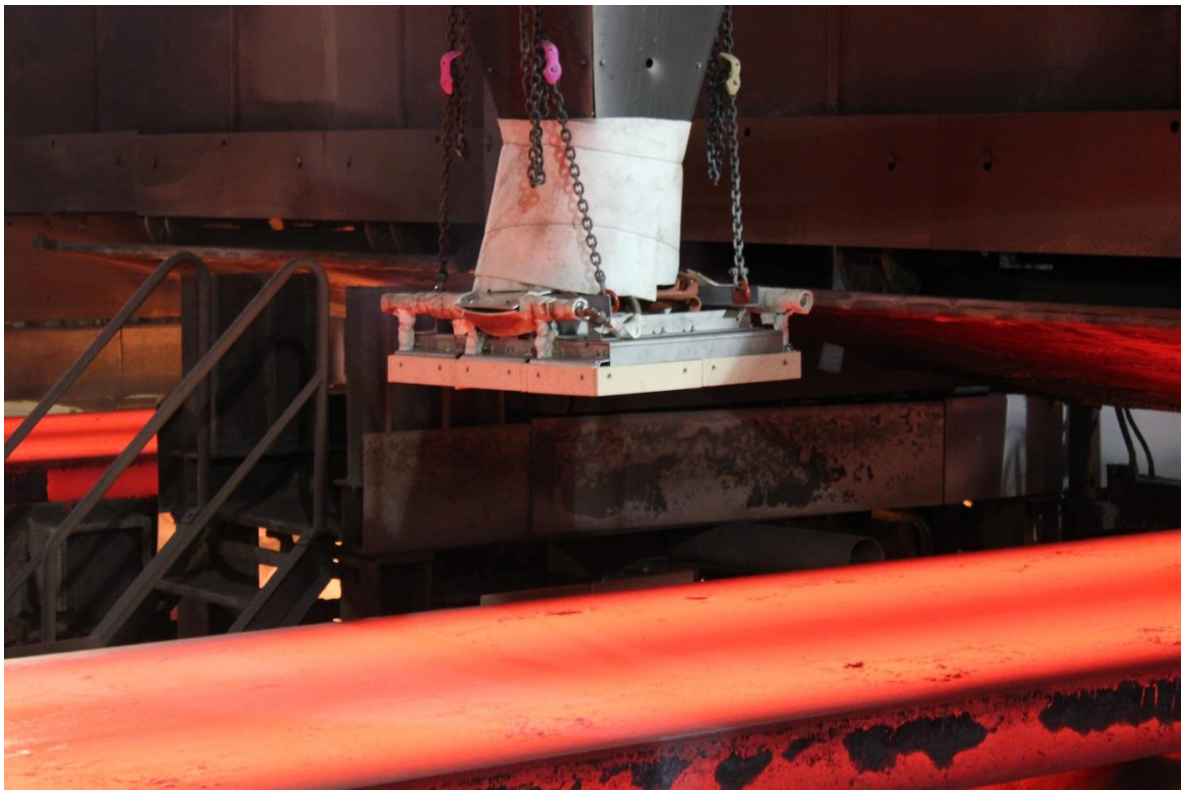
Public Final Report – TEEI214003
TEG - Steel

Thermo-elektrische terugwinning van restwarmte in de staalindustrie
Thermoelectric waste heat recovery in the steel industry



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This report can be ordered free of charge in electronic form by e-mail to: info@rgsdevelopment.nl

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1. Introduction

Thermoelectric power generation is a promising technology to recover part of today's wasted industrial process energy that is lost in the high temperature range between 700°C and 1200°C. Such a "solar panel for waste heat" produces useful electricity from the estimated 20-50% energy losses today's industrial manufacturing processes. These energy losses exist in the form of exhaust gas, cooling water and heat losses from products and equipment. The availability of thermoelectric power generation will help the industry to increase process energy efficiency and to operate under continuously more demanding environmental regulations.

2. Thermoelectric power generation

A thermoelectric generator (TEG), also called a Seebeck generator, is a solid state device that converts a heat flux (causing a temperature difference over the TEG) directly into electrical energy through a phenomenon called the Seebeck effect. The figure below shows a schematic sketch of such a device.

