Geothermal Energy (Week 14, 2 Dec)
- Economic Analysis & Summary of the course

민기복

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Monday

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- Term project instruction
  - Updated instruction
  - Assessment criteria
- Report Writing Guide
  - Report Writing Guide by Hagan and Mort (2009)
  - Process, structure, format, style, referencing
- Presentation Guide
  - Strategy
  - Useful English Expressions

Term Project
Instruction

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- Both report and presentation should be in English
- Timeline
  - 4 Dec — Submission of final report (~20 pages)
  - 7 Dec, 9 Dec — Presentation of term project
  - 14 Dec — Upload of revised final report
- English will NOT be assessed but your English needs to be good to deliver your message.
  - Your reports will be checked by an editor whose first language is English – will be returned within a week.

Term Project
Final Report

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- Your final reports will be compiled and published as a conference proceedings.
- ~25 copies distributed to the students, and interested people (including KIGAM).
- This proceedings will be also available in the SNU OpenCourseWare website (http://ocw.snu.ac.kr/).
- Be punctual on 7 Dec & 9 Dec, by 09:00, -5 on late participation
- Be sure to include disclaimer about the originality of the report.

Final Report
Statement of originality

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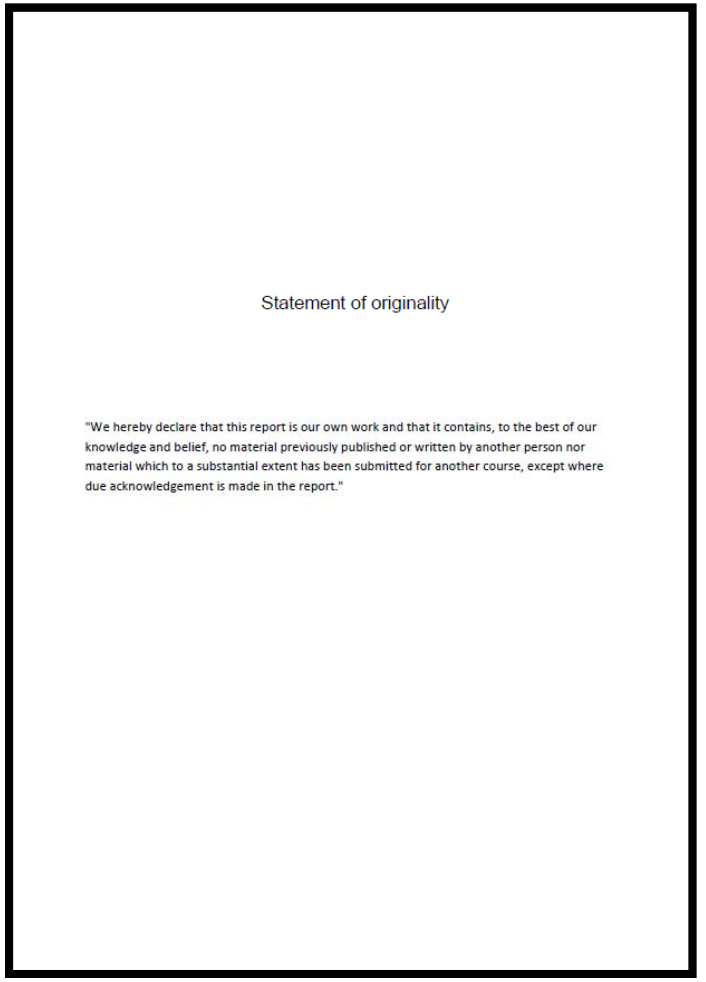
- Statement of originality (right after the cover)
  - "We hereby declare that this report is our own work and that it contains, to the best of our knowledge and belief, no material previously published or written by another person nor material which to a substantial extent has been submitted for another course, except where due acknowledgement is made in the report."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Final Report
Assessment Criteria

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- Six categories for assessment
  - Summary (10%)
  - Introduction (10%)
  - Interpretation/synthesis of information (20%)
  - Methodology/Analysis (30%)
  - Conclusion (10%)
  - Layout and standard of report (20%)
- Excellent – Good – Satisfactory – Unsatisfactory – Poor
- Bonus points considering other factors.

