



FINAL REPORT

2012 - 2015

Efficient maintenance of geothermal power plants

Project ID: GEORG 11-04-005

Coordinator: Rúnar Unnpórsson

Start date: 01.04.2012

Duration: 3 years

Partners: Reykjavik Energy, HS Orka, Landsvirkjun and Innovation Center Iceland

1 General status of the project

This project has been effectively completed. The project resulted in two M.Sc. theses, that have successfully been defended, and one Ph.D. thesis yet to be defended. The project resulted in six ISI journal articles, five conference proceedings and several poster presentations. The M.Sc. students were Almar Gunnarsson and Ari Elísson and the Ph.D. student was Reynir Smári Atlason. The theses by Almar and Ari can be accessed through Skemman – a repository of academic and research documents ([Almar's thesis](#) and [Ari's thesis](#)). The Ph.D. thesis by Reynir Smári will be accessible on skemman.is as soon as Reynir has finished his defence. Current plans are to have the thesis late in 2015. The project's results have been presented on two conferences; the ASME Power conference in Boston in 2013 and the ASME Power conference in Baltimore, 2014.

The main body of funding was used throughout this project to fund the Ph.D. student throughout his research. The last paper published (in the ISI journal Energies) from this project summarises the results from the previous studies conducted within this project to form a system dynamics causal loop diagram. The abstract for the last paper is as follows:

“As renewable energy sectors evolve and grow within a country, the need for expertise to maintain its infrastructure grows. Such expertise is often provided by foreign industries. It is in the global interest to facilitate expertise to grow domestically, eventually leading to widespread clusters of industries around a renewable energy sector and a global growth of expertise. This ultimately fast tracks the development in the renewable energy sector since more players become active in developing solutions. In this article the factors influencing domestic development are identified from previous studies conducted within the Icelandic geothermal sector. The cause and effect relationships between the identified factors are then mapped. A system dynamics causal loop diagram based on Icelandic case studies is presented to visualise how the formation of industrial clusters in the renewable energy sector can be initiated. This visualisation, based on the Icelandic geothermal sector, can be of use for other industries in the renewable energy sector who are attempting to conduct their maintenance procedures domestically and increase the rate of innovation within a country.”

Throughout the project the collaboration was successful and the Icelandic Energy companies were very open to the students and provided good access to information and data. Without such good collaboration the amount of publications would not have been realized.

1.1 Major milestones of this project

- Two M.Sc. theses (+ oral presentations) completed
- Six ISI journal articles published
- Nine oral presentations of the projects status/results
- Two conference articles(+ oral presentations) published at ASME Power 2013, Boston
- Three conference articles(+ oral presentations) published at ASME Power2014, Baltimore
- Six poster presentations.
 - Two on the Arctic energy summit, Akureyri.
 - Two on Georg Open day and
 - Two at the master's day at the University of Iceland.
- A Ph.D. thesis has been completed by Reynir S. Atlason, consisting of the articles published. The defence is being prepared and is estimated later this year (2015).

1.2 Project progress/time schedule:

The project progress, when looking at it retrospectively, is best presented through publication dates. Shown in the figure below, are the publications and work period by the students. The beginning of each series represents submission date of the relevant article and the end point when the article gets published. With regards to the students, the graph begins when they begin their work and ends when they graduate. Note however that Reynir began in the end of 2012.

