Evaluation of the KME Programme 2010–2013

Consortium Materials Technology for Demonstration and Development of Thermal Energy Processes (KME)

ELFORSK

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R. Nilsson, H. Gåverud, A. Agüero Bruna, R. Blum & C-J Fogelholm

Sammanfattning

Utvärderingens syfte är att analysera den femte perioden (2010-2013) av Elforsks KME-program. Utvärderingen omfattar teknisk och vetenskaplig kvalitet, industri- och energirelevans, måluppfyllelse, resultatspridning, programstyrning etc. Utvärderingen bygger huvudsakligen på genomgång av tillgänglig projektdokumentation, inklusive projektsammanfattningar som utarbetats för utvärderingen, och utvärderingensgruppens möten med företrädare för KMEs styrelse och styrgrupper samt med samtliga projektledare.

Den dominerande övergripande slutsatsen är att KME är ett välfungerande forskningsprogram med ett tydligt mål, aktiva aktörer och en administrativ struktur och funktion som betraktas som mycket bra. Vidare är det uppenbart att KME bidrar till integration mellan näringslivet och universitet och forskningsinstitut på ett mycket positivt sätt. Forskningsverksamheten bedöms i allmänhet ligga på en utmärkt vetenskaplig nivå. Vissa projekt kan betecknas som forskning i internationell toppklass. En annan slutsats är att den konkreta visionen att bidra till att en fullskalig demonstrationsanläggning kommer till stånd är en adekvat tillämpning av KMEs resultat och mål.

Verksamhetens fokus är i alla avseenden i linje med programmets övergripande mål och inriktning. Det projekt som bedrivs i syfte att utveckla en fullskalig demonstrationsanläggning följer emellertid inte helt den tidsplan som fastlades inför programperioden. En viktig anledning till detta är att det inte är klart med en värd för demonstrationsanläggningen. Eftersom ett värdskap kräver ett investeringsbeslut från ett energibolag ligger detta till stor del utanför KME:s möjligheter att påverka. KME planerar emellertid att presentera modellanläggningskonceptet enligt plan. Det kvarstår dock grundläggande tekniska utmaningar inom ramen för projektet, utmaningar som riskerar att kunna innebära att målet inte kan komma att nås. Dessa möjliga begränsningar bör identifieras så snart som möjligt. Detta bör göras innan andra projektspecifika utredningar inleds för att undvika att resurser läggs på anläggningsspecifik verksamhet om det slutligen visar sig att utfallet av de grundläggande undersökningarna är negativt. Vidare bör KME söka efter sätt att utnyttja forskningsresultaten om den planerade demonstations-anläggningen inte kommer till stånd.

Inför en fortsättning av forskningsprogrammet bör balansen mellan insatser som huvudsaklingen fokuserar på ökad bränsle- och lastflexibilitet snarare än på effektivitet och verkningsgrad övervägas. De ekonomiska förutsättningarna för elproduktion förändras och det kan finnas en osäkerhet avseende nyttan med enbart förbättrad effektivitet för anläggningar i det aktuella lastområdet. Samtidigt finns faktorer som talar för att behovet av bränsle- och lastflexibilitet ökar.

En annan övergripande slutsats kring programverksamhet är att det finns ett behov av att fördjupa samarbetet och utbytet mellan de olika projekten, eftersom det finns projekt som arbetar med likartade eller närliggande frågor. I syfte att uppmuntra till mer omfattande samarbete och kunskapsöverföring mellan projekt i den kommande programperioden, kan ett alternativ vara att organisera verksamheten i kluster redan i början av programperioden. En

sådan modell skulle kunna stimulera forskningen generellt, skapa synergier och därmed främja den allmänna utvecklingen av KME.

Inom KME pågår en diskussion om hur programmet bör organiseras. Mer specifikt övervägs om programmet bör fortsätta att vara uppdelat i två delar (delprogram eller dylikt) eller om de två delprogrammen bör inrättas som två separata forskningsprogram. Ett alternativ skulle kunna vara att ha en styrelse/ett programråd för ett fortsatt samlat program och sedan välja styrelse-/programrådsrepresentanter, eller andra representanter som väljs av styrelsen/programrådet, med ansvarar för olika forskningskluster. En sådan modell skulle kunna vara ett effektivt sätt att skapa rutiner för samordning av och kunskapsöverföring mellan projekt och också att skapa förutsättningar för utvecklad medverkan från styrelsen/programrådet i forskningsverksamheten.

Det har under utvärderingen även konstaterats att de naturabidrag som sätts in i programmet från industriella partners i vissa fall överskrider de formellt redovisade bidragen till KME (genom att arbetstid läggs ned i större omfattning än vad som redovisas). Den verkliga budgeten kan således skilja sig från den redovisade budget som beslutats för programperioden vilket får konsekvenser för möjligheterna att följa upp enskilda projekt, såväl som för uppföljning av programmet i sin helhet. En sådan situation är inte önskvärd och intressenterna bör uppmuntras att vara så tydliga som möjligt om nivån på det egna bidraget, såväl naturabidrag som kontantinsatser.

Summary

The purpose of the evaluation is to analyse the fifth period (2010-2013) of Elforsk's KME programme. The evaluation covers both technical and scientific quality, industry relevance, goal achievements, dissemination of the results, programme governance etc. The evaluation is mainly based on review of available project documentation, including extended summaries prepared by the projects for the purpose, and the evaluation group's meetings with representatives of the KME board and steering committees and with all project managers.

The dominating overall conclusion is that KME is a well-functioning research programme with an obvious goal, active stakeholders and an administrative structure and function that has to be considered as very good. Furthermore it is obvious that KME contributes to integration between industry and universities in a very positive way. The research activities are in general on an excellent scientific level. Some of the projects are to be classified as top class researching projects in an international perspective. Another conclusion is that the concrete vision to contribute to a full scale demonstration power plant to be built is a satisfactory application of KME's goals.

The programme's focus is in all respects in line with the programme's overall objective and goals. However, the development of a full-scale demonstration plant is not totally in line with the schedule. A major reason for this is that it is not decided who will host the demonstration plant. Since a host requires an investment decision from an energy company, this is partly beyond KME's influence. However, KME plans to present a concept for the demonstration plant according to the programme description schedule. But some generic questions remain and need to be answered. As long as these questions are not answered, there is an ucertainty on wheter the target can be achieved. Those showstoppers have to be identified as soon as possible. This should be done before other project specific investigations are commenced in order to avoid spill of resources on specific plant activities if the final conclusion on the generic items are negative. Moreover, KME should seek for ways of exploiting the research results in case the plant is not built due to lack of commitment from the present candidates.

Furthermore, the KME management should consider the balance regarding focusing primarily on efficiency rather than fuel flexibility and load flexibility. The economical conditions for power generation vary continously and thus there is an uncertainty regarding the benefits from increased efficiency. Furthermore there are factors that indicate that the demand for fuel flexibility and load flexibility is increasing.

Another conclusion is that there is a need for deepening collaboration and exchange between the different projects since there are projects working on similar or related issues. In order to encourage more extensive collaboration between projects for the subsequent programme period(s), an alternative could be to cluster the activities in the beginning of the programme period. Such a model could improve the research activities further, create synergies and promote the general development of KME.

Within KME there is an ongoing discussion on the organisation of the programme, more specifically if the programme should continue being divided into two parts (subprogrammes or similar) or if the two subprogrammes should be divided into two separate programmes. One alternative could be to have one board/programme council for the programme and then select board/council representatives, or other representatives selected by the board/council, that are responsible for the research clusters. Such a model could be a more effective way to get a routine for coordination of the projects and include involvement of the board/committee representatives in the research activities.

During the evaluation, it has also been found that the in-kind contributions from some industrial customers exceed the formal contributions to KME (by more working time spent in projects than what is reported). Thus the real budget share for the customers might differ from the formal budget share. For the possibilities to follow up individual projects, and also the overall programme, such a situation is not desirable and the stakeholders should be encouraged to be as clear as possible about the level of the own contribution, in kind as well as cash contribution.

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1 Introduction

1.1 Background

Consortium Materials for Thermal Energy Processes, KME, conducts in cooperation with Competence Centre for High Temperature Corrosion, HTC, materials research on thermal energy conversion processes. For the period 2010–2013 KME has a total budget of MSEK 103.5, of which 60% is financed by industrial partners and 40% by the Swedish Energy Agency. KME has been carried out in stages since 1997. The current period 2010–2013 is the fifth in the programme. Since its inception, the programme is administered and coordinated by Elforsk which is a R&D organisation jointly owned by the electricity branch organisation, Swedenergy (75%), and the Swedish transmission system operator, Svenska Kraftnät (25%).

During the period April-May 2013, an evaluation of the 2010–2013 programme period was carried out by Grontmij AB, Ronny Nilsson and Henrik Gåverud, supported by technical experts; Dr. Alina Agüero Bruna from INTA[1] (Spain), recently retired R&D director at DONG Energy thermal power Rudolph Blum (Denmark) and Professor Carl-Johan Fogelholm at Aalto University (Finland). Dr. Agüero has been working with R&D both in the industrial and government sector for more than 24 years in protective coatings for several applications including high temperature corrosion. Rudolph Blum has 40 years expertise in power plant materials performance and development and in development of new advanced power plant concepts achieving highest possible efficiency on coal, gas and biomass. Professor Fogelholm has been working fifteen years at power industries in Switzerland and Finland on several international projects. He has been active in Nordic Energy Researchers, IEA and other international R&D projects during 20 years as professor at Aalto University.

1.2 Purpose and scope of the evaluation

The purpose of the evaluation is to analyse the fifth period of the KME programme. The evaluation covers both technical and scientific quality, industry relevance, goal achievements, dissemination of the results, programme governance etc. Furthermore, the evaluation will provide guidance and recommendations for the design and decisions of a subsequent stage of KME. The complete evaluation directive (in Swedish) follows in Appendix 1.

1.3 Method

During the period 8–11 April 2013, the evaluation group, as presented above, arranged joint meetings with representatives of the KME board and representatives of all KME projects, particularly the project managers but also

[1] National Institute for Aerospace Technology

project members and representatives of the following participating industrial partners: Siemens Industrial Turbomachinery, GKN Aerospace, Sandvik Materials Technology and Sandvik Heating Technology. The meetings took place in Stockholm, Linköping and Gothenburg. A complete overview of the meetings and the meeting participants is available in Appendix 2.

About two weeks before the meetings, extended summaries of the projects were put to the evaluation group’s disposal. It was a major advantage for the evaluation group to have the possibility to have access to these summaries before the meetings. In addition to the extended summaries the evaluation group has also had the possibility to take part of the programme and project descriptions, minutes from board meetings etc., available at the restricted access section of the KME website.

2 Consortium Materials Technology – Programme description

KME is a consortium for material technology development, established in 1997. KME consists of six industrial partners, the Swedish Energy Agency and Elforsk. The industrial partners are Siemens Industrial Turbomachinery, GKN Aerospace (former Volvo Aero), Sandvik Materials Technology (including Kanthal), Sandvik Heating Technology, Outokumpu Stainless and Metso Power. Furthermore, Elforsk represents 18 Swedish energy companies in the consortium.[2] KME's objective is to form a base to make thermal energy processes more effective, i.e. the programme has a broader focus than just material technology. The aim is more effective power and heat production with high fuel flexibility and also to improve utilisation of limited fuel sources and heat sinks for combined heat and power, CHP, as well as to reduce environmental impact. The programme's long-term vision is to improve electrical efficiency and overall efficiency when utilising climate neutral fuels in thermal energy conversion processes. This includes construction of a new full scale demonstration CHP plant in 2017-2018, fired with renewable biofuels and/or refuse fractions, with a higher electrical efficiency than commercial plants that has been built to date. As mentioned in the introduction, the programme is financed by industries (60%) and by the Swedish state, through the Swedish Energy Agency (40%). The 2010–2013 period is the fifth phase of the KME-programme and the budget for the period is 103.5 MSEK.

An important task for KME is to create and encourage cooperation between the industry and the academy. Thus, all KME-projects are performed as close co-operations between enterprises and universities or institutes. The programme is supervised by a board with representatives from the stakeholders. The fifth period of the KME programme constitutes of two subprogrammes, (1) Material Technology, the base programme (MATBAS), and (2) the programme area More Effective Power Production (EPP). Each subprogramme is guided by a steering committee and Elforsk is responsible for programme administration and coordination. As in previous programme periods, the programme is carried out in co-operation with Competence Centre for High Temperature Corrosion, HTC, at Chalmers University.[3]

2.1 Programme focus

In the programme description for KME's fifth phase the long-term vision, the programmes objective and the goals for the actual programme period are stated. Furthermore, KME has also identified a number of success criteria.