Presentation
Instruction

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- Presentation
  - **Presentation is an extremely important part of your professional life.** Therefore, you have a good reason to be serious about this.
  - 20 minutes + 5 min (questions)
  - Be dressed professionally (e.g., tie/suit)
  - Split the time of presentation between your members
  - Presentation files should be uploaded via eTL (before or after the presentation).
  - As usual, one question will get 2 points as a participation activity.
  - Be present when others are presenting. (late or absent -5)

Presentation order

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- Mon 7 Dec
  - Group 1 (김한나, 이헌주, 조훈회)
  - Group 3 (김민수, 김성민, 손진, 오승찬)
  - Group 8 (신지연, 이동근)
- Wed 9 Dec
  - Group 2 (오은지, 주종웅, 최창조)
  - Group 6 (김태현, 이재원, 박영숙)
  - Group 7 (류성훈, 최승범)
- 발표날 09:00 이후에 오는 사람은 무조건 -5점.

Presentation
Assessment Criteria

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- Five Categories
  - Introduction (15 %)
  - Content Quality (20 %)
  - Conclusion (15 %)
  - Visual Aids quality (20%)
  - Verbal Presentation (30%)
- Excellent – Good – Satisfactory – Unsatisfactory – Poor
- Bonus points considering other factors.

Report Writing Guide
Report Writing Process

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- Drafting and Editing
  - Be selective
    - Critically comment on the veracity and usefulness of your work and collected information.
    - Decide what is essential and discard non-essential work/information
  - Create a structure: sections, paragraphs and sentences
  - Edit then edit again
    - Put aside the draft for at least 24 hours → read with a fresh pair of eyes → more likely to spot errors
    - Ask someone else for their comment on the report, preferably who is familiar with your field
    - Use checklist

Report Writing Guide
Structure

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- Summary (synopsis, executive summary or abstract)
  - Contains an overview of the most important aspects of a report
  - Succinctly state the objective, the process/method involved in the investigation, major findings, and finally major conclusions (and recommendations)
- Introduction
  - Should clearly define the objectives of the study as well as any constraints or boundaries related to the study

Report Writing Guide
Structure

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- Conclusions
  - Concluding statement linking the original objective with the outcomes of the study
  - Comment on the impact of the study and how knowledge has been furthered as a result
  - Demonstrate your insight on the topic and an ability to synthesize new information
- References
  - Any information extracted from a textbook, conference paper or other report must acknowledge the original source.

Presentation
Strategy

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- Enunciate
- Be honest
- Be confident
- Be enthusiastic
- Keep the time
- Good engagement with audiences (eye contact)
- Practice, practice and practice

Today

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- Economic Analysis of Geothermal Energy

- Summary of the course

Economic Analysis
Importance

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- In general, direct use compete on the market.
- Geothermal electricity generation faces financial challenges.
- Economic analysis necessary to identify the crucial cost drivers

Economic Analysis
Cost categories

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- Resource definition and confirmation
  - Cost of determining temperature, depth, well productivity, size of reservoir and drilling/testing of the wells
- Wellfield construction
  - Preparing the sites, drilling the wells and connecting them to the power plant
- Reservoir management
  - Well field operation and maintenance including any replacement of well
- Conversion system
  - Performance and cost of power plants
- Economics
  - Cash flow analysis