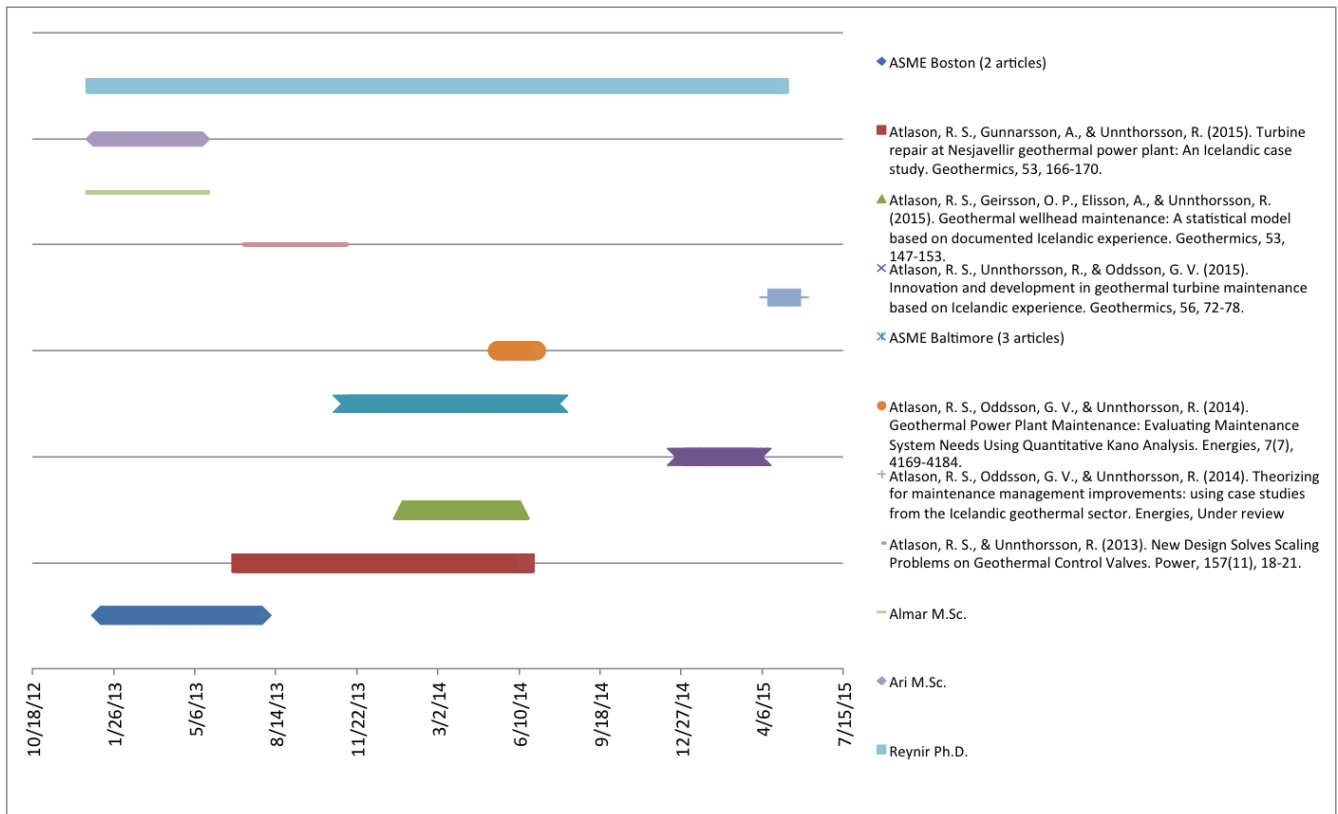


Figure 1. The progress of the project presented through publication dates and work by students.

2 Project Management

Dr. Rúnar Unnþórsson, associate professor at the Industrial engineering, mechanical engineering and computer science department at University of Iceland, oversaw the project and managed the work carried out by the M.Sc. and Ph.D. students. Dr. Magnús Þór Jónsson co-supervised Almar and Ari MSc theses and in 2014, Dr. Guðmundur Valur Oddsson, assistant professor at the same department, joined the team and contributed to several studies. Rúnar and Guðmundur both mentored the Ph.D. candidate for the ASME Power conference held in Baltimore, 2014.

3 Student involvement

The three students involved in the project and their supervisors were those who worked mainly on the project. Reynir Smári Atlason, as the major part of his Ph.D. thesis, Almar Gunnarsson as his M.Sc. thesis and Ari Elísson as his M.Sc. thesis. Both Ari and Almar graduated in 2013 and Reynir's defence is planned late 2015. Oli Pall Geirsson, a Ph.D. candidate in mathematics co-authored one ISI article with Reynir and Rúnar. The paper was published in [Geothermics](#). Table 1 lists the persons who participated in the project, their academic title and gender.

Table 1. List of the persons that participated in the project.

