Sökande organisation			
HTC/Chalmers Tekniska Högskola			
Postadress (högskola anger institution, ev avdelning)			
412 96 Göteborg Institutionen för Kemi och Bioteknik, Energi och Material, Oorganisk Miljökemi			
Projektledare (efternamn, förnamn, titel och inst)		**E-mail**	
Jonsson, Torbjörn, Dr., Institutionen för Kemi och Bioteknik		tj@chalmers.se	
Telefonnummer	**Telefaxnummer**	**Organisationsnummer**	**Postgironummer**
031-7722835	031-7722853	556479-5598	4589358-3
Ev. medsökande (efternamn, förnamn, titel och institution)			
Mikkelsen, Lars, Dr., B&W Völund Liske, Jesper, Ass. Prof., Institutionen för Kemi och Bioteknik Hellström, Kristina, Ass. Prof., Institutionen för Kemi och Bioteknik Jönsson, Bosse, Dr., Sandvik Heating Technology			

Ansökan avser nytt projekt [X] Ansökan avser fortsättning på pågående projekt [ ]

[x] Ansökan avser industriellt samarbetsprojekt

Detta projekt är [ ] i sin helhet lika med projekt för vilket ansökan ingivits till

[ ] i vissa delar lika med projekt för vilket ansökan ingivits till

Motivation

High temperature corrosion of the pressure part materials in waste incineration and heat recovery boilers is a major challenge in utilisation of the energy in domestic and industrial waste. From an energy recovery efficiency point of view high steam pressure and superheater temperature are of paramount importance. In order to achieve a thermal efficiency close to other types of boiler fuels e.g. fossil fuels and clean biomass fuels the superheater temperature must be increased from now being in the area of 400°C. This is with the present boiler and material technology not possible due to excessive high temperature corrosion. Babcock & Wilcox Vølund has proposed a new technology aiming to increase the steam temperature called Steamboost. The idea behind Steamboost is that the corrosive species are released over the first part of the grate such that the flue gas is less corrosive over the last part of the grate.

The scientific idea behind Steamboost is to utilize Computational fluid dynamics (CFD) modeling in order to identify fractions (positions) where the flue gas from the grate have a high heat flux and a low chlorine concentration. Superheaters may then be positioned in a part of the furnace within the less corrosive flue gas and subsequently increase the steam temperature up towards 500°C. This novel approach will then increase the possibility to generate higher steam data contributing more electricity being produced and thereby to the KME objectives. The procedure linking CFD calculations in a boiler with local deposit composition and corrosion rate is generic and can be utilized in any boiler.

The careful characterization of the deposit chemistry at different positions gives a unique possibility to generate knowledge about the corrosion resistance of different material classes. The aim of this project is therefore to test conventional superheater materials as well as state of the art stainless steels. These materials will be compared with FeCrAl alloys, which will be studied in the laboratory in order to identify and understand the usefulness and limitations of aluminum oxide forming materials as components for biomass- and waste-fired boilers. Exposures of manufactured FeCrAl alloys will also be conducted in the waste fired boiler. The purpose is to expose aluminum oxide forming materials in different environments and temperatures.

The results from the project aims to give input so that high temperature corrosion of the pressure part materials in waste incineration and heat recovery boilers will be limited. The results will in addition be implemented in a second step of the project. Based on the, CFD calculations, deposit tests, corrosion test and material evaluations a steamboost superheater will be utilized at a plant in Denmark.

Kontaktperson(er), företag	Telefonnummer
Lars Mikkelsen, B&W Völund	+4543265811
Bosse Jönsson, Sandvik Heating Technology	+46767848088
Jan Högberg, Sandvik Materials Technology	+4626264478

Förteckning över bilagor

CV of involved persons, will be submitted to energimyndiheten.

Datum och behörig firmatecknares (pref motsv) underskrift	Datum och projektledarens underskrift
Namnförtydligande, titel och telefonnummer	Namnförtydligande och titel .

Steamboost

– Increased steam temperature in grate fired boilers

Background

Problem area

Renewable energy sources such as biomass and waste are important for the Swedish energy supply. However, these fuels are challenging to combust because of their heterogeneous nature and the relatively high levels of alkali and chlorine, see e.g. [1-3]. The fuel composition results in a flue gas environment, which is more corrosive compared to fossil fuels.