Economic Analysis
composition of investment

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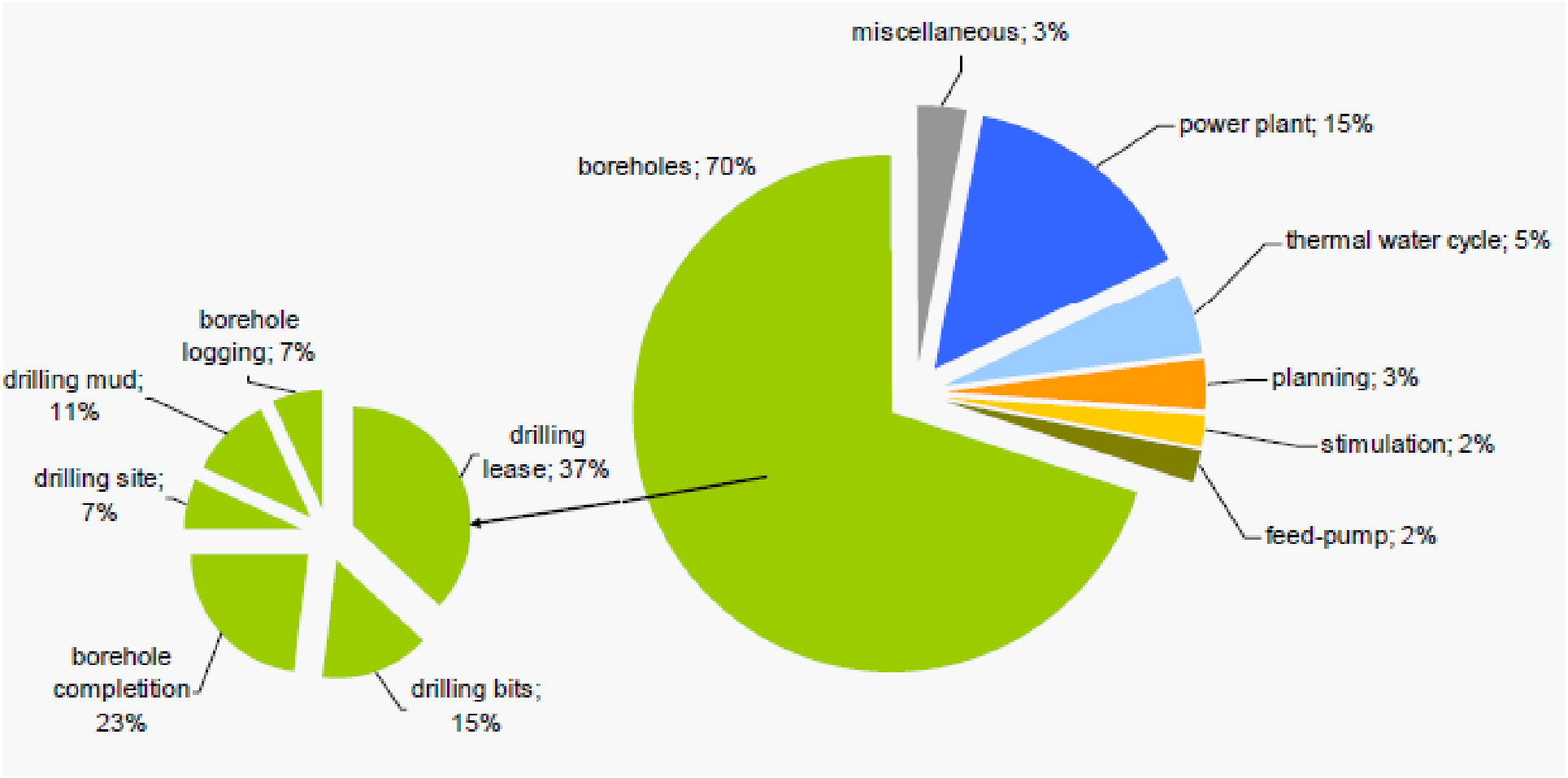

Enhanced Geothermal Network of Europe, WP5 Deliverable D35

Economic Analysis
composition of investment

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Table 5: Investment and operation costs for the reference plants