<i>Name</i>	<i>Gender</i>	<i>degree</i>
Reynir S. Atlason	Male	MSc. Env. and Nat. Resources
Almar Gunnarsson	Male	MSc student Mech. Engr.
Ari Elísson	Male	MSc student Ind. Engr.
Óli Geirsson	Male	MSc Mathematics
Rúnar Unnþórsson	Male	PhD Engineering
Guðmundur Valur Oddsson	Male	PhD Engineering
Magnús Þór Jónsson	Male	PhD Engineering
Sæmundur Guðlaugsson/ Guðmundur Hagalín (OR) + other staff at OR	Male	Marine Engineers
Þrándur Rögnvaldsson (LV) + Steinn Ágúst Steinsson + other staff at LV	Male	Marine Engineers
Hreinn Halldórsson (HS) + other staff at HS	Male	Marine Engineers

4 Publications and disseminations

The following is a list of publications resulting from this project:

4.1 Theses

- Gunnarsson, A. (2013). [Maintenance of the steam turbines at Hellisheiði power plant](#). M.Sc. Thesis in mechanical engineering
- Elísson, A. (2013). [Performance Indicators for Maintenance in Geothermal Power Plants](#). M.Sc. Thesis in industrial engineering
- Atlason, RS. (2015). Theorizing for improved maintenance management: using case studies from the Icelandic geothermal sector. Ph.D. Thesis (to be defended in environment and natural resources)

4.2 Oral presentations

- Gunnarsson, A. (2013). [Maintenance of the steam turbines at Hellisheiði power plant](#). Public presentation of Gunnarsson's M.Sc. thesis in mechanical engineering
- Elísson, A. (2013). [Performance Indicators for Maintenance in Geothermal Power Plants](#). Public presentation of Elísson M.Sc. thesis in industrial engineering
- Unnthorsson, R. (2012), "Efficient Maintenance Management of Geothermal Power Plants", a public presentation at GEORG open house, 22. nov., National Museum of Iceland.
- Smáráson, R.S. (2015), "Efficiency and Innovation in geothermal power plant maintenance", a public presentation at GEORG open house, 14. jan., National Museum of Iceland.
- Gunnarsson, A., Elisson, A., Jonsson, M., & Unnthorsson, R. (2013, July). [Specified Maintenance of Steam Turbines in Geothermal Power Plants](#). In *ASME 2013 Power Conference* (pp. V001T05A005-V001T05A005). American Society of Mechanical Engineers.
- Atlason, R. S., & Unnthorsson, R. (2013, July). [Operation and maintenance in Icelandic geothermal power plants: Structure and Hierarchy](#). In *ASME 2013 Power Conference* (pp. V001T05A007-V001T05A007). American Society of Mechanical Engineers.
- Atlason, R. S., Gunnarsson, A., & Unnthorsson, R. (2014, July). [Necessity is the Mother of Invention: The Dawn of Domestic Geothermal Turbine Repairs in Iceland](#). In *ASME 2014 Power Conference* (pp. V001T05A010-V001T05A010). American Society of Mechanical Engineers.
- Atlason, R. S., & Unnthorsson, R. (2014, July). [Wellhead Scaling Problems in Geothermal Power Plants Addressed Using a Needle Valve Derivative](#). In *ASME 2014 Power Conference* (pp. V001T05A009-V001T05A009). American Society of Mechanical Engineers.
- Atlason, R. S., Geirsson, O. P., Elisson, A., & Unnthorsson, R. (2014, July). [Go With the Flow: The Evolvement of Geothermal Wellhead Maintenance at the Hellisheidi Power Plant](#). In *ASME 2014 Power Conference* (pp. V001T05A011-V001T05A011). American Society of Mechanical Engineers.

4.3 Posters

- Atlason, R. S., & Unnthorsson, R. (2012), "Efficient Maintenance Management of Geothermal Power Plants", GEORG open house, 22. nov., National Museum of Iceland.
- Gunnarsson, A., Jonsson, M., & Unnthorsson, R.(2012) "Maintenance of steam turbines", GEORG open house, 22. nov., National Museum of Iceland.
- Gunnarsson, A., Jonsson, M., & Unnthorsson, R. (2012) "Maintenance Of The Steam Turbines At Hellisheiði Power Plant", Arctic Energy Summit, Akureyri, Oct 8-10, 2013
- Reynir Smari Atlason and Runar Unnthorsson, Asset Management Model for Geothermal Power Plants Based on Icelandic Experience, Arctic Energy Summit, Akureyri, Oct 8-10, 2013
- Gunnarsson, A., Jonsson, M., & Unnthorsson, R. (2013) "Maintenance of steam turbines", Open masters day at the University of Iceland, May.
- Ari Elísson, Magnus Þór Jónsson, Rúnar Unnpórsson (2013), Performance Indicators for Monitoring Maintenance in Geothermal Power Plants - A case study of the Icelandic geothermal industry, Open masters day at the University of Iceland, May.