High temperature corrosion of the pressure part materials in waste incineration and heat recovery boilers is a major challenge in utilisation of the energy in domestic and industrial waste. From an energy recovery efficiency point of view high steam pressure and superheater temperature are of paramount importance. In order to achieve a thermal efficiency close to other types of boiler fuels e.g. fossil fuels and clean biomass fuels the superheater temperature must be increased from now being in the area of 400°C. This is with the present boiler and material technology not possible due to excessive high temperature corrosion.

High temperature corrosion in waste incineration boilers is caused by chemical reactions between the boiler tube metals and the aggressive components in the combustion gases. Combustion gases from waste incineration are compared with fossil fuel gases known to contain particularly reactive and aggressive to most steel metals and Alloys. The corrosive fireside environment is generally considered to be caused by alkali chlorides and heavy metal salts. These have for the last years been the basic problem of improving the efficiency and performance of waste incineration boilers.

State of the art

Waste incineration is a complex combustion processes. The processes in a burning fuel bed include several different processes over the grate [4, 5]. Babcock & Wilcox Vølund has proposed a new technology aiming to increase the steam temperature called Steamboost. The idea behind Steamboost is that the corrosive species are released over the first part of the grate such that the flue gas is less corrosive over the last part of the grate, see Fig. 1. Full-scale experiments were performed on a plant in Denmark to verify the concentration of corrosive species in the flue gas over the grate. These measurements confirmed a low concentration of corrosive species near the end of the grate.

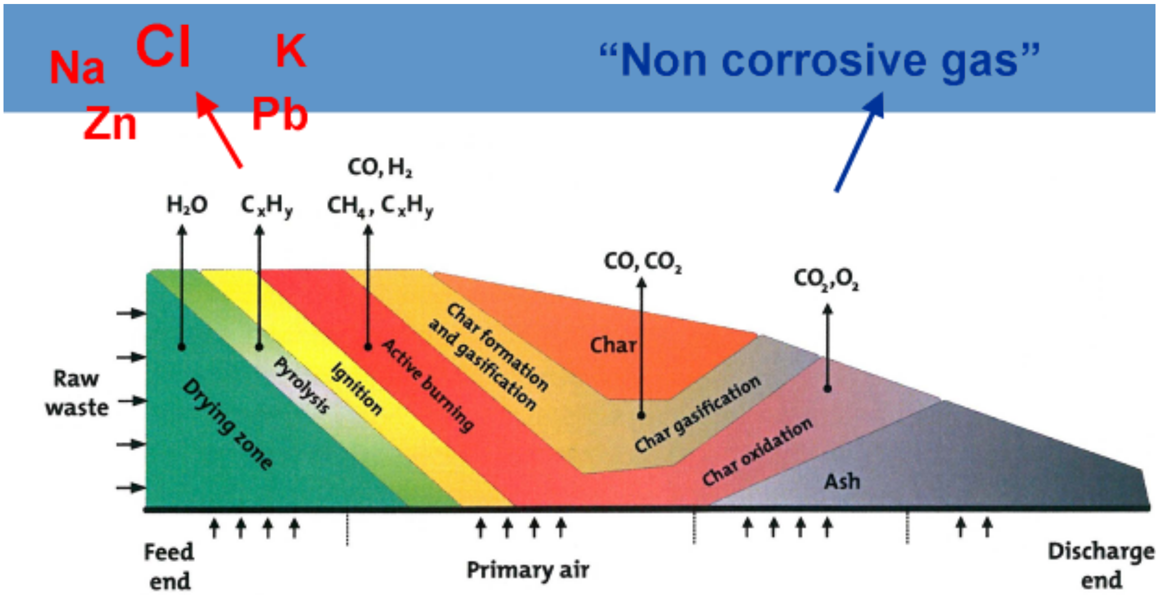

Figure 1: A schematic drawing of the idea behind Steamboost. The corrosive species are released over the first part of the grate such that the flue gas is less corrosive over the last part of the grate [4].

The scientific idea behind Steamboost is to utilize CFD modeling in order to identify fractions (positions) where the flue gas from the grate have a high heat flux and a low chlorine concentration. Superheaters may then be positioned in a part of the furnace within the less corrosive flue gas and subsequently increase the steam temperature up towards 500°C. This novel approach will then increase the possibility to generate higher steam data contributing more electricity being produced and thereby to the KME objectives.