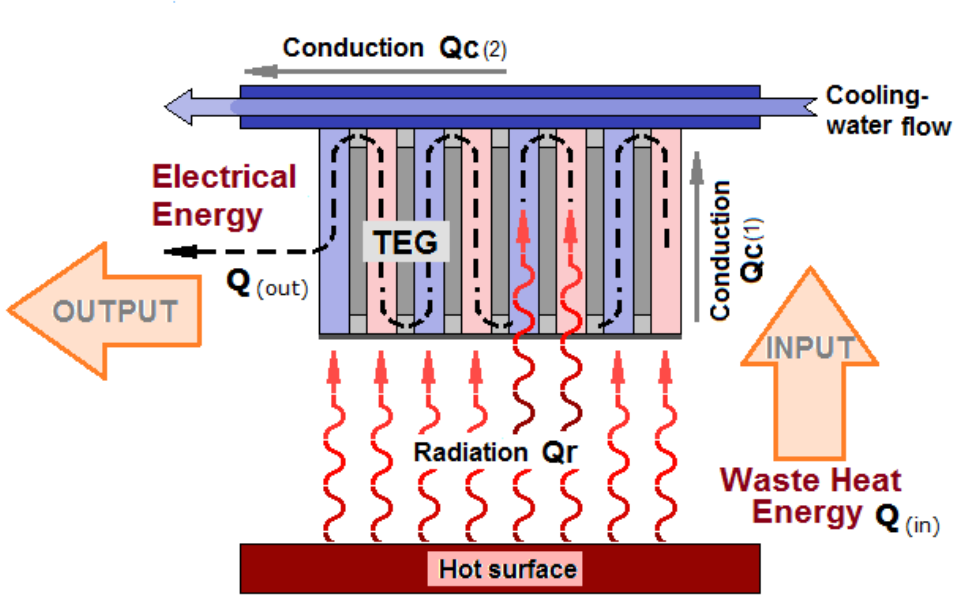

Figure 1: Schematic principle of a thermoelectric generator. A hot surface at the bottom emits heat radiation towards the TEG receiver. In the TEG receiver two types of semiconductor elements are electrically connected in series. The lower side of the semiconductor devices receives the heat radiation, while the top side is water cooled. Due to the temperature difference over the semiconductor elements the Seebeck voltage is generated, which adds up to the voltage of the TEG generator.

In this project, the waste heat emitted from a steel slab after the steel slab casting process at Tata Steel Ijmuiden was the source for the thermoelectric power generation. The TEG modules, panels and finally the TEG system was produced by RGS Development. The final thermoelectric power generation system that went under test at Tata Steel Ijmuiden consisted of six TEG panels of 200 x 300 mm^2 dimension.