[2] Vattenfall, E.ON Värme Sverige AB, E.ON Climate and Renewables (UK), Dong Energy, Fortum Värme, Svensk Fjärrvärme (Swedish District Heating Association), Göteborg Energi, Mälarenergi, Skellefteå Kraft, Växjö Energi, Öresundskraft, Kraftringen Produktion AB (Lunds Energi), Söderenergi, Ena Energi, Eskilstuna Energi & Miljö, Umeå Energi, Falu Energi & Vatten and Tekniska Verken i Linköping.

[3] http://www.htc.chalmers.se/

2.1.1 Long-term vision and goal

The overall long-term vision for KME is to contribute to the conversion to a sustainable energy system by development of more effective energy processes. To put this into practice, the objective is that, by material technology development, improve electrical- and overall (CHP) efficiency when utilizing climate neutral fuels in thermal energy conversion processes. The aim is more effective power and heat production with high fuel flexibility and also to improve utilisation of limited fuel sources and heat sinks for CHP as well as to reduce environmental impact.

A concrete vision of the programme is to, within the time perspective 2017–2018, demonstrate a new full-scale CHP-plant with higher electrical efficiency compared to today's levels for operational commercial plants.

2.1.2 Objective and goals for the 2010-2013 programme period

KME's objective is to contribute to making electricity production using thermal processes with renewable fuels more effective. The programme shall contribute to increasing knowledge to forward the development of thermal processes. Focus is primary on combustion with an effective steam turbine process.

In order to ensure that the current and forthcoming activities is in line with the overall vision and objective, KME has identified a number of goals to be achieved for the 2010-2013 period:

- Presentation of technical solution for a commercial feasible reference power plant as a basis for the demonstration plant
- Deeper understanding and knowledge of material process solutions to prevent super heater and furnace corrosion with advanced steam data[4]
- Lab tests to appoint mechanisms affecting material life time during new advanced steam data requirements
- Exposure tests with partly new boiler super heater materials and compare them with results from cooled material probe tests
- Exposure tests with new alumina forming FeCrAl-materials and explore the possibilities for future use
- Development of improved analysis methods to determine weldability of Ni–based super alloys
- To show that conventional materials can be joined by welding with high temperature materials in order to get more cost effective solutions
- Integration between a new KME-project and the international welding project Weldmat for increased knowledge base
- Validation of materials and surface coatings for coming industrial gas turbine plants optimised for requirements concerning efficiency and robust design (availability and long technical life time)

[4] Material pilot tests in existing boilers with at least 50 degrees Celsius higher steam temperature than have been used to date will be performed.

- Continue to build networks between industry and universities;
  - Contribute to introduction of new associate professors at universities
  - Project participation from post-PhDs, if possible full - or part time employed at one of the industry stake holders
  - At least two licentiate thesis and two PhDs will graduate during the programme period with financial support from the KME-programme
  - At least one degree thesis yearly will be supervised by an industrial stake holder during the programme period
  - Project cooperation with at least one international leading university.

There are also a number of milestones and targets for each year during the programme period. The milestones and targets for 2010-2012 were analysed in the interim evaluation in 2012[5]. In this evaluation for the whole programme period focus will be on the overall goals rather than the milestones. Thus the milestones will not be further described here. However, it might be necessary to consider the milestones and targets in the case that an overall goal not is considered as satisfied.

2.1.3 Success criteria

Besides the vision, objective, goals and milestones KME has also identified a number of success criteria. The purpose of those criteria is likely to put the programme's activities in a broader context and thus make it possible to evaluate the alignment of the programme. The identified success criteria are:

- Possibility to offer industry, authorities and other customers a continuing attractive and concentrated research environment for coordination, problem solving and long term knowledge acquisition within the field of effective thermal processes
- To have active participation from the involved industries in the programme board concerning the implementation and financing of research programmes of common interest to attract larger contributions from potential customers
- The programme has a clear problem solving profile, is competitive internationally and can adapt and strengthen this in accordance with the needs of interested parties and technological or societal developments
- KME renews and expands its circle of interested parties among customers in Sweden
- KME is well established within universities
- KME is marked by a reciprocal exchange of personnel between the R&D environments of the university and the customers

[5] Gåverud, H. and Nilsson, R. (2012), *Interim Evaluation of the KME Programme 2010-2013 – Consortium Materials Technology for Demonstration and Development of Thermal Energy Processes (KME)*

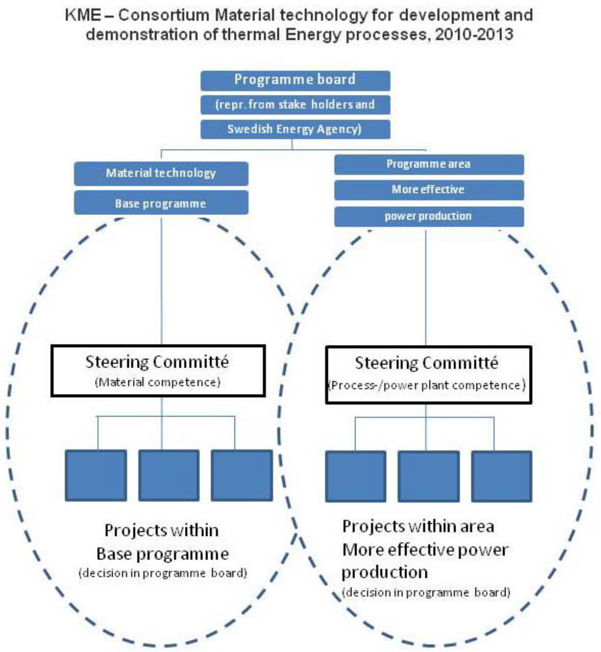
- R&D personnel from the customers are active within the programme's university environment
- KME cooperates and has exchange when appropriate with other research programmes such as HTC, Värmeforsk, Turbokraft and CECOST
- Achieves results that the customers have use of and which lead to scientific qualifications (PhD/licentiate degrees)
- All projects within KME shall publish important results in reputed international journals
- KME cooperates with other research groups and research institutions, primarily within Sweden but also in Europe
- The research programme engages equal numbers of men and women and has a representative ethnic balance in the programme board, steering committees and project reference groups

The Swedish Energy Agency is supposed to follow up the programme through reviews of results and with indicators.

2.2 Organisation

Activities within the KME programme are divided into two subprogrammes; the base programme on material technology (MATBAS) and the programme area More Effective Power Production (EPP). Each subprogramme has a steering committee but it is the KME programme board that is responsible for all activities within the programme.

Figure 1 KME organisation



A programme manager at Elforsk leads and administrates the work within KME. Since the start of the programme in 1997 Erik Skog has had the role as board chairman. Furthermore, the board constitutes of representatives from participating companies, universities and Swedish Energy Agency. Formally, the programme board members are approved by the Swedish Energy Agency in order to ensure that the board members have a broad knowledge base, with competence in, among other fields, process technology and material technology. The programme board is responsible for and approval of project decisions for KME.

However, it is the steering committees that have the monitoring role and to ensure that the activities are carried out as planned. In order to provide a satisfactory specialist competence, interested parties are invited to participate in the committees. The chair for each steering committee reports to the KME board. Both committees should provide an annual updated activities plan for their programme area for approval by the KME board.

2.3 Financing

As mentioned, KME is financed by industry companies (60%) and the Swedish Energy Agency (40%). The total budget for the current four year period, 2010-2013, is 103.5 MSEK, see Table 1.

Table 1 KME's financing 2010-2013, kSEK

Industry customer	Administrative contribution (percentage)*	In-kind and cash project contribution (of which is cash contribution)	Total contribution	Percentage of KME's total budget
Siemens Industrial Turbomachinery AB	160	17 500	17 660	17 %
Vattenfall AB	160	9 667 (1 252)	9 827	9 %
GKN Aerospace Sweden AB (former Volvo Aero AB)	160	5 785	5 945	6 %
Sandvik Materials Technology AB	160	5 604 (680)	5 764	6 %
Sandvik Heating Technology AB	160	5 102	5 262	5 %
E.ON Värme Sverige AB	160	2 865	3 025	3 %
AB Fortum Värme samägt med Stockholm stad	160	1 957(930)	2 117	2 %
Dong Energy A/S (Denmark)	160	1 840	2 000	2 %
E.ON Climate and Renewables (UK)	-	2 000	2 000	2 %
Metso Power	160	1 832 (100)	1 992	2 %
Outokumpu Stainless AB	160	1 256	1 416	1 %
Other energy companies**	3 011	2 229 (2 229)	5 240	5 %
Industry customers, total	4 611 (44 %)	57 637 (5 191)	62 248	60 %
Swedish Energy Agency	5 789 (56 %)	35 438 (35 438)	41 227	40 %
KME Programme, total	10 400	93 075	103 475	100 %

*) Administrative contributions cover costs for administration (i.e. Elforsk's contribution), a position as adjunct professor at Chalmers University, seminars, reports and evaluations.

**) Ena Energi AB, Eskilstuna Energi och Miljö AB, Falu Energi & Vatten AB, Göteborg Energi AB, Kraftringen Produktion AB, Mälarenergi AB, Skellefteå Kraft AB, Svensk Fjärrvärme AB, Söderenergi AB, Tekniska Verken i Linköping AB, Umeå Energi AB, Växjö Energi AB and Öresundskraft AB.

Both payments and in-kind financing is included in the table. In-kind financing refers to participation and commitment in research projects and can be both human resources and utilisation of technical equipment (e.g. a boiler). Swedish Energy Agency has formed guidelines on how in-kind financing should be calculated – each participating company's in-kind financing is calculated according to these guidelines.

As shown the major part of the contributions from the industrial participants is in-kind financing; less than 10 % of the total contributions from the industry are cash contributions, mainly from the energy sector companies.

An administration fee is included in the totals. The administration fee is the same amount for all members of the consortium and covers all programme administration. This also includes the position as adjunct professor at Chalmers, held by Erik Skog, for project initiation, strategic planning and result feedback in KME and also in HTC and Värmeforsk. The administration fee for the current period amounts SEK 40 000 per year for each company, i.e. SEK 160 000 for the whole period. The energy companies that participate active in the projects (named "Other energy companies" in the table) contribute with an amount between SEK 44 000 and SEK 920 000 for the whole programme period. These contributions, in total MSEK 5.24, are mainly used for administration (57.5 %) and KME 601 (36 %).[6]

2.4 Programme areas and projects

As mentioned, KME is divided into two subprogrammes for the 2010-2013 programme phase – the base programme on materials technology and a programme area covering activities on more effective power production. The programme area More Effective Power Production includes partly new activities within process technology, plant technology and financial analysis, with the goal of successively being able to demonstrate more effective and profitable thermal processes for electricity production in comparison to present day technology. The base programme is a direct continuation of KME's activities in previous programme periods and provides materials technology support for the programme's activities on more effective power production. In Table 2 and Table 3 on the forthcoming pages the ongoing projects in respective subprogramme area are listed. More detailed information on each project's focus will follow in chapter 3.

[6] SEK 300 000 is used within KME 509 and SEK 29 000 within KME 508.