	Upper Rhine Graben (URG)		South-German Molasse Basin (SGMB)		North-German Basin (NGB)	
	Power	Power &Heat	Power	Power &Heat	Power	Power &Heat
Investment costs in Mio. €						
Boreholes [a]	9,5	9,5	16,1	16,1	19,9	19,9
Stimulation	-	-	0,1	0,1	1,0	1,0
Thermal water pumps	0,25	0,25	0,48	0,48	0,2	0,2
Thermal water cycle [b]	0,32	0,32	0,45	0,45	0,25	0,25
Power plant [c]	2,4	2,5	3,3	3,3	1,9	1,9
Heat extraction	-	0,11	-	0,14	-	0,08
Planning and miscellaneous	0,44	0,45	0,73	0,73	0,80	0,81
Additional charge for unforeseen [e]	1,6	1,6	2,6	2,6	3,2	3,2
Insurance	0,78	0,78	1,2	1,2	1,4	1,4
Total	15,2	15,5	25,0	25,1	28,6	28,7
Operation costs [d] in Mio. €/a						
Overhaul and maintenance	0,09	0,09	0,14	0,14	0,14	0,14
Management and personnel	0,25	0,25	0,37	0,37	0,41	0,41
Auxiliary power	0,23	0,23	0,40	0,40	0,23	0,23
Total	0,57	0,57	0,92	0,92	0,77	0,77

[a] incl. drilling site, borehole logging and production tests; [b] incl. filter and slop-systems, [c] incl. power connection and building; [d] basic year 2006; [e] referring to borehole construction

Enhanced Geothermal Network of Europe, WP5 Deliverable D35

Economic Analysis
production cost / kWh

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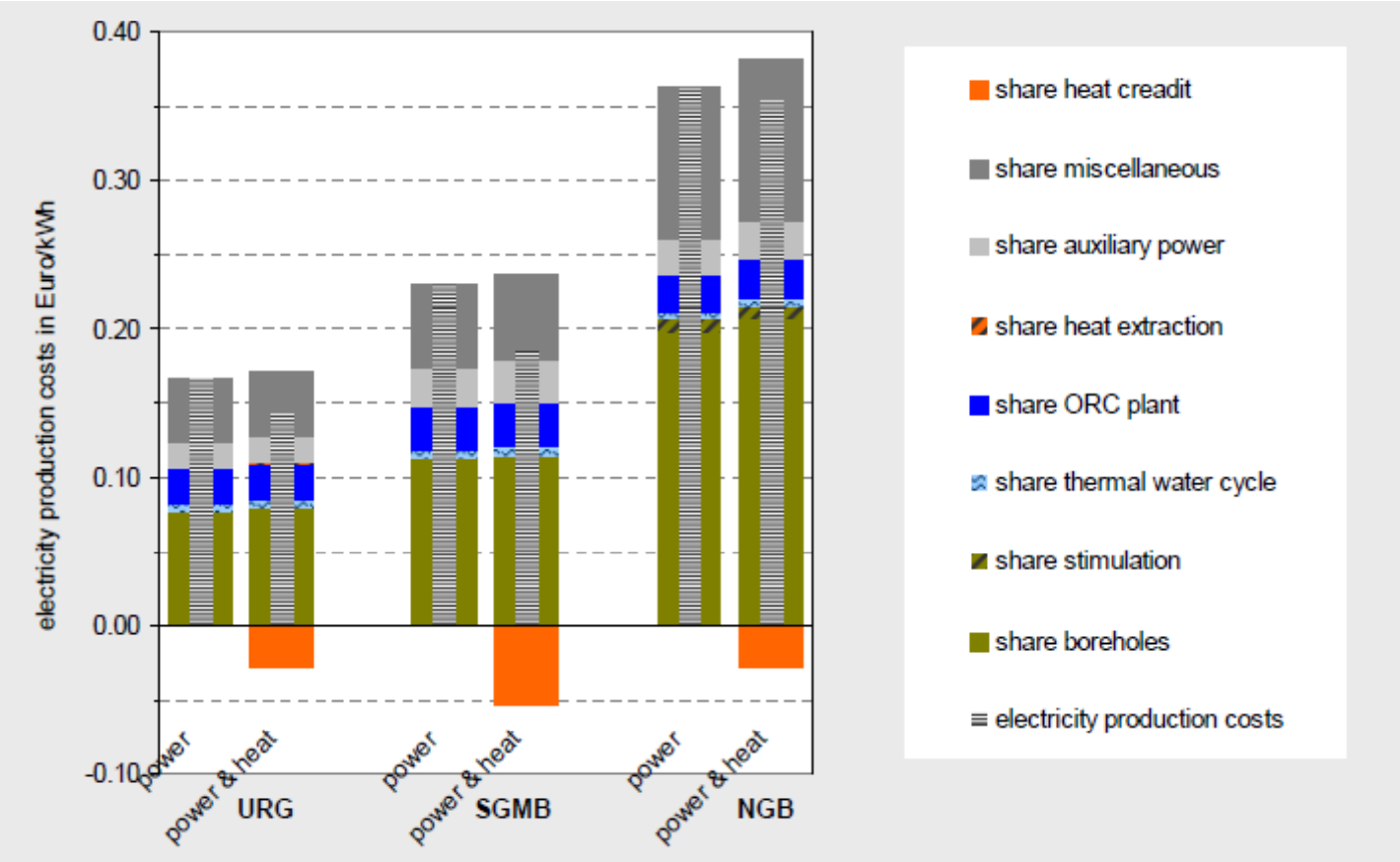