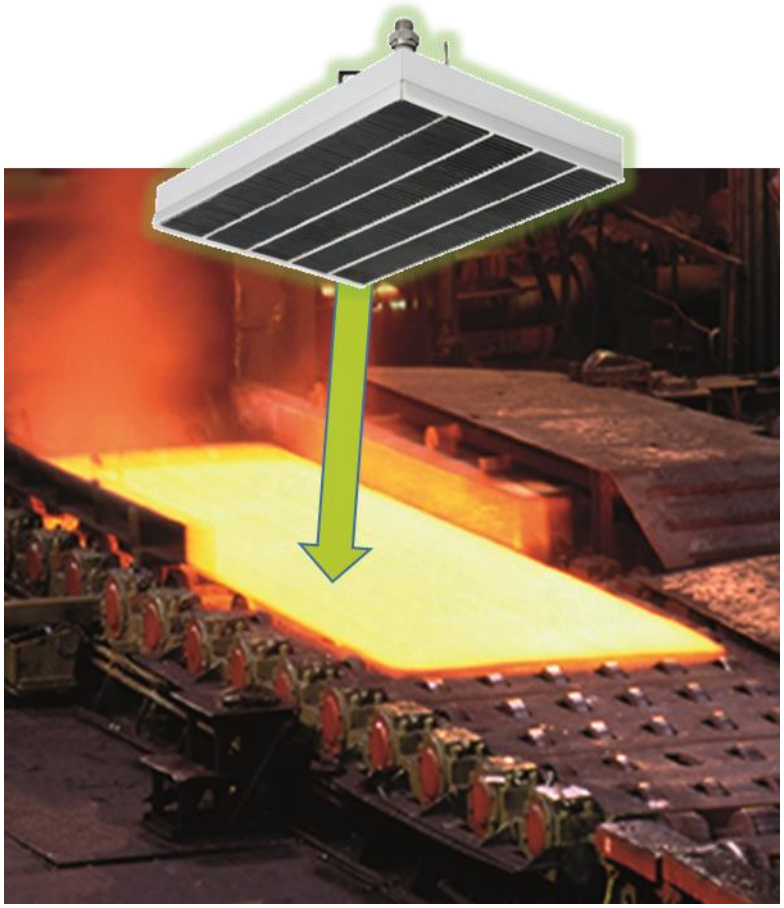

Figure 2: The objective of the TEG steel project was to test and demonstrate the behaviour of a TEG system on the steel slab caster at Tata Steel Ijmuiden.

The advantages of thermoelectric power generation in comparison to other technologies is that:

- There are no movable parts in the system, which results in low maintenance.
- Systems can be installed in a flexible way in any required areas from kW to MW scale.
- TEG systems can be combined with hot water or steam generators, when the cooling water respectively steam is used in a second process. Such a combined system will result in higher conversion efficiencies.

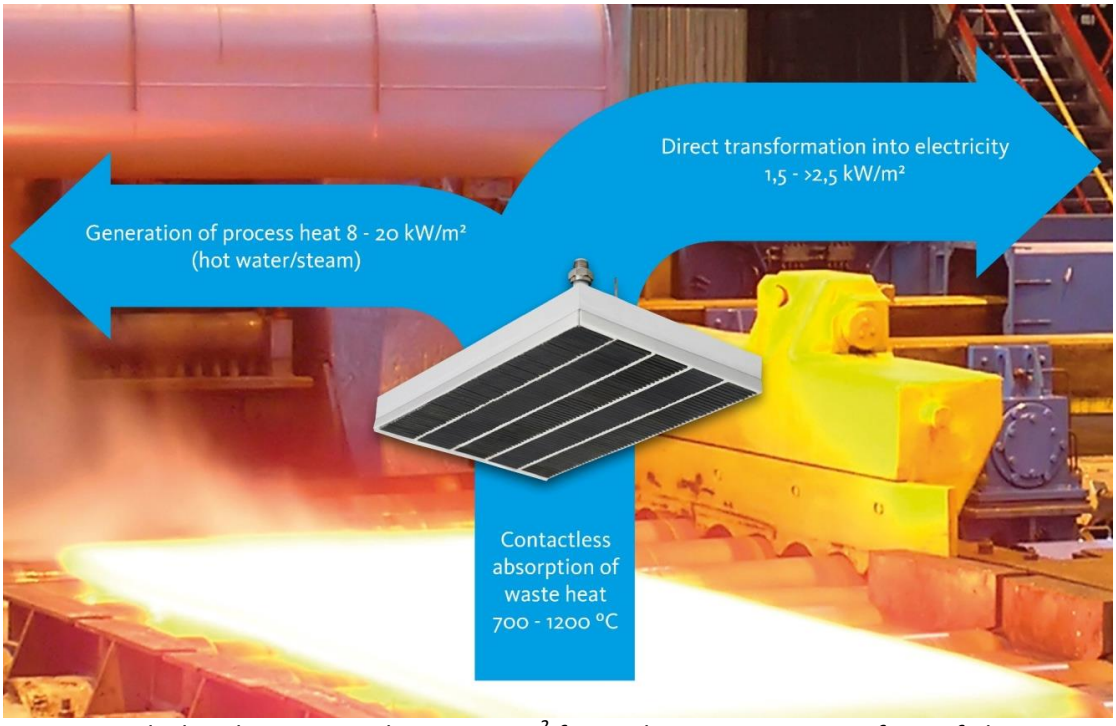

Figure 3: Calculated energy production per m^2 from a hot environment in form of electricity and heat in the cooling water.

3. TEG Steel project

Prior to the TEG Steel project, Tata Steel Ijmuiden and RGS Development modelled the potential use of a thermoelectric generator on different locations in the steel manufacturing process at Tata Steel in Ijmuiden. From this theoretical study the conclusion was that there is sufficient potential for waste heat energy recovery in such an environment and that TEG systems can be produced in a cost efficient way by the ribbon growth on substrate material casting process. Based upon the theoretical estimation the project partners engaged in the TEG Steel project to test TEG modules, panels and finally a TEG system under realistic conditions of a steel process.