Table 2 KME Projects in the Materials Technology Base Programme 2010–2013

Project	Project Name	Total Project Budget, kSEK	Performed by	Industry Partners	Project Manager
KME 501	Long term high temperature behaviour of advanced heat resistant materials	6 982	Linköping University	AB Sandvik Materials Technology	Sten Johansson
KME 502	Fatigue in nickel-based superalloys under LCF and TMF conditions	12 467	Linköping University	Siemens	Johan Moverare
KME 503	New Durable MCrAlX Coatings for High Temperature and Corrosive Environment Applications in Advanced Engines	2 327	Linköping University	Siemens	Ru Peng
KME 504	Correlation between deposit chemistry and initial corrosion of super heaters	2 294	Swerea KIMAB and SP	Vattenfall	Rikard Norling
KME 505	Properties of alloyed MoSi2 matrix composite for hot corrosion and elevated temperature components of gas turbine	1 995	Chalmers	Siemens and Sandvik Heating Technology	Yiming Yao
KME 506	Weldability Limits for Superalloys in High Temperature Applications for Gas Turbines	9 459	Chalmers	GKN Aerospace	Lars Nyborg
KME 507	FeCrAl alloys for components in biomass and refuse fuelled boilers – prestudy	6 483	HTC	Sandvik Heating Technology, E.ON Värme, Vattenfall and Metso Power	Kristina Hellström
KME 508	Furnace wall corrosion in biomass and waste-fired boilers at higher steam pressures	11 509	KIMAB, SP and KTH	Sandvik Heating Technology, Sandvik Materials Technology, Outokumpu, E.ON Värme, Vattenfall, E.ON Climate and Renewables and Metso Power	Pamela Henderson
KME 509	Concentrated approach on super heater corrosion in boilers fuelled with biomass and refuse	3 491	HTC	E.ON Värme and Metso Power	Jesper Liske
KME 510	Design of a new generation of 12% chromium steels	3 325	Chalmers	Siemens and Dong Energy	Hans-Olof Andrén
KME 511	Critical corrosion phenomena in power generation from biomass – Identification of chlorine resistant high temperature coatings/materials	1 733	HTC	Dong Energy	Torbjörn Jonsson
KME 512	Fuel additives to reduce corrosion at elevated steam data in biomass boilers	2 552	Vattenfall Research and Development, SP, Åbo Akademi	E.ON Värme Sverige, E.ON Climate and Renewables, Metso, Outokumpu, Sandvik Heating Technology	Maria Jonsson, Vattenfall
KME 514	Increased electrical efficiency and service life assessment of super heaters from combustion of difficult fuels	2 511	HTC	Fortum	Jesper Liske
KME 515 (Expansion of KME 508)	Furnace wall corrosion in biomass and waste- fired boilers at higher steam pressures	300	Vattenfall and SP	Vattenfall	Pamela Henderson, Vattenfall
KME 518 (Extension of KME 506)	Weldability of superalloys - physical metallurgy extension	158	Chalmers	GKN Aerospace	Lars Nyborg
KME 519	FeCrAl alloys as components in biomass- and waste fired boilers with sulphur additives	1 929	HTC	Sandvik Heating Technology	Kristina Hellström
KME 520 (Extension of KME 503)	Extension of the project KME 503 on "New Durable MCrAlX Coatings for High Temperature and Corrosive Environment Applications in Advanced Engines	1 214	Linköping University	Siemens	Ru Peng
KME 521	Thermomechanical fatigue in virgin and aged stainless steels	1 673	Linköping University	Sandvik Heating Technology	Johan Moverare

Table 3 KME Projects in the Programme Area More Effective Power Production 2010–2013

Project	Project Name	Total Project Budget, kSEK	Performed by	Industry Partners	Project Manager
KME 601	More Effective Power Production from Renewable Fuels – Reference Power Plant (RPP)	4 300	Pöyry Swedpower (former Vattenfall Power Consultant)/ Konsultbyrån Skog KB	Siemens, Metso Power, Vattenfall, E.ON Värme, Fortum Värme, Kraftringen Produktion, Svensk Fjärrvärme, Göteborg Energi, Mälarenergi, Skellefteå Kraft, Växjö Energi, Öresundskraft, Söderenergi	Erik Skog
KME 606[7]	Procurement investigation within KME's part programme, more efficient electricity production with renewable fuels	Financed outside KME's budget	Styrman and Manergy	-	Bengt Wegemo and Olle Mårdsjö
KME 607	Improved steam turbine design for optimum efficiency and reduced cost of ownership	4 825	Lund University	Siemens Industry Turbine	Magnus Genrup
KME 608	Study of corrosion memory in boiler heat surfaces by field tests with biomass fuel mixes including sulphur and refuse fractions	1 750	Pöyry Swedpower (former Vattenfall Power Consultant)/HTC	E.ON Värme, E.ON Climate and Renewables, Sandvik MT	Lars Wrangensten

[7] KME 606 is not financed by the KME-programme. The project is instead financed as a separate Elforsk project.

3 Project evaluations

In previous programme periods KME's focus has been basically on material technology, i.e. this is the first period with a programme area on more effective power production. The reason for the increased focus on more effective power production, and in particular the goal to establish a demonstration plant with increased efficiency, is to further ensure that the research within the programme is practical beneficial and applicable. Furthermore, it is understood as there should be an overall focus in all projects to contribute to the solution for the planned reference power plant concept with increased efficiency. The plant should be a full scale demonstration plant, completed in 2017–2018. Hereby, the project KME 601, More Effective Power Production from Renewable Fuels – Reference Power Plant Project, occupies a coordinating role.

In this chapter each project is described and analysed. The descriptions are based on the project's published documents (extended summary, status reports etc.) and the presentations made during the meetings with the project managers, project members and/or industrial partner representatives. The analyses of the projects have been done from both an overall programme perspective and from a scientific perspective for each project.

The evaluation group found it useful to divide the projects in five groups, depending on which of the programmes goal the project is aimed to support. These five groups are:

(1) Projects involving specific activities supporting the development of a reference power plant

(2) Projects related to materials technology and design activities for the development of the reference power plant

(3) Projects aiming at providing general knowledge supporting the development of a reference power plant

(4) Projects specifically related to improved gas turbine performance

(5) Projects concerning high temperature material for thick section boiler components and steam lines in steam power plants.

Projects in each subgroup are considered in conjunction.

3.1 Projects involving specific activities supporting the development of a reference power plant

In this section the projects that have the main focus on the development of a reference power plant will be reviewed. These projects are KME 601 and KME 606.

3.1.1 KME 601 More Effective Power Production from Renewable Fuels – Reference Power Plant Project

The goal for this project is to create and update reference power plant(s) concepts in cooperation and dialogue with the steering group for the subprogramme More Effective Power Production and the KME stakeholders. The reference power plant model concept(s) is presented to aim to be realised in demonstration project(s) and will be moving target(s) that will be elaborated along with new findings and results from projects within the programme. This project should be seen as a base for evaluation, prioritisation and coordination of project proposals in order to secure that the projects are mainly supporting common objectives stated in the programme description.

Evaluation Review

The goal for the project is considered as clear and ambitious, stimulating for all other projects in the KME programme. However, the market for this type of production plants – biofuel CHP for plant sizes less than 100 MW_e – is rather specific for Sweden and to some extent to the other Nordic countries, Germany and Austria. There can be concerns as to how realistic it would be to obtain a major improvement of efficiency by elevated steam parameters for this relative small plant sizes. Shortage of customers may influence the manufacturer’s interest to develop the concept just for the limited Scandinavian market.

The project has identified the main challenges for improved efficiency by elevating steam parameters, in particular corrosion related to exposure of potassium chloride from the biomass atmosphere in superheater sections of the boiler, but also plumbum corrosion for a wider range of fuels, creep in loop seal beds, corrosion attacks in furnace walls etc. should be mentioned. A list of prioritized areas of research to solve the main problems has been prepared in an excellent way. This study could have been used to better focus the programme if the results had been available at an early phase of the current KME programme period. Some very important issues have not been yet addressed, such as carrying out tests with superheater tubes and probes in loop seals at steam temperature up to 620 ºC, and to evaluate easy and frequent replacement of materials versus use of expensive materials.

It is therefore advised that project activities within KME should be directed in greater extent to solve problems related to the high temperature performance of superheater sections in the flue gas flow and the final superheater in the loop seal bed. In existing boilers the main problem in loop seal superheaters is erosion. With higher steam data the materials issues related to corrosion will increase. Materials for the loop seal should either be resistant to corrosion or coated. Alternatively any exposure of potassium chloride should be avoided. For other superheaters, exposed to more moderate biomass atmosphere, the efforts should be directed to finding materials with an acceptable lifetime and coatings should also be considered. Preferably these issues are addressed immediately by the project, and validation of materials up to these temperatures should be undertaken. But this is probably not possible given the actual budget situation (a further discussion on this will follow in chapter 4 and 5). The advice is, however, to start these activities as soon as possible since these problems can be showstoppers for the major programme goal. Thus it is vital that activities are started soon to reveal the problems. The ongoing projects in the MATBAS subprogramme do not fulfil these needs completely.

As presently there is no real commitment by any of the stakeholders to build the reference power plant. However, even if the plant is not built, benefits will still be acquired by increasing knowledge regarding materials operating at more extreme conditions. In order to decrease the risks associated with the project on a reference power plant, efforts should also be directed to increase fuel and load flexibility.

3.1.2 KME 606 Procurement Investigation within KME’s Part Programme, More Efficient Electricity Production with Renewable Fuels

This project is an investigation on the conditions for the purchase of the two main components in a plant, the boiler and the turbine. The objective is to analyse the possibilities to, within KME’s demonstration programme, carry out procurement of the more advanced technical solutions required for the demonstration plant within the KME programme. The study is done within KME but is financed as a separate Elforsk project, as it does not comply with the rules on how the Swedish Energy Agency’s contributions are allowed to be used within the programme. The project is not as extensive as other KME-projects, both the budget and the time schedule are more limited and there is no reference group assigned to the project. The project started in March 2012 and a final report from the project was presented at the KME conference in Gothenburg in November 2012. It was decided to not present the report as an official KME report.[8]

Evaluation Review

The study is not reviewed in same extent as other projects since it is not financed within KME and was not intended to have an academic approach. An overview of the project report shows general conclusions regarding

[8] Minutes from board meeting 2013-02-07

procurement procedures and procurement rules which may be applicable for the type of demonstration plant EPP aims to provide.

3.2 Projects related to material technology and design activities for the development of the reference power plant

Projects within this group address very specific details in relation with the Reference Power Plant.

3.2.1 KME 501 Long Term High Temperature Behaviour of Advanced Heat Resistant Materials

In this project the long term high temperature behaviour of advanced heat resistant austenitic and nickel base materials are evaluated. The aims of the project are presented as improved understanding of

1. Influence of low and very low strain rates (down to 10-6/s) on the deformation, damage and cracking behaviour,
2. Influence of long term ageing (up to 30 000 hours) and tough environments on the structure integrity and safety, and
3. Influence of cold deformation on the stress relaxation cracking behaviour.

During the project dynamic strain ageing behaviour and ageing of heat resistant stainless steels[9] have been done. The material preparation for the study of stress relaxation behaviour has been performed and the study is ongoing and will be finalised during 2014.

Evaluation Review

The work presented is considered to be of high scientific quality, but more a PhD project than an industrial R&D project. The project offers good possibilities to write a PhD thesis. This could justify the existence of the project also if the industry relevance might be uncertain, since one KME goal is to generate PhD theses. Anyhow, the criteria for the selection of the studied materials can be considered doubtful since the chosen materials have been subjected to similar tests and studies that have been reported during several years. More convenient could be to include a more thorough survey of existing data regarding the mechanical properties for said materials (Sandvik, the AD700-project[10] and USC power plant projects[11] have for example a lot of proven data, including Sanicro 25). It is advised to reconsider selection of materials, relevant testing and timing in relation to the KME-programme’s fundamental goal.

[9] AISI 310M, Sanicro 25, Sanicro 28, Alloy 800HT, Alloy 617

[10] The research project AD700 is a joint European project involving more than thirty manufacturers, operators and organisations.

[11] U. S. Program on materials technology for USC (Ultrasupercritical) power plants

The project's presented publications list[12], containing five scientific publications prepared for presentation and publishing, is impressing.

3.2.2 KME 521 Thermomechanical Fatigue in Virgin and Aged Stainless Steels

The project was accepted by the KME board in October 2012 and started as recently as in March 2013. The purpose of the project is to evaluate and rank the susceptibility to thermomechanical fatigue damage of several austenitic materials. The underlying mechanisms will be studied in order to better take the effect of temperature and straining history into account from a component perspective.

The project plan includes thermomechanical fatigue testing at maximum temperature 800°C and long term ageing performed at 800°C for 2000 hours. Investigation of deformation and damage mechanisms by SEM[13] will also be done during the project.

Evaluation Review

The project is similar in focus and structure to KME 501. The same concerns as for KME 501 regarding selection of materials and timing in relation to the major goal for the programme apply. The materials intended for testing have been thoroughly studied in other research programmes and the planned tests do not include testing of the materials' resistance to high temperature corrosion under influence of the atmosphere present in a biomass boiler.

3.2.3 KME 607 Improved Steam Turbine Design for Optimum Efficiency and Reduced Cost of Ownership

This project aims at evaluating the maximum cost effective efficiency potential of industrial steam turbines, by introducing improved blade profiles and advanced blade stacking technologies. The project is intended to explore the future path for higher-performing steam turbine plants with emphasis on demonstration within the KME-project. The ultimate goal is reduced cost of ownership from increased production revenues. The goal for increased stage efficiency with advanced blade rows is 2%.

