GEOTHERMAL DEVELOPMENT: A GAME OF CHANCE AND WIT

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ABSTRACT

In order to inspire diverse young people into STEM careers, colleagues from Mercury NZ Ltd partnered with The University of Auckland (UoA) Women in Engineering Network (WEN) and presented an introduction to geothermal development to high school aged youth during Enginuity Day 2019. Beyond typical methods of industry presentation to students, the Mercury team decided to create an interactive game to foster engagement and learning.

The sequence of the game leads players through the entire process from exploration to commercial development of an unexplored geothermal resource. In the first stage, participants are provided maps and geoscience data, which they analyse to select well locations. In the second stage, they discover the productivity and enthalpy of their new wells. Penultimately, using well data and information about the efficiency of various power plant types, they place a fictional power plant and design pipelines to connect their wells. Finally, the game is scored by translating the production of their powerplant and wells drilled into an economic output.

To simulate the unpredictable reality of geothermal development, chance cards are allocated at multiple stages with varying degrees of financial setback.

The reception to the game was overwhelmingly positive. While it was designed specifically to introduce high school aged women to the geothermal industry, a similar style of game could be adapted to engage other ages or to focus on other topics.

1. INTRODUCTION

Despite similar levels in educational attainment, women remain underrepresented in STEM disciplines and careers. It was noted during the design phase of the game that presentation of STEM subjects through classroom or lecture environments don't necessarily do justice to the fascinating, dynamic nature of employment in STEM fields.

The objectives of the presentation were to introduce students to the geothermal industry and to give some context to the diversity of STEM careers available in this field. Quite different from the environment of any Science, Technology, Engineering or Maths classroom, the game is intended to give some purpose to the pursuit of STEM subjects and build enthusiasm for the outcomes of studying in those areas.

2. GAME SETUP AND PLAY

The aim of the game is to develop the most financially profitable geothermal powerplant among the participants. By managing a combination of known and unforeseen developments, participants are challenged to make optimised decisions even as the inputs are evolving.

Either individually or in teams, the game begins with receiving four maps:

1. Aerial imagery - Figure 2
2. Topographical data - Figure 3
3. Geology & surface features - Figure 4
4. Resistivity (magnetotelluric data) - Figure 5

Each party also receives the worksheet in Figure 9 and Figure 10, which prompts the structure of the game as depicted in Figure 1.

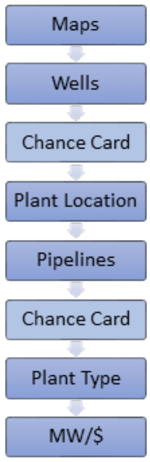

Figure 1: Flow chart of the game. First, participants study the given maps of the game area. Well locations are chosen, and the flowrates, enthalpies and drilling costs of each well are revealed. A chance card is drawn resulting in a financial setback of some amount. A location is chosen for the power plant. Routes are selected for pipelines to connect the wells to the plant. Another chance card is drawn resulting in another financial setback. Finally, a binary or flash plant is chosen. The power generation of the resulting plant is compared to the amount spent, and the player with the highest ratio wins.

2.1 Maps

The maps contain clues for good drilling locations and the management of multiple datasets, which may contradict each other in places to add complexity. This is done deliberately in the game to mimic the uncertainty of explorational drilling. The player or team must piece together data from the maps to select the best drilling locations. There remains an element of luck in selecting where to drill, as it is impossible to predict what the output of each well will be.

The maps were fabricated by adding imaginary data to satellite imagery and topographical information of a fictional geothermal field. A location with high topographical contrast

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was chosen, and satellite and aerial maps extracted using free online mapping tools. Fictionalized geological and resistivity (magnetotelluric) data were created to give useful insight into the potential of each drilling location.

2.2 Well Drilling

Players must rationalise information about the terrain, topology and whatever else they can glean from the provided maps. They would also be wise to consider the proximity of their wells to each other and to the prospective location of their station.

One grid block is selected for each well. In selecting the well, pipeline, and plant locations, players learn about the effects of topography, land use, faults, and surface features.

Once the player has selected locations to drill three wells by marking the grid location on the topographical map, the enthalpy, flow rate and cost of drilling is revealed by the presenter using the Answer Key in Figure 6. These are recorded on the answer sheet. There are several locations in which drilling rights may be denied, due to significant thermal features (geyser), town centres or national parks (volcanoes). In this case, the player will have to select another drilling location.

There is no penalty for having selected a prohibited drilling location. The inconvenience of selecting a new location to drill is intended to mimic the time but not actual cost of researching non-viable options.