However, the CFD calculations needs to be verified by deposit probes linking the theoretical approach to the actual deposit formed in the furnace. Little is, in addition, known about the corrosion of superheaters within the furnace. This project will therefore investigate the link between the CFD calculations and the actual deposits formed in the boiler. The corrosion properties of several possible superheater materials will additionally be investigated in order to get a fundamental knowledge of the corrosion behaviour of alloys within the furnace. The project will also investigate possibilities of optimizing the flue gas chemistry in the furnace more to decrease the corrosion rate even further. Furthermore, CFD analyses of the furnace were performed to ensure the corrosive part and the non-corrosive part of the flue gas would not mix during operation. The need for air nozzles in the back of the furnace was identified by the CFD analyses.

Recently, a steam system has been built at AffaldPlus in Næstved, Denmark. This setup enables part of the steam after superheater 2 to go into superheaters within the furnace and returning to the main steam line after superheater 3. This advanced setup has recently been used to test a superheater tube with the length of 300 cm in the furnace for one year. The inlet temperature of the steam was 340°C and the outlet temperature was 380°C. Post test analyses was very promising and showed that the steels tested exhibited reasonable low corrosion losses of less than 1,5 mm/year.

Careful characterization of the deposit chemistry at different positions gives a unique possibility to generate knowledge about the corrosion resistance of different material classes. The aim of this project is therefore to test conventional superheater materials as well as state of the art stainless steels. These materials will be compared with FeCrAl alloys, which will be studied in the laboratory in order to identify and understand the usefulness and limitations of aluminum oxide forming materials as components for biomass- and waste-fired boilers. Exposures of manufactured FeCrAl alloys will also be conducted in the waste fired boiler. The purpose is to expose aluminum oxide forming materials in different environments and temperatures.

Much research has been directed towards fireside corrosion and fouling in these plants in order to decrease maintenance costs and enable increased power efficiency. However, this novel approach has never been used before and if successful it will increase the possibility to increase the heat change in the boiler and generate higher electrical efficiency.

References

1. Nielsen, H.P., *The Implications of Chlorine-associted Corrosion on the Operation of Biomass-fired Boilers.* Progress in Energy and Combustion Science, 2000. **26**: p. 283 - 298.
2. Sroda, S., et al., *The effect of ash deposition on corrosion behaviour of boiler steels in simulated combustion atmospheres containing carbon dioxide (CORBI PROJECT).* Materials and Corrosion-Werkstoffe Und Korrosion, 2006. **57**(2): p. 176-181.
3. Uusitalo, M.A., P.M.J. Vuoristo, and T.A. Mantyla, *High temperature corrosion of coatings and boiler steels in oxidizing chlorine-containing atmosphere.* Materials Science and Engineering a-Structural Materials Properties Microstructure and Processing, 2003. **346**(1-2): p. 168-177.
4. al, *High Electrical Efficiency by Dividing The Combustion Products*. in *16th Annual North American Waste-to-Energy Conference*. 2008. Philadelphia, Pennsylvania, USA.
5. Bøjer, M., et al. *Release of Potentially Corrosive Constituents from the Grate of a Waste-to-Energy boiler*. in *IT3'07*. 2007. Phoenix, AZ, USA.

Goal

General project goals

The overall goal of the project is to improve plant economy by enabling an increased electricity production. This will be achieved by generating new knowledge to facilitate the implementation of CFD modelling, deposit test and corrosion tests. The aim of this project is also to find suitable materials in terms of corrosion for a Steamboost superheater positioned within the furnace. Convectional superheater materials as well as state of the art stainless steels will therefore be investigated. These materials will be compared with FeCrAl alloys, which will be studied in the laboratory in order to identify and understand the usefulness and limitations of aluminum oxide forming materials as components for biomass- and waste-fired boilers. Exposures of manufactured FeCrAl alloys will also be conducted in the waste fired boiler. The purpose is to expose aluminum oxide forming materials in different environments and temperatures.

Project goals in relation to KME goals

This project proposal contributes to the following KME goals:

- Higher steam parameters and thereby higher electrical efficiency.
- Development of novel solutions where steam is superheated in the furnace.
- Develop improved material solutions – including alumina forming alloys.

Project plan

The project will be divided into two separate phases. Initial testing of CFD calculations/deposits, corrosion probes and separate components/materials will be performed (phase one). The results from phase one will then be used in order to set up phase two. The aim with phase two is to test a steamboost superheater at a plant in Denmark. The two separate phases are described below. In parallel to the research performed at the boiler, this project will also include a laboratory study. The laboratory study follows the setup of the boiler exposures, i.e. divided into two phases where the results from phase one input for the second phase. The aim of the laboratory studies are to generate knowledge about the corrosion mechanism of FeCrAl alloys exposed in environments mimicking those of waste and biomass fired boilers. The laboratory part is linked to the field exposures in this project but also builds on the results obtained in KME 414, KME 507 and KME 519. The corrosion mechanisms of FeCrAl alloys are in addition investigated in the waste fired CFB boiler P15 at Händelö (KME711 project). The FeCrAl part of the project will therefore be coordinated with the planned activates in the KME711 project.