The project objective was to practically verify the assessment assumptions in a prototype test system under realistic conditions at the steel slab casting environment at Tata Steel in Ijmuiden.

The planned results of this project are:

- to verify all relevant assumptions for the application of a thermoelectric system for industrial waste heat recovery in a steel plant casting production line and
- to build, install and test a "1m^2" demonstration thermoelectric power generation system in a casting production line at Tata Steel.

In the first project phase TEG test modules with dimensions of 40 x 40 mm^2 and 100 x 40 mm^2 were produced by RGS Development and tested in the R&D facilities at Tata Steel Ijmuiden. The test results were used as input to improve the TEG test module manufacturing process and make them more resistant with respect to the conditions in the anticipated environment. With a module duration test of 1000 hours in a laboratory furnace the technical milestone of the first project phase was achieved.

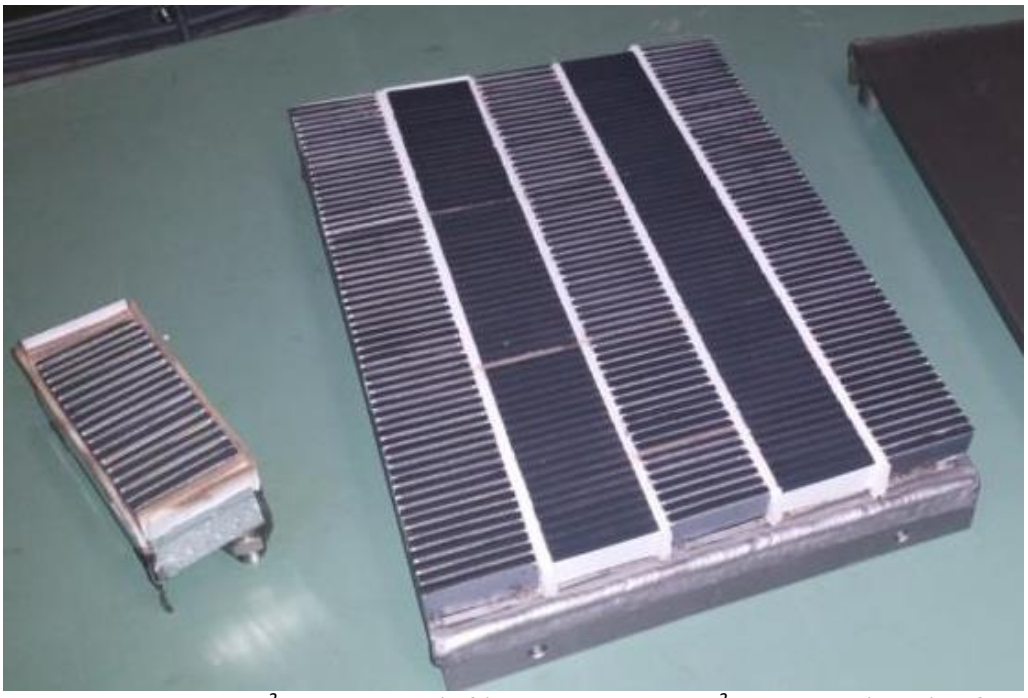

Figure 4: 40 x 100 mm^2 TEG module (left) and 200 x 300 mm^2 TEG panel (right) before installation in a TEG system.

In the second project phase, detailed system engineering was started to design, build and install a TEG system on the steel slab casting line at Tata Steel in Ijmuiden. This system was operated in February 2017 on the desired spot, after which is was brought back to RGS Development for disassembly and analysis.

Figure 5: TEG panel in the door of a test furnace. In such furnaces duration tests of components were made prior to installation in the production environment.

The technical results from this project were:

- It is possible to produce thermoelectric modules that can operate for long periods in a furnace environment with controllable degradation (1000 hours operation).
- A system design including technical infrastructure such as integration into production site cooling system and DC-AC electrical conversion has been produced, installed and tested on site.
- The test evaluation showed very valuable results for the next generation of TEG systems in the foreseen up-scaling of this technology. Special emphasis must be given to the protection of the thermoelectric generators against water and thermal

shock. These lessons learned from the test under realistic conditions will be incorporated in future TEG system design.