More specifically the work has been directed at improving the Siemens SST-900 by increasing the performance, to the level of state-of-the-art technology for large turbines. Large size turbines have both larger volumetric flows and

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[12] One paper to ECF 19, 2012, Tata rep. Russia has been published, which was selected to be published on the Journal of Applied Mechanics: "Influence of dynamic strain ageing on damage in austenitic stainless steels"; two papers have been accepted to be published at ICF 13, 2013, Beijing China, "Damage and fracture behaviours in advanced heat resistant materials during slow strain rate test at elevated temperature" and "Influence of high temperature ageing on the toughness of advanced heat resistant materials"; two papers have been accepted to be published at MSMF7, 2013, Brno, Czech Republic, "Advanced microstructure studies of austenitic materials using EBSD in high-temperature in-situ tensile testing in SEM." and "Damage and fracture behaviors in aged austenitic materials during high-temperature slow strain rate testing".

[13] Scanning electron microscope

expansion ratios (or pressure ratios). An industrial turbine has, on the other hand, typically both lower flows and pressure ratios and therefore lower efficiency potential. The lag between the industrial- and utility size is unnecessary large and cannot be explained by the size reasoning alone. A significant part of the difference is due to the lower technology level.

The project work is based on a traditional design approach for turbomachinery and the design is created in an iterative fashion. The first part was to establish the baseline within the computational toolbox. The turbine baseline steam turbine geometry have been implemented and modelled in AxCent (through flow blade geometries) and Ansys CFX (Turbogrid). The implementation in the design system revealed some issues related to the datum/reference turbine blade geometry definitions.

The next step in the project is to optimize the blade profiles and stacking into three-dimensional stators and rotors.

A Ph.D.-student was recruited from India during summer 2012. The student was not in place in early November 2012 due to the expatriation process from India to Sweden and a two month notice time from his employer in India after the employment process. The Ph.D.-student has a strong background in the turbomachinery industry and the delay is not considered as a significant issue with respect to the time plan.

Evaluation Review

The project is directed to optimize blading for smaller steam turbines, which fit with the needs for the chosen plant size range for the KME demonstration power plant. In spite of the fact that the project supports the major goal for the programme and therefore the evaluation group should have no critical concerns for the project as such. Anyhow, it is questionable if a major improvement can be obtained when unit size of 100 MW or even less is the goal. .The project does not directly aim at solving the problems that could be showstoppers for the attainment of the major programme goal. Thus, the benefits from this project are to a large extent dependent on solutions on the fundamental challenges. The general advice is that KME should await starting projects that are not dealing with the main problems related to higher steam data for biofuel boilers until the specific basics for the major goal are investigated and found realistic.

3.3 Projects aiming at providing general knowledge supporting the development of the reference power plant

The projects within this group address material corrosion issues under biomass combustion, clearly the main issue affecting the reference plant.

3.3.1 KME 504 Correlation between Deposit Chemistry and Initial Corrosion of Superheaters

The main goals for the project is to quantify the deposit composition and the distribution of various compounds when injecting additives at various rates and see the effect on initial corrosion on different alloys at (steam) temperatures up to 600°C and to identify critical mechanisms for the initial corrosion in relation to deposit chemistry. The work is directed on making it possible to establish schemes for controlled dosage of additives, such as ammonium sulphate/phosphate.

The project is a continuation of a KME project in the 2006-2009 programme period, KME 408. Controlled pilot-scale exposures have been conducted at the 12 MW pilot CFB at Chalmers to study influence of excess air and sulphate and phosphate injection with specific focus on comparing the effects of sulphate and phosphate injection. Full scale verification tests have been performed at Vattenfall’s full scale BFB in Jordbro. Samples have partially been analyzed and further analyzes are ongoing. Preliminary results show consistency between the results from the pilot tests and the full scale tests and the project goals are expected to be met.

Evaluation Review

The project is considered as a very interesting investigation of diammonium sulphate and mono ammonium phosphate as well as the effect of the amount of excess of air for reducing the chloride content in the gas phase and in deposits. Full scale has been performed with diammonium sulphate, which gives clear verification of the pilot tests.

When completed, the investigation will provide an improved understanding of initial corrosion and the effects of additives. The results are important as a guideline for deposit and corrosion analysis.

3.3.2 KME 508 and KME 515[14] Furnace Wall Corrosion in Biomass-fired Boilers at Higher Steam Temperatures and Pressures

The project goal is to give recommendations about how to avoid water wall corrosion at increased boiler electrical efficiency/increased steam data when burning biomass and waste wood mixes. A review of experiences in biomass boilers is made which includes additives and current measures for reducing wall corrosion – design, operation and materials. The environment near the furnace is characterised for a variety of fuels and the deposits formed at different wall temperatures are collected by using wall probes. The chemical composition of deposits, compounds present and initial corrosion is analysed. Thermodynamic equilibrium calculations using chemical composition of fuel to evaluate the condensation behaviour at different temperatures are performed and the theoretical results compared to the experimental ones from deposits are analysed. Tests of water wall corrosion with different fuel mixes and different materials/coatings are performed with probes to evaluate at which temperatures there is increased risk for corrosion and for which materials and fuels.

Evaluation Review

The project exhibits an example of a very broad and impressing participation from different companies and academic environments – Vattenfall R&D (project management, measurements, calculations), Vattenfall Nordic heat

[14] KME 515 is an additional funding (300 kSEK) of KME 508 due to extra costs for ash particle measurements with impactor technology.

(testing support), E.ON (provision of deposits and tubes from different parts of furnace walls in boilers running on waste wood mixes), Metso (thermodynamic equilibrium calculations), Sandvik and Outokumpu (provision of material for testing, material knowledge and support), KTH (Development and evaluation of FeCrAl alloys, long term studies in lab furnace etc), KIMAB (deposit analysis and initial corrosion of short-term probe specimens), SP (impact or measurements in furnace) – which is worth emphasizing.

Among scientific results, the behaviour of coating materials on water walls shows that some materials reduce corrosion substantially, especially Ni-based alloys and to some extent FeCrAl materials and austenitic steels. The work indicates that stainless steels could be a good (and much cheaper) alternative to Ni-base alloys for protecting furnace walls. The method of applying the coating has been found to be critically important. In general, the thermally sprayed coatings did not adhere as well as the weld overlay coatings.

Also tests with additives have been performed showing that sewage sludge shows promising results but needs to be further investigated.

The project has collected a substantial amount of plant data about corrosion attack and means to avoid or reduce it. Such data is valuable for input to more detailed and thorough investigations as for instance modelling and establishing corrosion mechanisms. The evaluation group supports continuation of this type of activities.

3.3.3 KME 509 Improved Determination of Service Life of Superheaters in Boilers Burning Biomass and Waste

The project focuses on understanding the discrepancy between corrosion rate measurements using cooled probes and the corrosion rate of the real superheater. This is done by comparing time resolved cooled probe corrosion rate measurements with exposures of sample materials installed in the superheater tube loop. The results are intended to be used to facilitate the development of models for determination of the service life of superheater materials as a function of material temperature.

The project reports the following conclusions:

- The (large) exposure matrix went well and corrosion probes up to 5600 hours have been exposed in a time resolved manner.
- The corrosion rate of the probes and the tubes were similar, showing only small differences.
- The corrosion rate was generally low and at 420°C (current superheater temperature), near the detection limit. This correlates well with corrosion rate of the superheaters installed today which show low material wastages (life time today 12 years).
- At 500°C and long exposure times, a corrosive effect of the soot blower was observed as the sample surface facing was more corroded.
- The start-up of exposure seems to be of great importance for the overall corrosion rate (especially for shorter exposure times). Starting up by placing the probes directly into a hot boiler appears to give rise to a more severe corrosion attack.

Evaluation Review

The project is considered very substantial, showing how this kind of testing both cooled corrosion probes and mesurements from real superheatertubes should be accomplished. The project reveals important results regarding exposure time and temperature (up to 500 °C), exposure methodology, position of samples and in particular, the substantial difference in terms of corrosion resistance when the materials experience cold or hot start ups when tested. The relevance of the project is enhanced by testing several materials.[15]

3.3.4 KME 511 Critical Corrosion Phenomena in Power Generation from Biomass – Identification of Chlorine Resistant High Temperature Coatings/Materials

The overall goal for this project is to identify possible coatings/materials for superheater tubes, which allows an outlet steam temperature of at least 580°C on biomass converted fossil-fired units. This will be achieved by generating fundamental knowledge about the high temperature corrosion mechanisms in the presence of chlorine. Focus in this project is on chlorine induced corrosion and identification of new coatings/materials that are more chlorine resistant.

The project is performed in cooperation between HTC and Dong Energy. The first stage of the project have been fully completed, involving thermodynamic calculations in order to identify materials with low reactivity towards KCl and reference exposures of uncoated materials in the presence of KCl. Interesting superheater samples from straw-fired plants have been selected for investigation with advanced microscopy in order to give input to the project.

The second stage of the project is in progress, where the most promising materials will be exposed first in an O_2 and H_2O mixture without KCl in order to create references and then in the presence of KCl. Finally, in a third stage advanced microscopy will be performed on selected samples to characterize the corrosion attack. The third step is in an initial planning phase so far.

Evaluation Review

The project is considered as a solid and basic project for understanding of KCl corrosion on different materials and coatings in order to find a suitable coating. Alumina and nickel have already been selected as the most suitable materials. The reported results so far have demonstrated the complexity of the corrosion mechanism under these conditions. This project is very relevant and promising and it is recommended for continuation.

3.3.5 KME 512 Fuel Additives to Reduce Corrosion at Elevated Steam Data in Biomass Boilers

The use of additives/fuel blends to reduce the amount and/or corrosivity of deposits and slag on the furnace walls is one of the possible solutions to decrease furnace wall corrosion in plants that operate today at conventional/commercial steam data levels. There is little information

[15] 13CrMo44, 347H, 310H, Sanicro28, Inconel625, KanthalAPMT

available today on the use of additives or fuel blends to reduce furnace wall corrosion. The project is identifying and evaluating the use of additives and fuel blends to reduce furnace wall, and possibly also superheater corrosion for various biomass fuel mixes including waste wood. The project aims to give a recommendation if additives are a viable way to reduce corrosion and, in that case, recommend promising additive candidates for further evaluation.

At the time of the evaluation approximately half of the laboratory work, all of chemical fractionations and more than half of thermodynamic equilibrium calculations have been performed. Analyses of results from the lab tests are ongoing. First conclusions are expected to be available during spring 2013, which will form basis for continued work (second set of lab tests, evaluation of costs and practical aspects for the additives).

Task 1, which is fully completed including an inventory of possible additives, resulted in the selection of five different additives to investigate.[16] All other tasks are ongoing.

Evaluation Review
Understanding the effects of different types of additives (some sulphur free) is considered very useful. Moreover an economic cost-benefit analysis for the promising types of additives is considered as an important asset. A continuation of these efforts should be supported.

The project shows an impressive list of participants including international, as two different E.ON affiliates[17] and Åbo University.

3.3.6 KME 514 Increased Electrical Efficiency and Service Life Assessment of Super Heaters from Combustion of Difficult Fuels

This project aims to provide a model for more reliable assessments of the service life of superheaters, at current steam temperatures as well as higher steam temperatures. The project is also putting a special emphasis on the deposit growth and deposit chemistry linked to the boiler performance. The project shares its overall goal with the KME 509 project and the same research staff is involved in both projects, although the industrial partners are different. In KME 509 it is mainly E.ON and in KME 514 it is Fortum. The goal is to demonstrate the possibility to obtain a general, boiler independent, life time prediction model.

Field tests have been carried out in Fortum's CFB, P6, in Högdalen.[18]

Evaluation Review
In principle the project is considered as very valuable, as an assessment technology is needed. The studied areas were chosen due to practical circumstances but may not represent the areas more susceptible to corrosion. As field testing is the only reliable method for obtaining corrosions and mechanisms, it is vital that these exposures are executed in the most

[16] Sulphur, kaolin, digested sewage sludge, limestone and foundry sand
[17] E.ON New Build & Technology Limited and E.ON Climate & Renewables
[18] Foster-Wheeler, 91 MW_{th}, 60 bar/425 °C

corrosion exposed areas. Such data should be used to improve the laboratory based models.