The data returned by the answer key in Figure 6 are representative of the myriad factors that affect well productivity, including but not limited to geological structures, permeability, porosity and fluid properties.

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Figure 2: Aerial Imagery

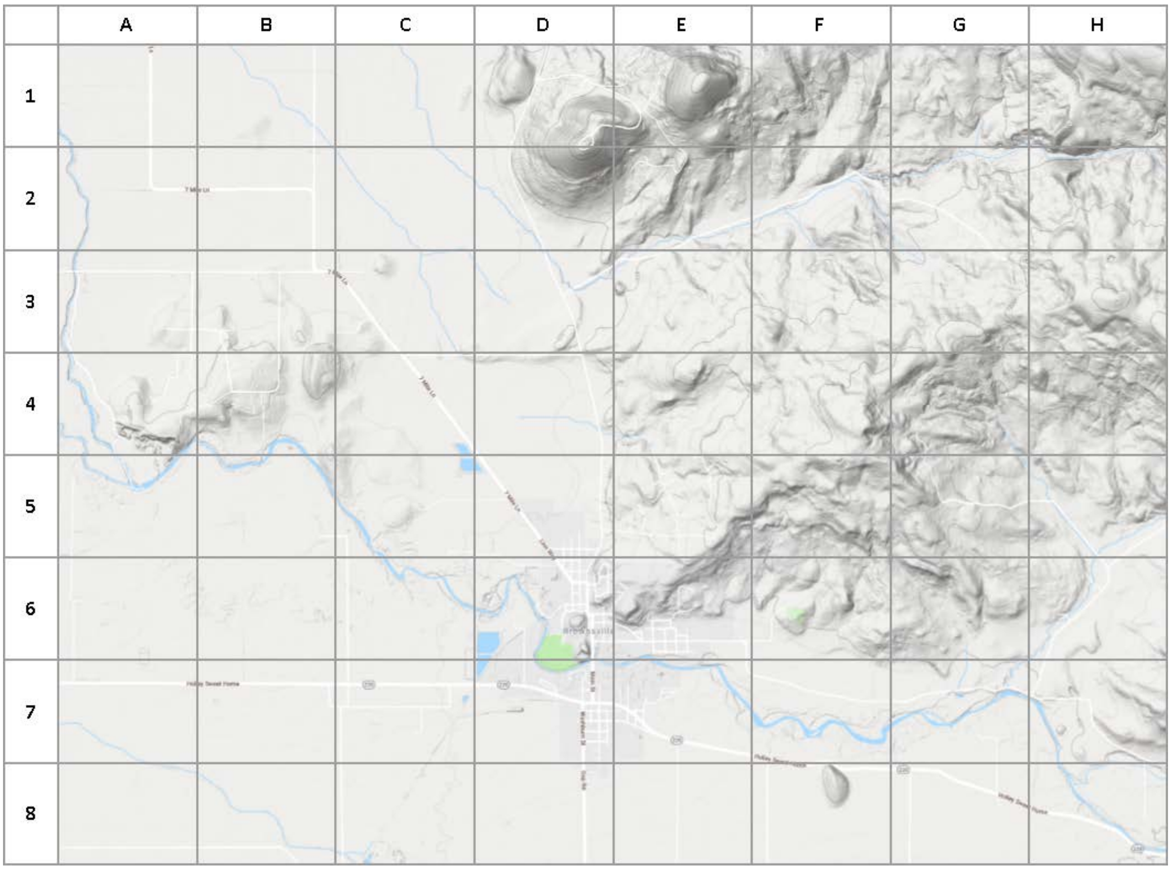

Figure 3: Topographic/Terrain Map

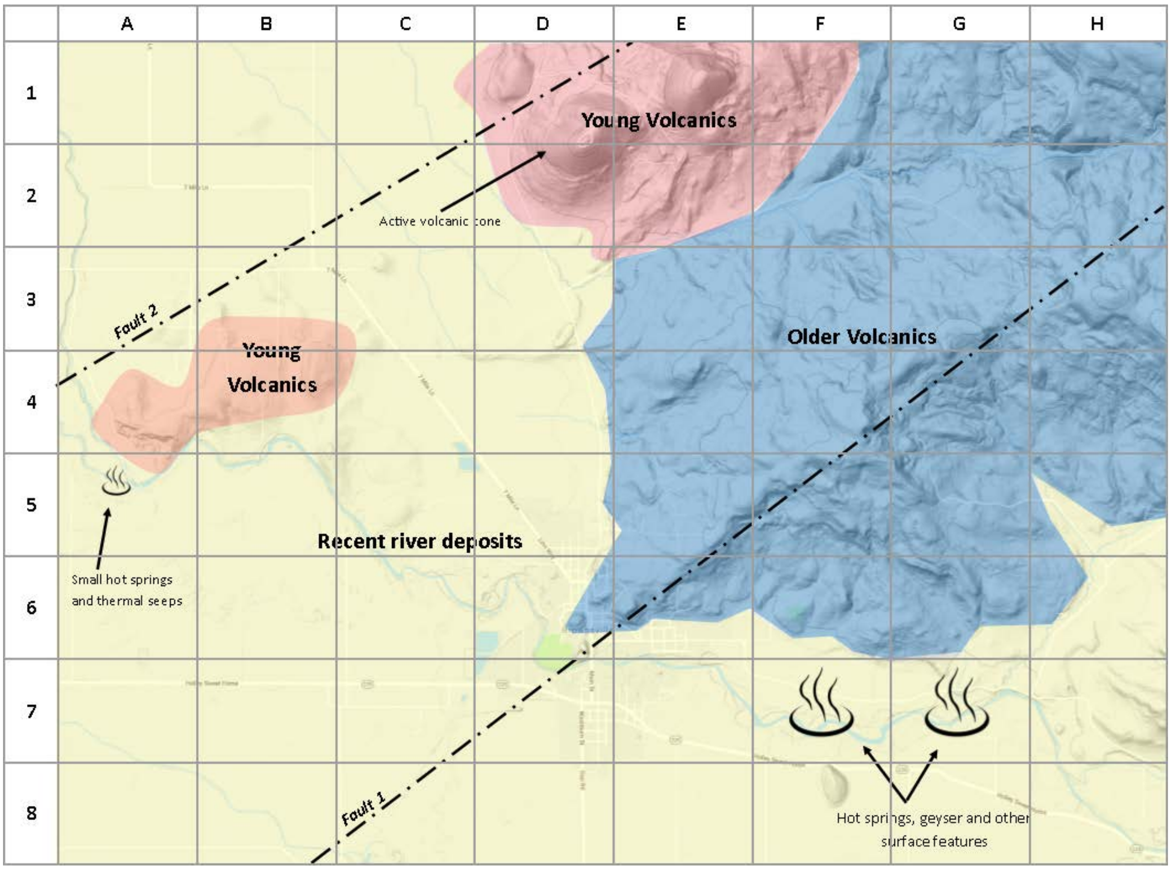

Figure 4: Geology and Surface Features

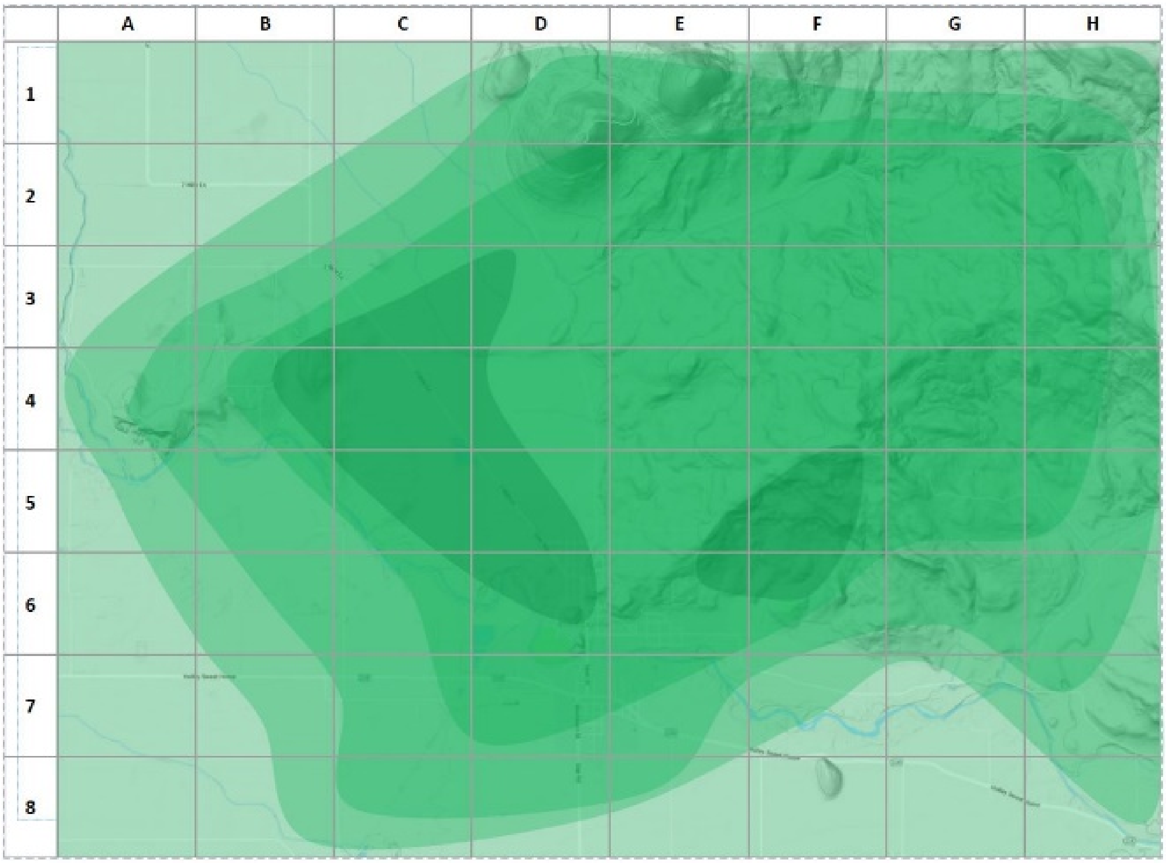

Figure 5: Resistivity / Magnetotelluric (MT) Data

	A	B	C	D	E	F	G	H
1	h: 1000 kJ/kg Drill: $ 5M F: 200 t/h Pipe: $ 1M	h: 900 kJ/kg Drill: $ 5M F: 200 t/h Pipe: $ 1M	h: 900kJ/kg Drill: $ 10M F: 200 t/h Pipe: $ 1M	X Protected land	X	h: 1100 kJ/kg Drill: $ 15M F: 850 t/h Pipe: $ 2M	h: 1100 kJ/kg Drill: $ 10M F: 550 t/h Pipe: $ 2M	h: 1100 kJ/kg Drill: $ 15M F: 850 t/h Pipe: $ 2M
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4	h: 900 kJ/kg Drill: $ 10M F: 200 t/h Pipe: $ 2M	h: 1200 kJ/kg Drill: $ 10M F: 550 t/h Pipe: $ 2M	h: 1300 kJ/kg Drill: $ 5M F: 1000 t/h Pipe: $ 1M	h: 1400 kJ/kg Drill: $ 10M F: 700 t/h Pipe: $ 1M	