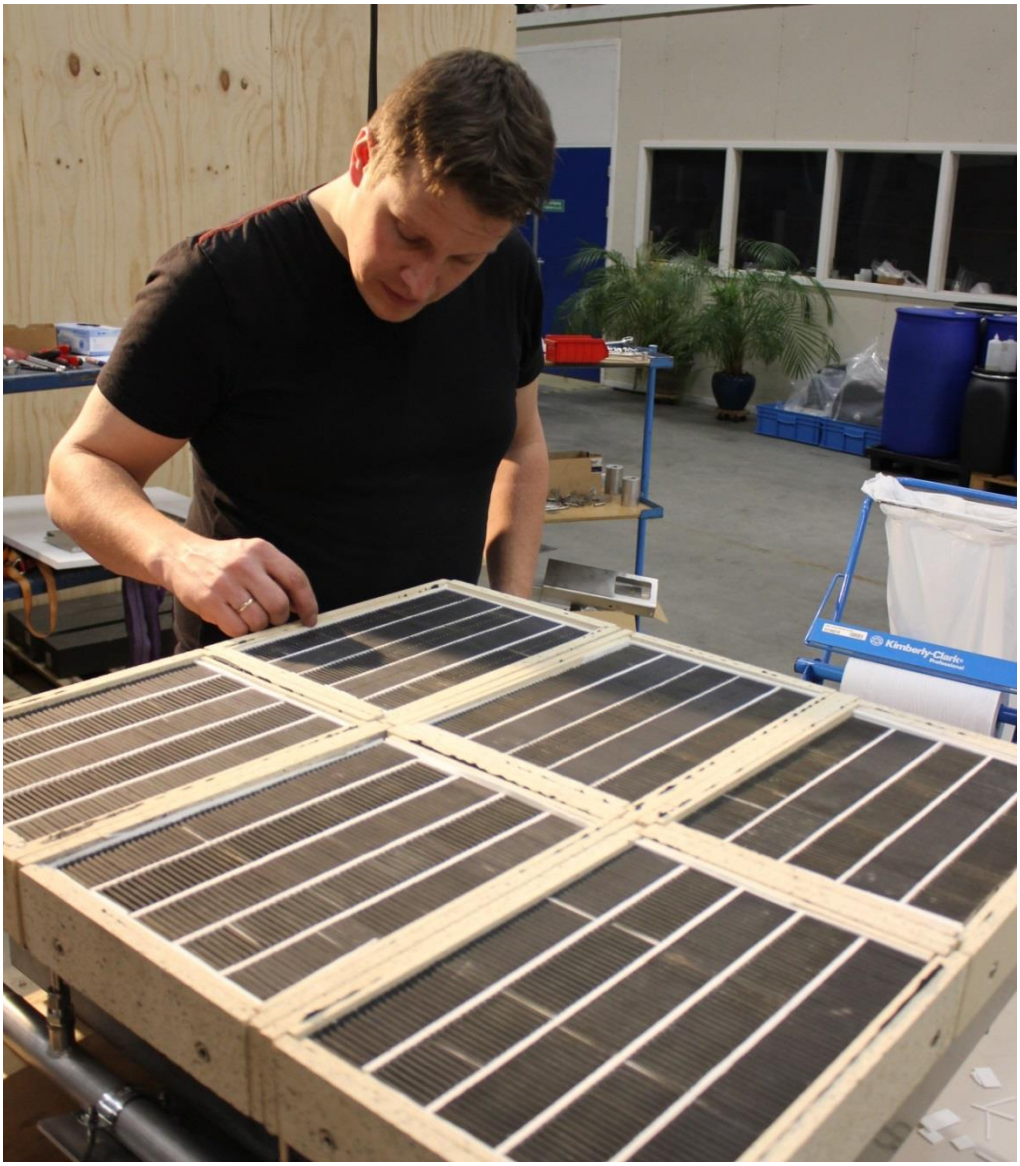

Figure 6: Manufacturing of the TEG system at RGS Development.