The project also involves studies of correlations between corrosion attack and the chemical composition of deposits. The tests have been carried out but analysis is still pending.

3.3.7 KME 507 FeCrAl Alloys as Components in Biomass- and Waste-Fired Boilers

The aim of this project is to identify and understand the usefulness and limitations of FeCrAl materials as components for biomass- and waste-fired boilers. Exposures of a number of chosen components, manufactured of these alloys, are conducted in an industrial waste fired boiler (corrosion probe tests). In addition well-controlled exposure in the laboratory is conducted. The purpose is to expose aluminium oxide forming materials in different environments and temperatures. The corrosion properties of commercial (FeCrAl) materials in this type of environments are investigated. A number of analytical methods are used which will give a thorough understanding of the formed oxide and oxidation process, specifically influence of exposure time, influence of water vapour and alkali salts as well as the effect of pre-oxidation prior to testing.

The laboratory tests performed shows very interesting results:

- KCl strongly accelerates the corrosion of Kanthal® APMT in O_2 + H_2O at 600 °C.
- Pre-oxidation at 900 and 1100°C results in a duplex continuous α-Al_2O_3 scaleand has a strong beneficial effect on the corrosion behaviour on Kanthal® APMT in the presence of KCl at 600 °C.
- The corrosion of the pre-oxidized material appears to start at defects in the protective scale

Evaluation Review

The project describes the corrosive behaviour of KCl + O_2 + H_2O on FeCrAl (Kanthal APMT) and how the corrosion attack can be reduced by peroxidising the material. The investigations are very thorough and carried out at 600 and 700º C, very much in line with the requirements of the reference power plant. However, it is recognized that the mechanical properties of this material need to be improved for it to be used to manufacture load bearing components. It would be more meaningful if instead of studing the bulk material, is is a pplied as a coating by thermal spray or welding.

The laboratory investigation shows alumina as a promising protective oxide to prevent KCl attack if it is free of defects. Pre-oxidation stimulates the benefit of the protection. Results from plant exposures are currently being analysed. As coatings seems to be an effective measure for avoiding or minimising fire side corrosion in bio mass boilers further investigations in this area are very welcome especially comprising in-plant test with test material incerted in an existing superheater.

3.3.8 KME 519 FeCrAl Alloys as Components in Biomass- and Waste Fired Boilers with Sulphur Additives.

The aim of this project is to understand the usability and limitations of alumina forming alloys in biomass and waste fired boilers when employing sulphur to determine its potential benefits. The work is focused on identifying mechanisms behind the corrosion and to find ways to alleviate the high temperature corrosion problems. For the investigation FeCrAl alloys in a biomass or waste fuelled boiler comparisons with conventional superheater materials will be performed.

The project started in April 2012 and the performed laboratory tests indicate a beneficial effect of S in terms of the alumina scale growth.

Evaluation Review

The project studies the effects of sulphur containing additives on FeCrAl materials at exposure times up to 168 hours and temperatures up to 600 ºC. First findings indicate that the oxidation rate is very low both in the presence and absence of SO_2, but in its presence, alumina outwards growth seem to be inhibited. It was also found that alumina prevents sulphur to enter within the alloy.

The same study will be carried out on pre-oxidised samples.

This is a fundamental study that can contribute to better understanding on how to protect materials from biomass corrosion. As in the previous project, the material should be applied and studied as a coating.

3.3.9 KME 608 Study of Corrosion Memory in Boiler Heat Surfaces by Field Tests with Biomass Fuel Mixes including Sulphur and Refuse Fractions

The aim of the project is to study the corrosion behaviour while alternating fuel type. The first set of samples has already been exposed and depending on the exposure sequence, different results are obtained.

Evaluation Review

The project has recently started. The project will study the effect of changing fuels on the corrosion behaviour on already exposed materials. The aim of the project is to demonstrate operation with wide fuel range/variations and still have a control of corrosion. This is considered as an important issue and the project should be supported.

3.4 Projects specifically related to improved gas turbine performance

These projects deal with several aspects of Ni base superalloys employed in gas turbines. This group of projects does not have direct relevance with the design and construction of the reference power plant. However increasing the efficiency and improving the materials behaviour in gas turbine are important issues that certainly merit efforts and dedication.

3.4.1 KME 502 Fatigue in Nickel-based Superalloys under LCF and TMF Conditions

In this project low-cycle fatigue (LCF) and thermo-mechanical fatigue (TMF) testing is carried out on selected Ni base superalloys The project is a continuation of previous KME projects KME 403 and KME 410, but intended to have more focus on more component-near conditions e.g. influence of multiaxial stress states at notches, environmental impact (oxidation) on fatigue and aspects of life time assessments of long term exposed material. The intention is also to study crack propagation under thermo-mechanical fatigue conditions, with emphasis on environmental impact from oxidation and corrosion.

Specific aims for the project is, according to the presentation made during the evaluation, (1) to improve the knowledge regarding the mechanisms that govern crack initiation and propagation under TMF conditions and to develop models that can be used to predict the service life of hot components in gas turbines and (2) to support the incorporation of micro structural aspects of TMF damage into new nickel-base superalloys design.

Evaluation Review

The project contributes to increase the basic understanding of fatigue exposure of gas turbine hot components. The performed work is of high quality and relevance. However, the reporting of the project could be improved by correlating the different results instead of describing each of the papers that have been issued, as if instead of a whole effort, the project would be the sum of separate independent activities. The experimental part presented shows interesting results. However, some tasks have been reduced or eliminated without reasonable explanations (lack of time?). It is considered important that the cancelled and reduced parts will be accomplished in the future.

3.4.2 KME 503 and KME 520[19] New Durable MCrAlX Coatings for High Temperature and Corrosive Environment Applications in Advanced Engines

The aim of this project is to develop new durable coatings for use as protective overlays and bondcoats. Recent research results are incorporated in the work and the increased turbine requirements are considered. Systematic work integrating thermodynamic modelling and experimental studies is carried out to optimise the chemical composition for better resistance against oxidation, corrosion and thermal cycling. The specific goals for the project includes that two coating compositions should be ready for component and field tests at the end of the project and a thermodynamic model should also be available, which can be used for development of life predicting model in the future. In addition, the project work should contribute

[19] KME 520 is an extension of KME 503 (158 kSEK). The aim of the extended experiment is to verify the thermodynamic simulations by high resolution micro-structure and chemical composition analysis and to obtain experimental data for certain X-elements needed for the chemical composition optimization in KME 503

to better understanding of fundamental issues regarding high temperature protections of superalloys.

The project reports that (1) several new MCrAlX coatings with promising oxidation resistance have been identified for further optimization, and (2) an oxidation-diffusion model, considering both surface oxidation and coating-substrate interdiffusion, has been developed. The predicted composition profile and micro structural evolution of a MCrAlY coating show good agreement with the experimental result. Three papers have been published at international conferences, one manuscript has been submitted to an international journal and a licentiate thesis has been published.

Evaluation Review

The project has already resulted in improving existing MCrAlX coatings based on thermodynamic modelling. An important goal is to contribute to understanding of the effects of minor alloying elements. Several compositions are promising and have been proposed for further testing. Together with KME 502 this project can contribute substantially to improved gas turbine performance and increase the life time of gas turbine components. A continuation of the project is recommended given the important supplement to the presented work.

3.4.3 KME 505 Properties of Alloyed $MoSi_2$ Matrix Composite for Hot Corrosion and Elevated Temperature Components of Gas Turbine

This project, which is a continuation of KME 405, performed during the previous stage of KME, is evaluating the mechanical properties at ambient and high temperature and thermal properties with thermal cycle and component exposure of composites. The results are compared with commercial candidate materials and research will be continued on optimising alloy content and manufacturing process parameters for toughening, oxidation/corrosion properties.

The specific aims of the project are presented as finding applications of MoSi2-based composites in power generation systems; and development of manufacturing methods for the components. MoSi2-ZrO2 and (Mo, Cr) Si2-ZrO2 composites have been developed in the previous KME project, and a heating shield prototype used for gas turbines has been prepared with Cr10-ZrO2.

Evaluation Review

The project deals with the influence of chromium in allowing faster formation of a protective scale on (Mo, Cr)Si2-ZrO2 composites at 1400 ^{o}C. The chromium content still has to be optimized. The component already developed needs further improvements. The work so far is considered as very successful.

3.4.4 KME 506 and KME 518[20] Weldability Limits for Superalloys in High Temperature Applications for Gas Turbines

The objective of the study, which is a continuation of KME 406 performed in the previous KME stage, is to find superalloy combinations, welding methods and appropriate heat treatment schedules to increase the potential of welding for hot gas turbine structures applications. To facilitate modelling, the aim is to establish fundamental understanding of improved weldability testing and the basic weld metallurgy through advanced materials testing and metallographic analysis/microscopy. This will lead to more competitive position in using superalloys not only for gas turbines but also in power plants. Realistic superalloy combinations and the associated weldability limits are evaluated, the role of trace elements in grain boundary cracking is studied and heat treatment restrictions are assessed.

Evaluation Review

The project is considered as a very comprehensive and solid work on the understanding of the complex metallurgical behaviour related to welding of superalloys. The investigations involve use of advanced and unique testing equipment (resulting in world wide recognised results) partly developed by the institute.

Based on the findings a systematic procedure involing testing and different characterization techniques has been established to better understand materials issued related to welding. By applying this procedure optimization of welding parameters can be done in a more efficient manner on the basis of understanding welding procedures specifications cand be established in a more efficient manner. The modelling and test equipment is considered to be proven also for land based gas turbines.

3.5 Projects concerning high temperature materials for thick section boiler components and steam lines in steam power plants

There is only one project in this group dealing with the design and optimization of a high Cr ferritic steel capable of operating at 650º C.

3.5.1 KME 510 Design of a New Generation of 12 % Chromium Steels

The thermal efficiency of steam power plants is limited by the maximum allowed steam temperature and pressure, which in turn are determined by the corrosion and creep resistance of available steels. All attempts so far to exceed 600-620°C with 11-12% chromium steels have failed. This project, which is a continuation of a former KME project, KME 404, aims at developing a new generation of martensitic chromium steels as a strengthening rather than weakening phase. If successful, the aim of 100 000 hours creep rupture strength of 100 MPa at 650°C may be within reach also for 12% chromium steels that have sufficient corrosion resistance for operation at this

[20] KME 518 is an extension of KME 506 concerning weldability and machinability of superalloys.

temperature. In case steam data of 650 °C/325 bar could be reached it would mean that electric efficiency of commercial steam power plants could rise to a approximately 50 %, from the average of 38 % today.

A new Ta-containing Z-phase strengthened 12% Cr steel has been developed, which shows promising creep strength, due to the formation of densely distributed and slow growing Z-phase precipitates. However, impact strength for the Ta-containing Z-phase strengthened steel is very low. Design optimization is under progress.

Evaluation Review

A new concept to strengthen ferritic steels by means of nano particles of Z phase has been implemented in order to allow use at 650 °C. The new materials will have a high Cr-content intended to increase the steam side oxidation resistance as well. The strength still has to be improved and the materials should be oxidation tested. The project has generated large amount of general knowledge regarding precipitation strengthening in 9–12 % Cr-steels. Atom probe tomography has proven as a very useful technique for understanding of the strengthening mechanisms. The aimed material is vital for further improvements of efficiency in thermal power plant especially for use in thick section boiler component and steam lines but also for superheater tubes if a suitable coating can be developed for fire-side corrosion resistance and if the high pressure steam oxidation resistance is adequate.

4 Evaluation of the programme

In chapter 3 all KME projects were described and analysed. In this chapter all KME activities will be evaluated in an overall context. The chapter is divided into four evaluation areas: (1) programme governance and organisation, (2) programme focus, (3) scientific activities and (4) budget review.

4.1 Programme governance and organisation

In the KME board there are representatives from industry partners, research institutes and the Swedish Energy Agency (see Appendix 3 for a full statement of the KME board). As mentioned in chapter 1, the programme is administered by Elforsk. Furthermore, Elforsk participates as an adjunct at board meetings and Elforsk effects all board decisions such as purchase orders, approval of final reports and organising of the annual programme conference.

Through spring 2013 the KME board has had totally 14 meetings – 3 teleconference meetings and 11 physical meetings. The attendance rate at board meetings is generally considered to be good (see Appendix 3 for a full compilation of the member's attendance).