h: 1200 kJ/kg Drill: $ 15M F: 900 t/h Pipe: $ 2M	h: 1400 kJ/kg Drill: $ 10M F: 1000 t/h Pipe: $ 2M	h: 1350 kJ/kg Drill: $ 10M F: 1200 t/h Pipe: $ 2M	h: 1325 kJ/kg Drill: $ 10M F: 900 t/h Pipe: $ 2M
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Figure 6: Answer key of enthalpy, drilling cost and flowrate for a well drilled at each grid reference. Also included is the cost to run a pipeline through that grid square.

2.3 Chance Cards

In the real world, even the most well-planned and thought out projects can have surprise setbacks that bring everyone back to the drawing board. The addition of chance cards into the game added this aspect of uncertainty and luck. The scenarios on the chance cards come from real experiences (with fictional costs), and each is designed to prompt players to think critically about the relationship between their efforts and the environment; how their hard work can impact stakeholder or how external factors can impact their timelines or budgets. The chance cards challenge the teams with unforeseen and unavoidable circumstances that throw a spanner in the works and add some drama to an otherwise straightforward game.

Unplanned expenses introduced by the chance cards in Figure 7 require participants to be more cautious of how much they spend on the powerplant and pipelines, as expenditure without production return will hurt their final game score.

The rain has turned your well pad into a muddy mess resulting in a 5-day weather delay. This has cost you $200,000 per day.

An endangered species of lizard has been found near the drill site. A 2-week delay sets you back $3M while a wildlife study and lizard collection and relocation takes place.

The turbine delivery has been delayed in shipping. This delay will cost you $500,000.

After a geological survey the land you wanted to build your plant on will not be suitable and will have to move slightly. This will result in an additional $2M in piping costs.

The drilling rig has lost its water supply. This shuts down drilling for 2 days while the water line is repaired. This costs you $200,000 per day.

The drill tool breaks off in the well and is unable to be recovered. A side-track well must be drilled for an additional cost of $10M.