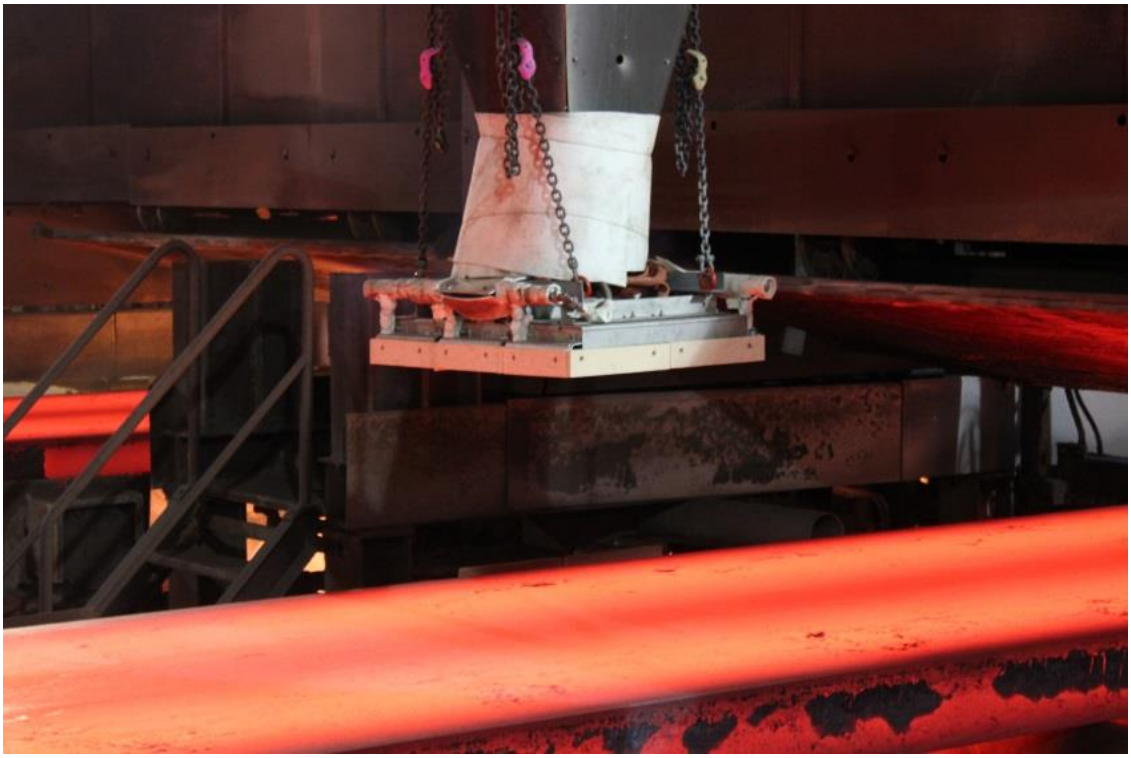

Figure 7: TEG system under operational conditions on top of the steel slab caster at Tata Steel Ijmuiden.

The tests in the first phase of the project proved to be relevant and resulted in improvement cycles of the TEG modules and panels. The number and time duration of these improvement cycles caused some project delay. However without the input from the realistic environment, these problem would have been detected in a much later development stage resulting in higher delays and higher development costs.
The final results of this project verified the modelling assumptions and resulted in important input to further improve the design package with real data from the testing done in the project. The testing under realistic conditions pinpointed additional requirements for TEG systems caused by the industrial environment (such as resistance to thermal shock and water resistance). These results form a valuable input for the up-scaling of this technology towards a planned 50 m^2 system that in addition to electricity production also utilizes the heat of the cooling system to produce steam. This upscaling project is planned by the project partners with addition of Engie as system integrator. Also in other fields of high temperature waste heat recovery the project result are very important and will be applied by the project partners.
With the results of the TEG Steel project an innovative Dutch technology has been demonstrated that enables the recovery of high temperature waste heat from industrial processes in a temperature region which is not easily accessible by other technologies.

4. Publications

The following table gives an overview on presentation and publications of results from the TEG Steel project.

	Partner	Form
M2I Meeting: Materials of the Future, December 2015	RGS Development	Oral presentation
14th European Conference on Thermoelectrics, September 2016 Lissabon	RGS Development	Oral presentation
Tata Steel Innovista 2017, Nominated project presentations, March 2017	Tata Steel	Oral presentation
IDTechEx, May 2017, Berlin	RGS Development	Oral presentation