Since the revision of the boiler follows a commercial time plan the project needs to adjust its time plan accordingly. This implies that the involved companies may have costs before the official project start date. These costs are associated to the boiler revision stop August-September 2014. During the revision preparations and installations will be performed that enables the testing of the three alternative solutions described under Phase 1 field Study below. This includes new steamboost superheaters that will be installed in the furnace. The superheaters must be manufactured before the revision. Preparations in addition needs to be performed for testing of the alumina-forming APMT and for testing a solution with a ceramic shields.

Phase 1 laboratory study (2014-09-01 ->2016-07-01)

There are promising results for the FeCrAl materials from studies in the field (KME 414 and KME 507), showing significantly lower material loss of a FeCrAl alloy than a high (and low) alloyed stainless steel. However, the laboratory studies show that also these materials suffer from alkali chromate formation and that an alumina scale fails to form. An attempt to circumvent this was done through pre-oxidation of the material to establish an alumina scale before exposure to the aggressive environment. When exposed to the aggressive environment the alumina scale fails. It seems as the corrosion start at sites with flaws in the alumina and continues from there. There are also indications that the surface finish affects the growth of the alumina scale and therefore also its protectiveness. Also, the grain size of the material appears to affect the protectiveness of the material. This project will investigate this further.

In order to be able to identify where FeCrAl materials can be used (temperature and environment) in the second phase the corrosion mechanisms will be studied in the laboratory. The laboratory exposures will be performed in environments mimicking that of the boiler. As described previously, the environment in the boiler in this project is milder in some parts and more aggressive in other parts. In the laboratory study a FeCrAl material will be exposed to a milder environment and compared to a more aggressive environment. To mimic the environment, the deposit study will be taken into account at the field exposure temperatures, ranging from 600 to 900°C.

The aim of the laboratory studies is to generate knowledge about the corrosion mechanism. This will help understand the usability and limitations of FeCrAl materials in biomass and waste fired boilers and how to develop a FeCrAl material suitable for these boiler environments.

Tools available for the laboratory investigations:

Short term exposures will be carried out in two state of the art thermo balance systems (Setaram TG) where samples are exposed to a controlled dynamic atmosphere with 1µg resolution. For longer exposures horizontal tube reactors consisting of a silica glass tube where the samples are mounted on an alumina holder are used. All systems have a well-defined gas atmosphere and are controlled by mass flow regulators.

Analysis of the corrosion products can be performed with Scanning Electron Microscopy (SEM) using high-resolution FEG-SEMs. Energy Dispersive X-ray analysis (EDX) can be used for chemical analysis, while crystalline phases can be identified by Electron Backscattered Diffraction (EBSD). Transmission Electron Microscopy (TEM) and Focused Ion Beam (FIB) milling can be employed to analyze the specimens in more detail. A new state-of-the-art 300 kV FEI Titan 80-300 TEM has recently been installed at Chalmers. It provides unique opportunities for analysing the oxide scales on the atomic level. Grazing incidence angle X-ray diffraction, GI-XRD can be used for characterization of crystalline corrosion products and in-situ diffraction. We will use a Siemens D-5000 instrument equipped with a Göbel mirror that allows us to detect 20 nm crystalline corrosion product layers. Time of Flight-Secondary Ion Mass Spectrometry (ToF-SIMS) can be used in order to determine low concentrations of elements in the formed oxide scale because of its high surface sensitivity in combination with an extremely low detection limit of ppm. Additionally, SIMS provides the possibility to detect isotopes such as the oxygen isotope O^{18}. A recent grant from the Wallenberg foundation to the NCIMS will also provide access to a NanoSIMS within this projects life span and the NanoSIMS can be used for ultra high resolution studies of the materials investigated this project. Combining SIMS results (qualitative element distribution) with Scanning Auger Microprobe analysis, SAM, that gives quantitative element distribution can provide important information on the composition of the oxide scale and corrosion products.