In addition to the programme board the two programme areas have one steering committee each. Through spring 2013 the material technology base programme steering committee has had 11 meetings and the steering committee for More Effective Power Production has had 13 meetings. The steering committee meetings are held adjacent, before the board meetings. The idea is that the steering committees should give the board a base for decisions. In reality this means that each steering committee gives the board a recommendation for decision making. Almost always the decisions correspond with the recommendations from the steering committees.

As mentioned in the introduction, the evaluation group has also had a meeting with representatives for the board and the steering committees (see Appendix 2 for a compilation of meeting participants). The conclusions regarding the programme governance that was made in the interim evaluation are still valid; the stakeholders take active part in the programme governance, there is a well-functioning meeting and document structure etc. Thus it is, once again, concluded that Elforsk is considered as a competent administrator of the KME programme and that the cooperation between the board and Elforsk seems to be well-functioning.

However, one particular administrative issue has been noted; there is a wide range regarding the extension and the details provided in the projects status reports and extended summaries. In order to favour the boards work, collaboration between projects, evaluations etc. a more detailed format for project reporting is desirable. In this context the templates need to be more specific than they are today, and possibly should include a minimum and a maximum length. A proposal is to clarify what is expected in each section in the templates, including a framework regarding size and format.

The current programme period is the first period in which a division of KME into two subprogrammes has been implemented. The purpose of the division is to contribute to practical application of the research work, i.e. an application programme area was added to the material technology base programme.

It has been concluded that the current organisation, with both a KME board and a steering committee for each subprogramme, is considered as a cumbersome and ineffective structure for decisions.[21] Furthermore, there is a process going on for reforming the organisation for the forthcoming programme period(s). This is also one of the main tasks for the KME future group that was formed in late 2012. The future group sees three alternative organisation structures for the next programme period of KME:[22]

(1) A division of the programme into three separate programmes; the material technology base programme, a programme for more effective power production and the project for the demonstration plant (i.e. KME 601). Here, there are three separate boards/steering committees, one for each programme.

(2) One programme with one board but without steering committees for the subprogrammes. For this alternative it is essential that the board has broad expertise in both material technology and power production. The project for the demonstration plant should, however, have a separate board/steering committee. Furthermore, this alternative is the same as the structure today but without the steering committees for the subprogrammes.

(3) The same structure as in (2) but here the applying part of the programme, i.e. more effective power production, is superior in relation to the material base programme.

Until now (April 2013) neither the future group nor the board has declared which alternative will be chosen for the future. Though, it can be noted that the Swedish Energy Agency has declared that they want a programme description that includes more than one programme area. Consequently they do not want a division into three separate programmes, they prefer a coherent programme. The Swedish Energy Agency instead suggests that the meeting structure is revised.[23]

A further aspect in this context is the Swedish Energy Agency’s new/reformed rules regarding external[24] programmes. In the future the external programmes will be replaced by “collaboration programmes”[25]. These programmes will have a programme advisory council. The council will evaluate research applications, take decisions regarding the industry financing and give recommendations to the Swedish Energy Agency. The formal

[21] Minutes from the future group 2012-11-22.
[22] Minutes from the future group 2012-12-10.
[23] Minutes from the future group 2013-01-23.
[24] The Swedish Energy Agency’s research financing is divided into internal and external programmes. Internal programmes are fully administrated by the agency while external programmes are administrated by an external institution. Since KME is administrated by Elforsk, the programme is classified as external.
[25] ”Samverkansprogram” in Swedish.

decisions regarding use of the funds from the Swedish Energy Agency will, however, be taken by the authority itself. A programme will have just one programme committee and further division into steering committees/groups is not possible.

4.2 Programme focus

KME's overall objective is to contribute to make electricity production using thermal processes more effective. In a broader perspective KME shall contribute to the national goal to conversion to a sustainable energy system. A concrete goal for the programme is to, within the time perspective 2017-2018, build a new full-scale CHP-plant fired with biofuels and/or refuse fractions with higher electrical efficiency compared to today's levels for operational commercial plants. As concluded in the interim evaluation, this is a concrete goal which is totally in line with the programme's overall objective. It is also in line with the recommendation to focus more within one area, or a limited number of areas, that was given in the evaluation for the 2006-2009 programme period.

In the interim evaluation an initial analysis of the goals, milestones and targets, success criteria etc. was done. Generally it was concluded that the activities within the material technology base programme were proceeding according to plan but activities for developing a reference power plant were partly delayed, mainly because of the fact that there has been no firm offer as to who will build a demonstration plant. Furthermore, this analysis will connect to the analysis in the interim evaluation and focus on the issues identified there.

4.2.1 Goals

For the 2010-2013 programme period ten goals have been identified, goals that constitute steps towards the fulfilment of the objective and long-term vision (see section 2.1 for descriptions of the goals). In the interim evaluation, it was concluded that eight of these ten goals are either satisfied or on the way to be satisfied. In Table 4 the goals and the interim evaluation assessment of the status for the actual target is shown.

Table 4 Interim Evaluation (2012) Assessment of the KME-goals for the 2010-2013 Programme Period

Goal	In line with schedule 2012?
1. Technical and commercial solution for the demonstration plant	No
2. Deeper knowledge of materials technology process solutions to minimise corrosion	Yes
3. Lab tests to appoint mechanisms affecting material life time during new advanced steam data requirements	Yes
4. Exposure tests with partly new boiler super heater materials and compare them with results from cooled material probe tests	Yes
5. Exposure tests with new alumina forming FeCrAl-materials and explore the possibilities for future use	Yes
6. Development of improved analysis methods to determine weldability of Ni-based super alloys	Yes
7. To show that conventional materials can be joined by welding with high temperature materials	Yes
8. Integration between a KME-project and the international welding project Weldmat	No
9. Validation of materials and surface coatings for coming industrial gas turbine plants optimised for requirements concerning efficiency and robust design	Yes
10. Continue building networks between universities and industry	Yes

As shown, eight of the goals concern material technology issues (goal no. 2-9). The conditions for fulfilment of these goals are to be considered as very good since there are relevant and initiated projects working on these issues. The projects have been further reviewed in chapter 3 and there is no reason for revising the assessment done in the interim evaluation for these goals.

Also further integration between universities and industry (goal no. 10) was considered as fulfilled in 2012. More specifically it is stated that KME should contribute to (1) introduction of new associate professors, (2) project participation from post-PhDs, (3) graduation of PhDs and licentiates with financial support from the KME-programme, (4) supervision of theses by industrial stakeholders and (5) project cooperation with at least one international leading university[26]. All of these goals were satisfied in 2012 and since then the project activities have deepened the integration and collaboration between the industry and universities. Thus, it is once again concluded that KME contribute significantly to deeper cooperation between the participating industrial companies and universities.

As shown in the table two of the goals were not considered as being on the way to be fulfilled in 2012. But one of these, the goal on integration with the international welding project Weldmat (goal no. 8), is beyond KME's influence since Weldmat has not started. Thus there is nothing KME can do in order to fulfil the goal without revising it. A formal revision of the goal has not, however, been made.

The other goal that was not in line with the schedule in 2012, that is the development of the reference power plant (goal no. 1), is still delayed comparing to the time schedule in the programme description. Since this already has been described and analysed in section 3.1.1 there is no need for once again going into details on this issue. The uncertainty regarding the development of the demonstration plant might be problematic for KME since this goal is the fundamental target for the programme in an overall perspective. The situation regarding potential hosts is more or less the same as in 2012, i.e. there are three companies interested but there is no

[26] Within KME 505 tests were performed at National Physics Laboratory in England.

commitment by any of them. The companies that are potential hosts are E.ON Climate & Renewables (100-200 MW_e condensing plant in Antwerp, Belgium), Falu Energi och Vatten (20 MW_e CHP plant in Falun) and Vattenfall (50-70 MW_e CHP plant in Uppsala). According to the work plan for KME 601 host and site should be decided in late 2013 and the plant should be commissioned in 2017.

4.2.2 Success criteria

A number of success criteria has been formulated and published in the programme description, see section 2.1.3. In general, the success criteria focus on KME's contribution between the industry and the academy and that the programme achieves concrete results through successful research. As already concluded, KME is assessed to be a successful research programme with clear focus, obvious goals and a good reputation in the academia as well as in the industry. Consequently, it was concluded in the interim evaluation that the success criteria in general are either achieved or about to be achieved. However three criteria were further commented in the interim evaluation.

One of the success criteria is that all KME projects publish important research results in reputated international journals. It can be noted that the number of published articles has increased comparing to the previous programme period. But the majority of the KME projects have not yet published results in journals, so the criterion is in May 2013 still far from achieved. However, almost one year is still remaining for the programme period and most projects are still in an active phase. It is reasonable to suppose that the number of published papers will increase during 2013 and some results will probably be published after the end of the programme period, as usually it may take from six months to one year or even more to prepare and write papers once the experiments have been completed. As a matter of fact, papers resulting from the previous period are included as outputs of the present projects. It is therefore not at this stage possible to evaluate whether this success criterion is going to be fulfilled or not. But as mentioned, it is noted that in general there are more results published during this programme period compared to previous period. The overall impression is therefore that KME has been inspired by the recommendations that were given in the evaluation for the 2006-2009 programme period.

Second, there is a success criterion stating that the programme should have ”a clear problem solving profile, is competitive internationally and can adapt and strengthen this in accordance with the needs of interested parties and technological or societal developments”. There is no doubt that KME has a problem solving profile. The fact that research from KME projects are presented on international conferences and are published in journals indicates that the activities are international competitive. Additionally the stakeholders seem to be more than satisfied with the work done within KME. Furthermore, as far as the evaluation group can assess this success criterion is satisfied.

Third, there is a criterion on gender equality and ethnic balance. The criterion states that both in the programme board as in steering committees and project reference groups there should be an equal gender distribution and a representative ethnic distribution. The ethnic structure has not been studied in detail neither within the interim evaluation nor within this evaluation. However, it can be concluded that there are a number of persons active in the projects and also in both steering committees that have a different ethnic background than the majority. Regarding the gender distribution, it can be concluded that the programme consists of an overwhelming majority of men, both in the programme board[27] as in the both steering committees.[28] In addition less than a third of the projects have a female project manager.[29] It can also be concluded that the budget share for these projects is less than a fourth of the total budget.[30] Thus female project managers are both underrepresented and the average budget for female project managers is also less than the total average project budget within KME. The gender distribution among the project managers might be a reflection of the corresponding distribution in the industry. Whether this is true, however, it is not relevant for the fulfilment of the success criterion since it is stated that the gender distribution should be equal, i.e. 50-50 men and women. Furthermore, the women’s even lower share of the budget can not be explained by the gender distribution in the industry. To summarize, the stated gender criterion is not fulfilled. The programme management might consider actions in order to fulfil this success criterion for the next programme period(s) or perhaps modify it taking into consideration the statistics regarding professionals working in the relevant areas both in academia and in the industrial sector.

4.3 Scientific activities

As shown in the project reviews (chapter 3) KME projects in general exhibit an excellent scientific level. Some of the projects are top class in an international perspective according to technical experts’ unanimous assessment, many have a very good standard and the lowest level is also considered as high. Anyhow some of the projects can be classified as scientific projects with minor industrial interest. Nevertheless these projects fulfil the goal to support PhD exams within KME. Additionally, published journal papers have resulted from many projects and the projects have also been presented at conferences.

[27] Nine men and five women.
[28] Eight men and four women in the steering committee for material technology and tweleve men and one woman in the steering committee for more effective power production.
[29] Six of the twenty projects (KME 505, 507, 508, 512, 515 and 519).
[30] The budget for these projects is in total 24.8 million SEK, i.e. around 24 % of the total budget of 103.5 million SEK.