On start up the turbine is less efficient than the design indicated. Your expected loss for the year will be $5M.

An earthquake during construction causes the site to be safely locked down until a survey of structures and piping can be completed. Construction is delayed by 1 month. The delays, surveys and damage recovery cost you $5M.

Figure 7: Chance cards provide uncertainty, which is characteristic of geothermal development

2.4 Location of Power Plant

Players must select a location for their geothermal power plant in a separate grid position from any of their existing wells. The players are prompted by the game presenter to consider proximity of their plant to their wells, the town and notable surface features and how the topography may affect their plant in terms of vehicle access and pipeline design. Some of these discussion prompts are included, however the presenters discovered that it was most effective to tailor the information based on the interest the players were showing at this stage of the game.

Wells far away from the power plant would require lengthy pipelines and would increase capital cost of the development. In reality, long pipelines would also introduce technical complexities (e.g.: significant hydraulic losses), although the game doesn't consider this in the scoring.

Local regulations may prevent industrial installations nearby residential areas, sparing residents the dust, debris and emissions which frequently accompany the noise of industry. Location of the plant would also normally consider access for workers and emergency services. Having an existing electricity grid connection point and cooling water supply near the vicinity of the plant would also normally prove a technical (and commercial) advantage.

Towns and surface features such as geysers, crater lakes, etc. may have commercial, aesthetic and cultural value to the local community. Intrusion of an industrial plant into the enjoyment of these features may draw negative response.

2.5 Pipeline Connection of Wells to Power Plant

Once the location of their plant has been specified, participants then connect their wells to the plant location by installing pipelines.

Again, participants must consider the implications of their choices, as each grid square they traverse will carry a pipeline construction cost. Based on the topography and land use, each grid square will carry a cost to run a pipe across it. Players determine the route their pipe network will take, connecting their wells to their power plant, by marking lines on the topographical map. The pipelines must follow straight lines (no diagonals) and can be joined to form branch lines. Each square which contains a line, well or power plant is counted in the overall cost based on the pipe cost values in the Answer Key (Figure 6).

2.6 Power Plant Type

In selecting the type of power plant to build, participants must understand how the output of their wells will translate to production at the power station. Players are coached through the trade-off of plant type in Figure 8 to learn which plant type is best suited given the enthalpy available from their wells. With the information from Table 1, they complete a calculation on the worksheet to determine the generation capacity and construction cost of their chosen plant.

Table 1: Approximate flowrate and cost for flash and binary plant options.

Plant Type	Generation (MW/flow)	Capital Cost (x$1000/MW)
Flash	0.042	2700
Binary	0.039	4800

Depending on the level of the players, the game presenter may choose to explain the true relationship between the well output variables and power plant production. In reality, the decisions around power plant type and design are numerous and complex, based on flow rate and enthalpy into the station, pressure at the separators, liquid and vapour ratios and temperature available for heat exchange. The game does not consider all these factors; instead, it condenses the decision about plant type to the enthalpy of the fluid and the production calculation to the total flowrate.

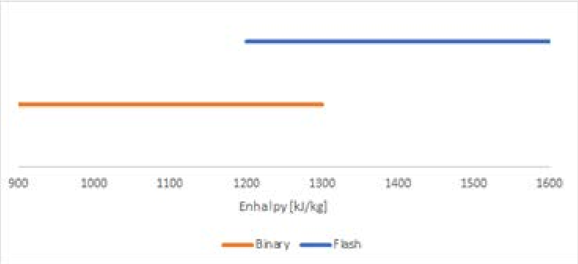

Figure 8: Plant type vs. available enthalpy

2.7 Scoring and Discussion

The final step of the game is scoring, which decides which participant or team has weathered the challenges and optimised the reservoir to make the most profit. Scoring is completed using a calculation prompted by the worksheet.

As a thought exercise, participants were also invited to discuss some of the real factors which affect well drilling and plant design, which were not included in the game design:

- How would throttling production from wells affect the life of the plant and/or reservoir?
- What will happen to production fluid on the other side of the power plant? Does it need to be injected?
- What is subsidence? What would we do if subsidence is observed?
- Will we require additional wells in the future? How will we plan for this?
- What knowledge and information about the resource would be useful? How do we obtain it?
- How does knowledge about resource depth, rock permeability, etc. affect the project?
- How would geothermal fluid chemistry affect the plant?
- What environmental policies and tax incentives are relevant?
- How might the electricity market influence design of a geothermal power plant?