Phase 1 field study (2014-09-01 ->2016-07-01)

The aim of the Steamboost superheater is to superheat the steam to at least 480°C giving a metal temperature of approximately 500°C. As little is known about superheter conditions and possible materials in this environment different scenarios will be investigated in phase one to fulfil the goals. Depending on the initial results of the project different scenarios is possible. The two first steps will be investigated and evaluated according to the detailed plan below. Depending on the outcome of the evaluation a decision regarding the third step will be taken. This will reflect the work during the second half of the project (see below) but is close linked to the first two steps and therefore put in this section in order to better overview the detailed plan.

1. Currently, a Steamboost test is conducted at AffaldPlus in Næstved, Denmark. In this test, superheater tubes are connected to the main steam of the plant. The inlet temperature of the steam is 350°C and the outlet temperature is 440°C giving a metal temperature of approximately 450°C. The tubes are composed of different materials welded together. Overlay welding as tube protection is tested as well.

- In this KME project, a test will be conducted where the inlet temperature of the steam is 350°C and the outlet temperature is 480°C. Different materials will be tested at different temperatures (metal temperatures ranging from about 350°C to 500°C).
- The corrosion behavior of the different materials at the different temperatures will be analyzed by weight loss measurements as well as detailed posttest analyses.
- Tests will be conducted with deposit probes under different primary and secondary air settings. This will be performed to optimize (i.e. decrease the deposition of corrosive species) the flue gas over the last part of the grate near the Steamboost superheaters.
- Corrosion tests may also be performed in the furnace of the boiler utilizing temperature controlled corrosion probes, see below.
- A commercial Steamboost superheater will be modeled utilizing CFD.
- Results obtained from CFD modeling, corrosion testing and from deposit probes will be compared and discussed.

2. As an alternative to the steel tubes, FeCrAl (alumina-forming) will be tested as a corrosion resistant material forming an alumina scale. The idea is to have a co-axial superheater with an inner super heater tube with the steam inside, and an outer corrosion resistant material (in this case FeCrAl). Coaxial tubes are normally used in CFB boilers and this is a new application.

- The corrosion properties of FeCrAl will be tested in this project in two ways. An initial test will be performed with a tube consisting of FeCrAl inside the furnace near the Steamboost superheater. The temperature of the tube will be measured during the exposure. This will give an indication of the corrosion properties of the alloy at different temperatures approximately between 550°C and 650°C.
- Secondly, the FeCrAl will be tested on a corrosion probe along with other promising materials.
- Different pre-oxidation treatments of the alumina-forming alloy will be performed.

- The heat flux across a co-axial tube will be modeled by CFD.

3. Based on the results in step 1 and 2 tubes with a ceramic shield may be tested. The idea behind this is that an inner super heater tube with the steam inside is protected by a ceramic material on the outside. The ceramic will be positioned with a small gap between the inner tube and the outer ceramic.

- In this phase, a ceramic solution may be tested. The temperature of the tube will be controlled by a flow of air.

Exposures will be carried out both with cooled probes and in tubes in the superheater loop. A cooled probe will be used for exposure of the same materials and materials temperature as a permanently installed loop but shorter exposure times in order to be able to generate knowledge about the corrosion mechanisms and the kinetics. The probe and the loop will be located as close as possible to each other and thus, as far as possible share the same exposure environment. The exposure time will be determined by the time between two outages. The materials investigated will be selected so that they cover several material groups used today for superheaters, e.g. low-alloyed steels, stainless steels and highly alloyed steels. In addition, FeCrAl samples will be of interest and exposed. Two material temperatures will be investigated; the current material temperature at the superheater loop (about 480°C) and the superheater material temperature corresponding to the steam temperature goal regarding waste. The higher steam temperature goal is only investigated by cooled probes.

Phase 2 field and laboratory study (2016-07-01 -> 2018-04-15)

The aim with the first stage of the project is to generate knowledge about:

- CFD calculations and actual deposit composition at different positions.
- The corrosion behavior of the different materials at the different temperatures. (both time resolved probe tests and Steamboost solutions).
- CFD modeling of a commercial Steamboost superheater.
- The corrosion properties of FeCrAl material, both by a tube consisting of FeCrAl inside the furnace near the Steamboost superheater and by corrosion probe tests.
- The need for a ceramic shield.
- Knowledge regarding the corrosion mechanisms in order to identify where FeCrAl materials can be used (temperature and environment).