Table 5 Publications and presentations[31]

Project	Status regarding Publications and presentations
KME 501	1 paper published, 4 papers accepted for publication
KME 502	8 papers published (4 in journals and 4 in conference proceedings), 2 theses (1 PhD and 1 Lic.), 2 more papers in preparation.
KME 503 and KME 520	2 papers published at international conferences, 1 paper submitted to conference
KME 504	-
KME 505	-
KME 506 and KME 518	2 articles presented at an international conference, these papers are also submitted to a journal. More publications are aimed to be carried out.
KME 507	2 papers have been sent in to a journal
KME 508 and KME 515	1 paper published, 1 paper accepted for publication, 1 paper and 1 Lic. thesis in preparation
KME 509	-
KME 510	3 articles published in journals, 2 papers presented on international conferences
KME 511	-
KME 512	-
KME 514	-
KME 519	-
KME 521	-

Initiatives have been taken in order to further collaboration and coordination within KME, e.g. two workshops have been arranged in addition to the annual KME conference. However, there might be a potential for thus better collaboration within the programme. There are projects working on similar or related issues without a sufficient coordination regarding the activities. With an extended and deepened coordination and interaction between these projects both the projects and KME as a whole could be even more successful. For instance, KME 504 deals with deposit composition and corrosion as well as the benefits of additives, while KME 508 and KME 515 also study deposits chemistry and the effects of additives on the firewalls. Moreover, KME 512 concentrates in laboratory experiments to study the effects of additives and KME 519 also deals with additives in the lab regarding FeCrAl corrosion. KME 507, KME 508 and KME 519 have tested similar materials as for instance FeCrAls. Both KME 508 and KME 511 include coatings for biomass corrosion in their studies. Another example is KME 510, in which high Cr steel is being developed for higher corrosion resistance, not taking into consideration the results of for instance KME 507 and KME 511 regarding the formation of potassium chromate on Cr steels and other Cr containing materials. To summarize, there are not sufficient information sharing and task coordination between the projects.

In addition to the potential for a further development of KME, deeper collaboration within the programme will also lead to individual development for the researchers in general and for the PhD students in particular. One of the goals for KME is to support PhD studies and a very essential topic in PhD education is training on team working and collaboration with other researchers. This is also a reason to improve collaboration between research groups.

Another important aspect to highlight in an overall context is the need for coordination of what is needed to be further done in order to create conditions for the fundamental goal to be achieved. There is a need for further analysis

[31] The presentation of publications i table 5 only contains the MATBAS projects. Until now the EPP projects have showed no publications. However, the focus in the EPP projects are mainly applying, rather than scientific, and thus it is not relevant to compare the academic results in the EPP projects with the publications made within the MATBAS projects.

on what is needed to be investigated for the development of a reference power plant. This applies in terms of analysis of the market demands as well as the most urgent technical issues to be clarified to motivate investment in a reference plant. These analyses are preferably done within KME 601 and then discussed and further implemented by the programme board.

4.4 Budget review

In section 2.3 KME's financing was described in detail. As mentioned, the total budget for the 2010-2013 programme period is almost 103.5 million SEK, 60 % financed by the industrial partners and 40 % financed by the Swedish state through the Swedish Energy Agency. In Table 6 KME's preliminary expenditures for the current programme period are shown.

Table 6 KME's Expenditures for the 2010-2013 Programme Period (by May 2013)

Budget follow up, total costs

Programme budget:, [kSEK]	MAT BAS	EFF	Total:	Programme and project financing:				Funds used, kSEK				
				SEA	%	Industry		Cash SEA		Industry total, kSEK		
								kSEK	%	In-kinds	cash	%
For projects	50 228	42 847	93 075	37 083	39,8%	55 992						
Administration	3 061	4 139	7 200	2 869	39,8%	4 331						
Associated professor*)	800	800	1 600	637	39,8%	963						
Seminars, reports	400	400	800	319	39,8%	481						
Programme evaluations	400	400	800	319	39,8%	481						
Sum:	**54 889**	**48 586**	**103 475**	**41 227**	39,8%	**62 248**						
Project decisions, [kSEK]:												
KME 501	605	6 377	6 982	2 782	39,8%	4 200		2 042	73%	2 549		61%
KME 502	12 467		12 467	4 967	39,8%	7 500		4 238	85%	7 410		99%
KME 503	2 327		2 327	927	39,8%	1 400		728	79%	1 400		100%
KME 504	2 294		2 294	914	39,8%	1 380			0%	1 613		117%
KME 505	1 995		1 995	795	39,8%	1 200		280	35%	390		33%
KME 506	9 459		9 459	3 769	39,8%	5 690		2 037	54%	4 448		78%
KME 507	5 486	997	6 483	2 583	39,8%	3 900		829	32%	2 145		55%
KME 508	7 012	4 497	11 509	4 540	39,4%	6 969		1 725	38%	4 871		70%
KME 509	2 493	997	3 491	1 391	39,8%	2 100		1 192	86%	1 962		93%
KME 510	3 325		3 325	1 325	39,8%	2 000		663	50%	1 148		57%
KME 511		1 733	1 733	693	40,0%	1 040		150	22%	401		39%
KME 512	582	1 970	2 552	1 017	39,9%	1 535		348	34%	700		46%
KME 514	628	1 883	2 511	1 004	40,0%	1 507		473	47%			0%
KME 515	183	117	300	119	39,5%	182			0%			0%
KME 518	158		158	63	39,9%	95			0%			0%
KME 519		1 929	1 929	767	39,8%	1 162			0%	103		9%
KME 520	1 214		1 214	486	40,0%	728		289	60%	140		19%
KME 521		1 673	1 673	669	40,0%	1 004		310	46%	181		18%
KME 601		4 300	4 300	0	0,0%	4 300		-	0%	494	2 375	67%
KME 607		4 825	4 825	1 930	40,0%	2 895		483	25%			0%
KME 608		1 750	1 750	700	40,0%	1 050			0%			0%
Administration	4 661	5 739	10 400	5 789	55,7%	4 611		4 346	75%		3 460	75%
Tot. for projects [kSEK]:	54 889	38 787	93 676	37 228	39,7%	56 449	Total:	20 133	54%	29 954	5 835	63%
Remaining budget, [kSEK]:	- 0	9 799	9 799	3 998	40,8%	5 800						
Share decided, %	100,0%	79,8%	90,5%	90,3%		90,7%						
Share remaining budget, %	0,0%	20,2%	9,5%	9,7%		9,3%						
New applications, [kSEK]:												

As shown 100 % of the budget for the material technology base programme (MATBAS) is distributed to projects. This was the case already a year ago, when the interim evaluation was done.

In the interim evaluation, however, it was concluded that it might be problematic that almost 30 % of the budget for the programme area on more effective power production (EFF) remained at that time. Since then, a new project (KME 608) has been started and the remaining share has decreased to 20 %. As concluded in section 3.3.9 this project is particularly relevant for KME but also for the development of the demonstration plant. However, there are other issues that are more relevant to investigate at this stage of development of the demonstration plant. For instance in KME 601, important issues that were identified among the prioritized areas have to be fully addressed, e.g. carrying out tests with superheater tubes and probes in loop seal at steam temperature up to 620 ºC, and evaluation easy and frequent replacement versus expensive materials as already mentioned.

An issue highlighted in the interim evaluation was the difference regarding the contributions between the industrial participant categories. More specifically, less than 2 % of the programmes total budget is contributions from boiler manufacturers, i.e. Metso.[32] In the interim evaluation it was stated that "the fact that boiler manufacturer constitutes a limited percentage of KME's total budget might also be one of the reasons behind the delay regarding the demonstration power plant". This has been discussed both in the KME board[33] and in the future group[34]. The future group stated that it might be problematic from a competition point of view to include also another boiler manufacturer in the programme. Among KME's industrial participants, there are practically just Outokumpu and Sandvik that compete with each other. But even these companies do not have identical products and thus not compete with each other. Neither Siemens nor GKN Aerospace has competitors participating in KME. In May 2013, however, Metso declared that the company will not continue as a participant in KME for the next programme period.[35] Thus the aspect regarding competition will not be relevant for the forthcoming programme period. But it will probably be a challenge from a practical point of view to involve another boiler manufacturer in KME since there is no Swedish boiler manufacturer existing for this range of boilers.

During the meeting with board representatives it was, however, stated that the in-kind contributions from e.g. Metso exceeds the industrial partner's formal contributions to KME. Project activities at the industrial companies continue also when there are no remaining funds in the budget. As a result of this, it is not possible to make an economic follow up that reflects the reality completely. Furthermore, the contributions from the Swedish Energy Agency are also affected if the formal budget is lower than the real budget – larger contributions from the industry will generate larger contributions from the agency. However, even if the contributions from Metso in reality exceed two percent, the share from the boiler manufacturing industry is still limited and constitutes just a few percent. This might have a limiting effect for financing certain projects that might be necessary for the development of the reference power plant. A concrete consequence of the fact that the contributions from the boiler manufacturing industry are limited is problems starting certain projects that are essential for the possibilities to reach the fundamental programme goal. Relevant examples of such activities are projects carrying out tests with superheater tubes and probes in loop seal at steam temperature up to 620 ºC and evaluation easy and frequent replacement versus expensive materials.

As another potential obstacle for the development of the reference power plant have the rules on how the Swedish Energy Agency's contributions are

[32] See Table 1 in section 2.3 for a complete compilation of the stakeholders contributions to the KME programme.
[33] Minutes from the board meeting 2012-10-15.
[34] Minutes from the future group meeting 2012-11-22.
[35] Minutes from the board meeting 2013-05-16.

allowed to be used within the programme been identified. According to the Agency's rules the contribution can only be used for contracting research institutions and not consultants/private companies. The rules might limit the possibilities for projects in the applying part of KME, i.e. the programme area for more effective power production and the overall goal to develop a full-scale reference power plant.

5 Conclusions and recommendations

Finally, conclusions and recommendations considered significant and important for future research stages in KME are summarized according to the following.

- KME is a well-functioning and successful research programme. All projects are of high quality and some projects are even matching international top class. Moreover some projects will produce results with high industrial relevance.
- The programme's focus is in all respects in line with the programme's overall objective and goals. However, the development of a full-scale demonstration plant is not totally in line with the schedule. As this project involves some generic questions which may end up with a negative answer those showstoppers have to be identified as soon as possible. A full investigation should give a solid answer. This should be done before other project specific investigations are commenced in order to avoid spill of resources on specific 600°C plant activities if the final conclusion on the generic items are negative. If a decision for a host for the realisation of a full scale plant is going to be taken by the end of 2013 all basic questions must be answered before that time. Moreover, KME should seek for ways of exploiting the research results in case the plant is not built due to lack of commitment from the present candidates.
- The programme should consider that the economical conditions for power generation may have changed since the programme was initiated since the economic conditions for power production vary over time (e.g. fuel and electricity prices). Thus there is an uncertainty regarding the benefits from increased efficiency. At the same time there are factors that indicate increased importance of fuel flexibility. Also the operation mode for power generation is changed, putting higher demand on improved load flexibility. When the share of wind and solar power generation in the power system is increasing, the load changes for thermal power plants will increase. There will be new requirements for power plant materials, stillstand corrosion will be more important and the construction including welding must be flexible for fast load changes. These issues should be considered when planning a new programme period. Another possibility might be to address these issues now. A project, studying the arising problems in relatively small power plants, due to new requirements on fuel flexibility and load flexibility, could be started if remaining funds for the current KME period can be used for that. Results from such project could be of great value in planning the next material technology programme.
- There is a need for deepening collaboration and exchange between the different projects. There are projects working on similar or related issues and there is a potential for extended and deepened coordination

and interaction between these projects. In order to encourage more extensive collaboration between projects for the subsequent programme period(s), an alternative could be to cluster the activities in the beginning of the programme period. Then each group of projects, each cluster, should be responsible for securing close collaboration and for having a workshop on relevant issues e.g. once or twice a year. Such a model could improve the research activities further, create synergies and promote the general development of KME.

- Within KME there is an ongoing discussion on the organisation of the programme, more specifically if the programme should continue being divided into two subprogrammes or if the two subprogrammes should be divided into two separate programmes. There is no decision taken regarding this but it is noted that the Swedish Energy Agency prefers to keep the KME activities within one programme but with a revised meeting structure. An option that appears more effective with potential benefits in terms of increased commitment and involvement with prospective improved collaboration between projects could be to have one board/committee for the programme with selected representatives, or other representatives selected by the board/committee, that are responsible for defined research clusters. Thus the organisation of the programme would have the potential also to become more flexible and could be fitted depending on the research activities.
- In the interim evaluation it was concluded that less than 2 % of the programme's total budget are contributions from boiler manufacturers, i.e. Metso. It was then concluded that this might be a problem for the activities related to the development of the demonstration power plant since this development presumes cooperation between the energy industry, material technology developers, turbine manufacturers and boiler manufacturers. For the next programme period this problem might increase since Metso has declared that they will not continue as a participant in KME. In the interim evaluation report extended cooperation with Finnish and Danish research programmes was suggested to improve the industrial participation in the KME programme. During the current evaluation the benefits of such a solution seems even more accenturated. The industrial activities in the field in Sweden and Finland are less competing than complementing each other. In Finland there are three[36] major boiler manufacturers specialized in biomass boilers and in fluidized bed boilers when in Sweden neither any engineering nor manufacturing of new boilers in such range occurs anymore. On the other hand Sweden has strong positions in turbomachinery as well as steel production and development of high quality steels. It is therefore adviced to initiate closer cooperation between Swedish and Finnish power plant research programmes. The current Swedish and Finnish programmes are not overlapping each other. On the industry side there is already cooperation as Sandvik is the main supplier to Andritz as well as Metso

[36] Andritz, Foster Wheeler and Metso

recovery boilers in the pulp and paper sector and also in fluidized bed boilers. Denmark should be included in this cooperation as the power generating in all three countries has a lot of similarities and the power markets are dependent on each other in increased extent. Then KME (or what it then would be called) could be treated as a Nordic programme, as the requirement for a Nordic programme is that at least three Nordic countries are involved.