Average electricity production costs for the reference plants

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Economic Analysis
production cost / kWh

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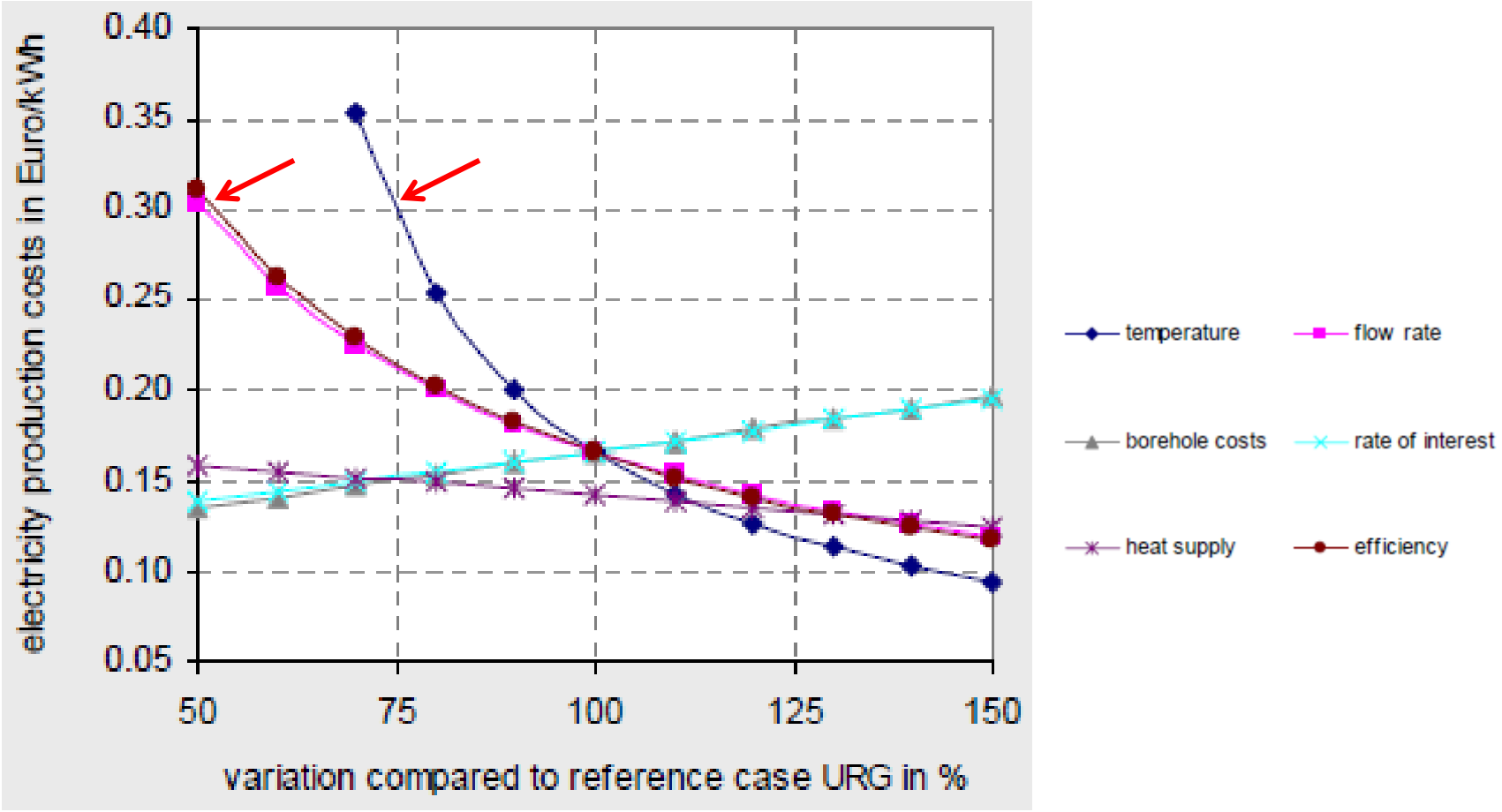