3. PRESENTATION AND RECEPTION

The presentation was given to groups of female high school students at Enginuity Day 2019, an event run by the Women in Engineering Network at the University of Auckland. The reception of the presentation was positive, as the students were enthusiastic to learn about the different technologies. They frequently asked to learn more about the factors contributing to decision making around the process of developing new wells, pipelines and power stations and how length and topography will affect pressure drop in the pipelines.

Overall, it was a successful presentation. The groups were interested in delving deeper than the basic parameters of the game, which gave them the context and vocabulary to question and discuss the different factors influencing geothermal development. Moving around the room, it was satisfying to hear the students debating the pros and cons of each decision, challenging each other and working through the process.

4. CONCLUSION

Presentation of the geothermal industry through a game was an immense success. Beyond simple lecturing, the game encouraged participation and discussion from the students. They were challenged to actively engage with each other and the presenters through each stage of the game, which maintained their focus and rewarded creative problem solving.

Prior to Enginuity Day 2019, the game was trialled with internal staff at Mercury Ltd; employees included those without technical backgrounds. The response was positive, which generally demonstrated that the game design and presentation can be customized for the audience. For example, it can be tailored to include deeper technical consideration for more advanced groups or simplified for a younger audience. As well as modulating the technical level of the game, the process could feasibly be applied to any development which follows a multiple step process, with specific benefits to STEM subjects.

The early years of STEM education are generally used to form foundational understanding of underlying concepts. It is often not for several years that students begin to experience the excitement and wonder which underpin a STEM career. Great effort has been made in recent years to bring that wonder into the classroom using experiments, projects and field trips. Interactive education, such as the Geothermal Development Game, offers an opportunity to close the gap further by applying STEM fundamentals to the actual employment that can result from study. In this case, female students were the audience, but the ultimate goal is to extend awareness of the inventive, dynamic and exciting nature of STEM to more young people, in the hope that they will not dismiss STEM subjects during high school.

The goal of Enginuity Day is to introduce female students to potential role models that have developed careers in STEM fields. The Geothermal Development game takes this a step further by empowering students to become their own role models as they see themselves acting as reservoir engineers, geoscientists, project managers and executives in their own fledgling geothermal development. By making visible and accessible the opportunities for careers and higher education in STEM, we aim to prevent internal bias away from science, to reduce imposter syndrome and self-doubt, and to develop the untapped potential lying dormant in the minds of students.

We aim to foster and welcome the next generation of Women in Geothermal.

Mercury

Enginuity Day – Let's Build a Geothermal Power Station with our Geothermal Engineers!

Step 1. Use the resources to select locations to drill 3 wells. Record these locations in the first column. Once you have selected your locations, ask one of the Mercury Engineers to fill in your flow, enthalpy and cost data.

	Location	Flow Rate	Enthalpy	Cost to Drill
Well 1				
Well 2				
Well 3				

Step 2. Grab a chance card from the Mercury Engineers. Record the financial impact here:

Financial Impact

Step 3. Select the location of your plant, and record the location here:

Plant Location

Step 4. Route your pipelines to carry fluid from your wells to your plant and ask the Mercury Engineers to show you the cost of the pipe. Record the cost in the table below:

	Well 1 to Plant	Well 2 to Plant	Well 3 to Plant
Pipe Cost			

Step 5. Grab a chance card from the Mercury Engineers. Record the financial impact here:

Financial Impact

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Figure 9: Worksheet of the Geothermal Development Game, page 1 of 2.

Step 6. Use the equations for binary and flash plant types, to see which will be the best decision. For this you will need to look back at the production data from your wells. Record the plant generation and cost based for the plant type you have selected:

$Generation_{Flash}$	= 0.042 x	______ (Total Flow Rate)	=	______ MW
$Generation_{Binary}$	= 0.039 x	______ (Total Flow Rate)	=	______ MW
$Cost_{Flash}$	= \$2.7m x	______ ($Generation_{Flash}$)	=	\$ ______
$Cost_{Binary}$	= \$4.8m x	______ ($Generation_{Binary}$)	=	\$ ______

Plant Type Binary / Flash *(circle one)*

Generation ______ MW

Plant Cost \$ ______

Step 7. Calculate the total capital cost of the work you have completed and use the equation to find your score:

Total Capital Cost \$ ______

Score = ______ **MW** (Total Generation) / **\$** ______ (Total Cost) = ______

The winner will have the highest generation/cost ratio!

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Figure 10: Worksheet of the Geothermal Development Game, page 2 of 2