Based on the results obtained for the different solutions, a Steamboost superheater connected to the main steam line will be tested in AffaldPlus, Næstved, Denmark. This will in addition influence the direction of the laboratory studies of the FeCrAl materials performed within the second stage. The details for the second step will be decided within the project group and presented for the reference group of the project.

Staff

The following personnel from industry will be participating in the project:
L. Mikkelsen, B&W Völund
B. Jönsson, Sandvik Heating Technology
J. Högberg, Sandvik Materials Technology

The following personnel at HTC (Chalmers) will be participating in the project:
T. Jonsson
J. Liske
K. Hellström
M. Paz
N. Israelsson (Planned to defend PhD end of 2014)
New PhD student (2015->)

Time schedule

The project will be divided into two separate phases. The results from phase one will then be used in order to set up phase two. The first part of phase one is planed in detail but after that part the results need to be analysed and will influence the other activities. The aim with phase two is to test a Steamboost superheater at a plant in Denmark. The details for the second step will be decided within the project group and in addition presented for the reference group of the project.

Phase 1: 2014-09-01 ->2016-07-01

Phase 2: 2016-07-01 -> 2018-04-15

Industrial reference and financing

The industrial partners that will participate in the project are listed in the table below.

Part	**Participants role in the project**
B&W Völund	Responsible for boiler operation. Responsible for probe exposures
Sandvik Heating Technology	Providing material and know-how.
Sandvik Materials Technology	Providing material and know-how.
Göteborg Energi AB	Providing know-how.
Chalmers/HTC	Responsible for corrosion evaluation

Bilaga till projektansökan inom Samverkansprogrammet Materialteknik för t

Fördelning av kostnader för varje ingående part

Sökande:	Torbjörn Jonsson, HTC vid Chalmers
Projekttitel:	Ökad ångtemperatur i rosterpannor - Steamboost (KME 709)

Part		**Kostnadsfördelning**									
		Lön	Konsult	Utrustning	Material	Laboratorie	Dator	Resor	Övrigt	Indirekta	**Summa**
	2014										0
	2015										0
	2016										0
	2017										0
	2018										0
	Summa	0	0	0	0	0	0	0	0	0	0
Sandvik Heating Technology	2014	400			300			10			710
	2015	500			250			10			760
	2016	500			200			10			710
	2017	500			0			10			510
	2018	300			0			10			310
	Summa	2 200	0	0	750	0	0	50	0	0	3 000
Sandvik Materials Technology	2014	20			50			16			86
	2015	20			46			20			86
	2016	20			46			20			86
	2017	20			46			20			86
	2018										0
	Summa	80	0	0	188	0	0	76	0	0	344,000
Babcock & Wilcox Vólund	2014	500			500			10			1 010
	2015	200			100			10			310
	2016	600			600			10			1 210
	2017	200			100			10			310
	2018	150			0			10			160
	Summa	1 650	0	0	1 300	0	0	50	0	0	3 000
	2014									0	0
	2015									0	0
	2016									0	0
	2017									0	0
	2018									0	0
	Summa	0	0	0	0	0	0	0	0	0	0
HTC vid Chalmers	2014	680			20	100		20		422	1 242
	2015	380			25	105		25		236	771
	2016	630			40	230		50		387	1 337
	2017	300			15	90		15		184	604
	2018	160			5	40		10		98	313
	Summa	2 150	0	0	105	565	0	120	0	1 328	4 268
		6 080	**0**	**0**	**2 343**	**565**	**0**	**296**	**0**	**1 328**	

STÖD FÖR REGISTRERING I ENERGIMYNDIGHETENS WEBPORTAL

Följande siffror kan användas för att fylla i projektets ansökan på Energimyndighetens webbportal E-kanalen. Tabellen skapas automatiskt utifrå

	SUMMA	2014	2015	2016	2017	2018
Lönekostnad	6 080 000	1 600 000	1 100 000	1 750 000	1 020 000	610 000
Konsultkostnad	0	0	0	0	0	0
Utrustning	0	0	0	0	0	0
Material	2 343 000	870 000	421 000	886 000	161 000	5 000
Laboratoriekostnad	565 000	100 000	105 000	230 000	90 000	40 000
Datorkostnad	0	0	0	0	0	0
Resor	296 000	56 000	65 000	90 000	55 000	30 000
Övrigt	0	0	0	0	0	0
Indirekta kostnader	1 327 666	422 333	235 667	387 333	184 000	98 333
SUMMA	10 611 666	3 048 333	1 926 667	3 343 333	1 510 000	783 333

8415000