Economic analysis
Determining factor in cost/kWh

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- Thermal water temperature
- Plant efficiency
- Flow rate
- Drilling cost (borehole cost)

Economic analysis
Thermal efficiency

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- Thermal efficiency: the ratio of the net power output to the rate of heat input
- Scattering is due to the variety of plant configurations

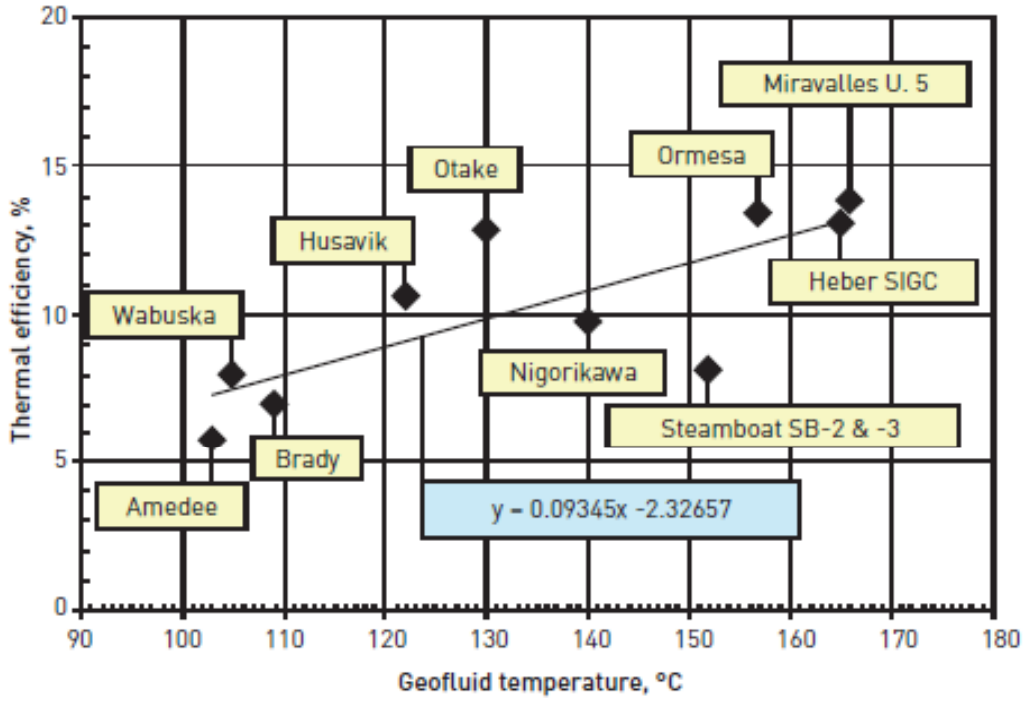

Figure 7.2 Correlation of binary plant cycle thermal efficiency with geofluid temperature in degrees Celsius (°C)

