy* 38 (2010) 7358-7369.

[16] ENOVA 2009, *Potentials for energy efficiency in Norwegian on-shore industry* (in Norwegian) (http://naring.enova.no/sitepageview.aspx?articleID=3573)

[17] Euractive 2010, *Energy efficiency: The EU's new action plan* (http://www.euractiv.com/en/energy-efficiency/energy-efficiency-eus-new-action-plan-linksdossier-496252)

[18] The Sleipner project: http://www.co2captureandstorage.info/project_specific.php?project_id=26