- It has also been stated that the in-kind contributions from some industrial customers, e.g. Metso, exceeds the formal contributions to KME. Thus the real budget share for the customers might differ from the formal budget share. For the possibilities to follow up projects, and also the overall programme, such a situation is not desirable. The fact that Metso’s budget share might be somewhat larger than is shown in the budget does not, however, change the overall situation regarding the unbalance between the customer categories (boiler manufacturer, turbine manufacturer, energy companies and the material technology industry). But despite that the stakeholders should be encouraged to be as clear as possible about the level of the own contribution.

Appendix 1 Evaluation Directive (in Swedish)

Utvärderare
Ronny Nilsson (sammanhållande) och Henrik Gåverud, Grontmij. Tekniska experter: Rudolph Blum, DONG Energy, delprogram materialteknik Alina Agüero Bruna, Laboratorio de Procesos y Tecnologías, INTA, delprogram materialteknik Carl-Johan Fogelholm, Helsinki University of Technology, delprogram effektivare elproduktion.

Övergripande mål
Energimyndighetens beslut och programbeskrivning är centrala dokument där målen och framgångskriterierna som sattes vid programmets start är utgångspunkt för utvärderingen. Utvärderingen ska undersöka vad som hittills uppnåtts och sannolikheten till att syftet med programmet kommer att uppnås. Vidare ska utvärderingen ge vägledning och rekommendationer för utformning och beslut av kommande etapp av KME.

Tidsplan
Utvärderingen genomförs under april månad (v 15), med utkast av utvärderingsrapport 2013-05-02, för att presenteras i KME:s styrelse 2013-05-16. Slutlig version av rapport skickas till Energimyndigheten och Elforsk 2013-05-31.

Genomförande
Utvärderingen genomförs genom besök och möten med programledning, forskare och industrirepresentanter, enligt särskilt besöksprogram som upprättas av Grontmij.

Utvärderingsfrågor
Måluppfyllelsen

- I vilken utsträckning har programmets mål uppfyllts?
- Har programmets syfte uppfyllts?
- Hur har framgångskriterierna uppfyllts; hur har programmet styrts mot framgångskriterierna?

Relevans och effekter

- Är projektportföljen relevant i förhållande till syfte och mål för programmet?
- Industrirelevans i verksamheten. Har resultat och effekter varit till nytta för avnämare och deltagande företag?
- Hur fungerar samverkan mellan avnämare/deltagande företag och UoH?

Effektivitet
- Hur har uppdelningen i två delprogram fungerat? Vilka fördelar/nackdelar har programstrukturen och arbetssättet inneburit?
- Har programmet stimulerat och uppmuntrat samarbete mellan forskningsprojekten?
- Hur effektiv har programmets styrning och administration varit?

Vetenskaplig kvalitet
- Vilken vetenskaplig kvalitet håller den forskning som genomförs? Även i internationell jämförelse.

Generellt
- Vilka brister finns?
- Förslag till förbättringar.

Slutsatser och rekommendationer

Appendix 2 Meetings within the evaluation

The evaluation began on April 8th with a meeting at Elforsk in Stockholm with board representatives. In this meeting, the board was represented by Bertil Wahlund (Elforsk), Sofia Andersson (Swedish Energy Agency), Helena Oskarsson (Siemens), Mats Åbjörnsson (E.ON) and Lars Wrangensten (deputy for Erik Skog, chairman of KME). Bertil Wahlund presented the boards overall view of the programme: goal achievements, relevance and effects, effectiveness, scientific quality etc. In this context, the evaluation group also had the opportunity to ask questions and initiate discussions.

On April 8th the evaluation group also had a meeting with Erik Skog. Erik is the chairman of KME but this meeting was primarily arranged with Erik in the role as project manager for the reference power plant project, KME601. At this meeting Maria Jonsson, Vattenfall, and Mats Åbjörnsson, E.ON, also participated.

On April 8th, meetings were finally also arranged with four project managers; Pamela Henderson (KME 508 and 515), Maria Jonsson (KME 512), Rikard Norling (KME 504) and Lars Wrangensten (KME 608).

On April 9th, meetings were arranged at Linköpings Univiersity with a number of project managers and industrial representatives. The project managers were Sten Johansson (KME 501), Johan Moverare (KME 502 and 521) and Ru Peng (KME 503 and 520).

On April 10th-11th, meetings were arranged at Chalmers University in Gothenburg with project managers, industrial representatives and representatives for Chalmers. The actual project managers were Torbjörn Jonsson (KME 511), Magnus Genrup (KME 607), Hans-Olof Andrén (KME 510), Yiming Yao (KME 505) and Jesper Liske (KME 509 and 514). Jesper Liske also presented Kristina Hellströms projects (KME 507 and 519) since Kristina was unable to attend. Unfortunately Professor Carl-Johan Fogelholm, one of the technical experts in the evaluations group, was unable to participate in the meetings at Chalmers.

In Appendix tables 1-8 the complete list of the meeting participants are presented.

Appendix Table 1 Meeting with KME Board Representatives, Stockholm April 8th 2013

Name	Role	Organisation
Sofia Andersson	Board Member	Swedish Energy Agency
Helena Oskarsson	Associated Board Member and Chariman for the Steering Committee for the Base Programme	Siemens
Bertil Wahlund	Associated Board Member	Elforsk
Lars Wrangensten	Former Associated Board Member and Deputy for Erik Skog (chairman of KME)	Pöyry Swedpower (former responsible for the KME programme at Elforsk)
Mats Åbjörnsson	Associated Board Member and Chairman for the Programme Area More Effective Power Production	E.ON Värme Sverige

Appendix Table 2 Meeting on KME 601, Stockholm April 8th 2013

Name	Role	Organisation
Erik Skog	Project Manager	Skog Konsult and Chalmers
Maria Jonsson	Project Reference Group Member	Vattenfall
Mats Åbjörnsson	Project Reference Group Member	E.ON Värme Sverige

Appendix Table 3 Meetings on KME 504, 508 512 and 515, Stockholm April 8th 2013

Name	Role	Organisation
Pamela Henderson	Project Manager KME 508 and 515	Vattenfall
Maria Jonsson	Project Manager KME 512	Vattenfall
Rikard Norling	Project Manager KME 504	Swerea KIMAB

Appendix Table 4 Meeting on KME 608, Stockholm April 8th 2013

Name	Role	Organisation
Lars Wrangensten	Project Manager	Pöyry Swedpower
Bertil Wahlund	Elforsk Representative	Elforsk

Appendix Table 5 Meetings on KME 501, 502, 503, 520 and 521, Linköping University April 9th 2013

Name	Role	Organisation
Matthias Calmunger	Project Member KME 501	Linköping University
Guocai Chai	Project Manager KME 501	Sandvik and Linköping University
Xin-Hai Li	Project Member KME 503 and 520	Siemens
Sten Johansson	Project Manager KME 501, Senior Researcher KME 502, Project Member 503 and 520	Linköping University
Daniel Leidermark	Project Member KME 502	Linköping University
Johan Moverare	Project Manager KME 502 and 521, Project Member KME 501	Linköping University and Siemens
Ru Peng	Project Manager KME 503 and 520	Linköping University
Mikael Segersäll	Project Member KME 502	Linköping University
Kang Yuan	Project Member KME 503 and 520	Linköping University

Appendix Table 6 Meetings on KME 507, 509, 511, 514 and 519, Chalmers in Gothenburg April 10th 2013

Name	Role	Organisation
Lars-Gunnar Johansson	Director HTC	Chalmers University
Torbjörn Jonsson	Project Manager KME 511*	Chalmers University
Jesper Liske	Project Manager KME 509 and 514*	Chalmers University
Jan-Erik Svensson	Deputy Director HTC	Chalmers University

*) Torbjörn Jonsson and Jesper Liske also presented KME 507 and 519 since Kristina Hellström, project manager, was prevented to attend.

Appendix Table 7 Meetings on KME 505, 510 and 607, Chalmers in Gothenburg April 10th 2013

Name	Role	Organisation
Hans-Olof Andrén	Project Manager KME 510	Chalmers University
Fang Liu	Project Member KME 510	Chalmers University
Magnus Genrup	Project Manager KME 607	Lund University
Srikanth Deshpande	Project Member KME 607	Lund University
Markus Jöcker	Project Reference Group KME 607	Siemens
Yiming Yao	Project Manager KME 505	Chalmers University
Xin-Hai Li	Project Reference Group KME 505	Siemens
Erik Ström	Project Reference Group KME 505	Sandvik

Appendix Table 8 Meeting on KME 506 and 518, Chalmers in Gothenburg, April 11th 2013

Name	Role	Organisation
Joel Andersson	Project Member KME 506 and 518	GKN Aerospace and Chalmers University
Lars Nyborg	Project Manager KME 506 and 518	Chalmers University

Appendix 3 The KME Board and the Board Attendance

Appendix Table 9 The KME Board 2010-2013

Erik Skog	Skog Konsult	Chairman
Bengt Gudmundsson	Siemens	Vice Chairman
Margareta Lundberg	Metso Power	Member
Per Kallner	Vattenfall Heat Nordic	Member
Bengt-Åke Andersson	E.ON Värme Sverige	Member
John Hald	Dong Energy	Member
Eva-Katrin Lindman	Fortum Värme	Member
Bo Jönsson	Sandvik Heating Technology	Member
Oliver Lindqvist	Chalmers	Member
Sofia Andersson	Swedish Energy Agency	Member
Mikko Hupa	Åbo Akademi	Member
Bertil Wahlund	Elforsk	Associated, Secretary
Helena Oskarsson	Siemens	Associated, steering group chairman for the base programme.
Mats Åbjörnsson	E.ON Värme Sverige	Associated, vice chairman steering committee

Appendix Table 10 The KME Board Attendance 2010 – May 2013

Meeting dates	Erik Skog	Bengt Gudmundsson	Margareta Lundberg	Per Kallner	Bengt-Åke Andersson	John Hald	Eva-Katrin Lindman	Bo Jönsson	Oliver Lindqvist	Sofia Andersson[1]	Mikko Hupa	Bertil Wahlund[2]	Helena Oskarsson	Mats Åbjörnsson[3]
2010-06-02	x	x	x	x		x	x	x	x	x	x	x		
2010-08-25	x	x	x	x	x	x	x	x	x	x	x	x	x	
2010-11-10	x	x		x	x	x	x	x	x	x		x	x	x
2011-03-29	x	x	x	x	x	x			x	x	x	x	x	
2011-05-12	x		x	x		x		x		x	x	x	x	
2011-09-08	x	x		x	x	x	x	x	x		x	x	x	
2011-11-17 (teleconference)	x	x	x	x			x	x		x	x	x	x	
2012-03-22	x	x	x	x	*	x		x		x		x	x	
2012-05-10	x		x	x	x	x		x		x		x	x	*
2012-09-12	x			x	x	x		x	x	x		x	x	
2012-10-01 (teleconference)	x	x	x			x		x	x	x		x	x	
2012-11-15 (teleconference)	x		x	x	x			x	x	*	x	x	x	x
2013-02-07		x	x	x	x					x		x		
2013-05-16	x		x	x	x			x	x	x		x	x	
Total	13	9	11	13	10	10	5	12	9	13	7	14	12	3

1) 2010-12 the Swedish Energy Agency was represented by Camilla Axelsson.
2) Until October 2012 Elforsk was represented by Lars Wrangensten.
3) Until November 2012 the steering committee for more effective power production was represented by Lars Hammar, Kraftringen Produktion.

*) The member was prevented to participate but was represented by a deputy from the actual stakeholder.

ELFORSK

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