4.4 Conference papers

- Gunnarsson, A., Elisson, A., Jonsson, M., & Unnthorsson, R. (2013, July). [Specified Maintenance of Steam Turbines in Geothermal Power Plants](#). In *ASME 2013 Power Conference* (pp. V001T05A005-V001T05A005). American Society of Mechanical Engineers.
- Atlason, R. S., & Unnthorsson, R. (2013, July). [Operation and maintenance in Icelandic geothermal power plants: Structure and Hierarchy](#). In *ASME 2013 Power Conference* (pp. V001T05A007-V001T05A007). American Society of Mechanical Engineers.
- Atlason, R. S., Gunnarsson, A., & Unnthorsson, R. (2014, July). [Necessity is the Mother of Invention: The Dawn of Domestic Geothermal Turbine Repairs in Iceland](#). In *ASME 2014 Power Conference* (pp. V001T05A010-V001T05A010). American Society of Mechanical Engineers.
- Atlason, R. S., & Unnthorsson, R. (2014, July). [Wellhead Scaling Problems in Geothermal Power Plants Addressed Using a Needle Valve Derivative](#). In *ASME 2014 Power Conference* (pp. V001T05A009-V001T05A009). American Society of Mechanical Engineers.
- Atlason, R. S., Geirsson, O. P., Elisson, A., & Unnthorsson, R. (2014, July). [Go With the Flow: The Evolvement of Geothermal Wellhead Maintenance at the Hellisheidi Power Plant](#). In *ASME 2014 Power Conference* (pp. V001T05A011-V001T05A011). American Society of Mechanical Engineers.

4.5 ISI Journal articles

- Atlason, R. S., & Unnthorsson, R. (2013). [New Design Solves Scaling Problems on Geothermal Control Valves](#). *Power*, 157(11), 18-21.
- Atlason, R. S., Gunnarsson, A., & Unnthorsson, R. (2015). [Turbine repair at Nesjavellir geothermal power plant: An Icelandic case study](#). *Geothermics*, 53, 166-170.
- Atlason, R. S., Unnthorsson, R., & Oddsson, G. V. (2015). [Innovation and development in geothermal turbine maintenance based on Icelandic experience](#). *Geothermics*, 56, 72-78.

- Atlason, R. S., Geirsson, O. P., Elisson, A., & Unnthorsson, R. (2015). [Geothermal wellhead maintenance: A statistical model based on documented Icelandic experience](#). *Geothermics*, 53, 147-153.
- Atlason, R. S., Oddsson, G. V., & Unnthorsson, R. (2014). [Geothermal Power Plant Maintenance: Evaluating Maintenance System Needs Using Quantitative Kano Analysis](#). *Energies*, 7(7), 4169-4184.
- Atlason, R. S., Oddsson, G. V., & Unnthorsson, R. (2015). [Theorizing for improved maintenance management: using case studies from the Icelandic geothermal sector](#). *Energies* 2015, 8, 4943-4962.

5 Cost statement

Rúnar Unnþórsson, the project leader/co-ordinator, has worked on the project since the beginning. The main work during the first 6 months was to recruit a PhD student for the project and plan the work ahead. Runar met regularly with the PhD student to provide him with advice on the project, the PhD thesis work, co-write conference papers, organise face-to-face meetings with partners and also to recruit and meet regularly with MS students.

Magnús Þór Jónsson, worked on the project from august 2012 to early year 2014. Magnús helped with recruiting MS students and has participated in the face-to-face meetings with the partners, attended the weekly meetings with students and he also co-wrote the students conference papers.

Early 2014, Dr. Guðmundur Valur Oddsson, assistant professor joined the project team and took on the role of co-advising Reynir – the PhD student. Dr. Guðmundur also co-authored two ISI papers with Runar and Reynir.

Selected persons at the power companies helped the students with gathering data and explaining the power plants to the students. This was done in the form of on-site tours around the power plants and answering and explaining all questions that rose during the course of the project.

Table 2 summarizes the project funding for the three years. The co-funding consists of own contributions (time contributed by participants), facilities (the office room of the students, printers etc.), contracted services (one student was reimbursed as a contractor), travel expenses and conference fees for the Power2013 and Power2014 conferences.

Table 2. Three year summary of Georg funding and co-funding for the project

	Georg Funding	Co- funding
<i>Year 1</i>	3.225	3.650
<i>Year 2</i>	5.125	6.256
<i>Year 3</i>	9.025	9.105
Total	17.375	19.011

Table three includes the final payment from Georg which was yet to be made at the time of writing.