$$\eta_{th} = 0.0935T - 2.3266$$

Tester et al., 2006

Economic analysis
geo-fluid temperature & flow rates

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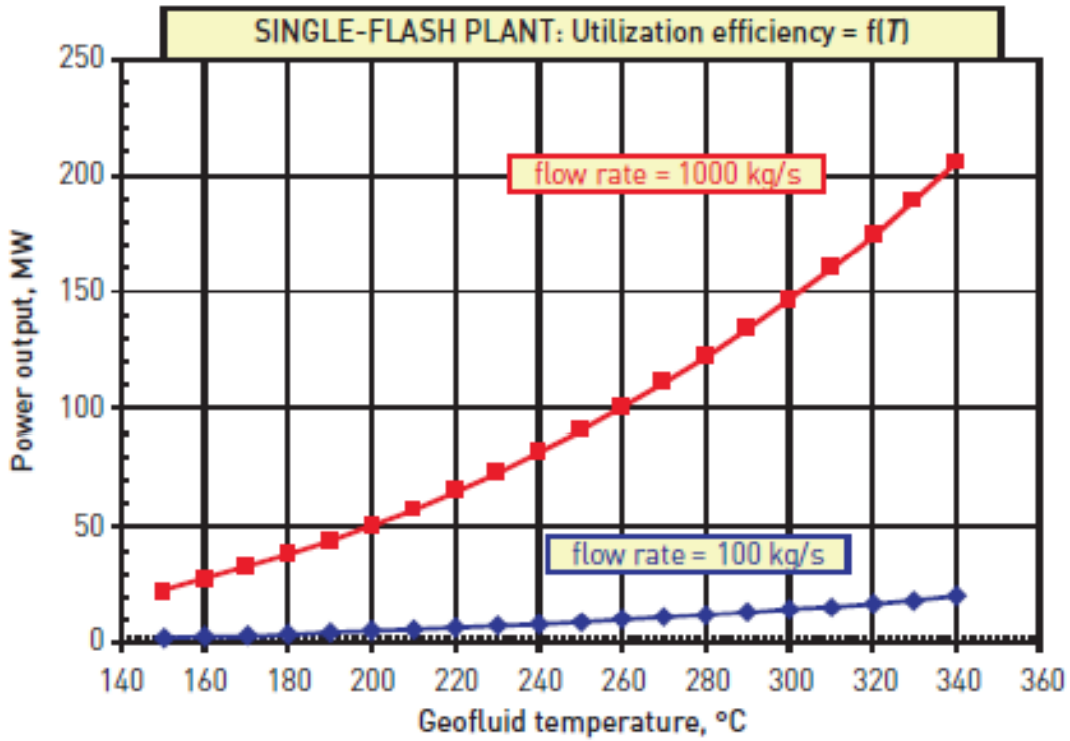

Figure 7.7 Optimized power output for a 1-flash plant as a function of geofluid temperature in degrees Celsius (°C) for geofluid flow rates of 100 and 1,000 kg/s.

Tester et al., 2006

Table 9.4 Parameter values for the base case EGS economic models.

Parameter description	Initial Values (today's technology, years 1-5)	Midterm Values (years 5-11)	Commercially Mature Values (years 20+)
Geofluid flow rate per producer	20 kg/s	40 kg/s	80 kg/s
Thermal drawdown rate	3 %/yr	3 %/yr	3 %/yr
Number of production wells per injection well	2	2-3	3
Maximum allowable bottom hole temperature	350°C	350°C	400°C
Average surface temperature	15°C	15°C	15°C
Impedance per well	0.15 MPa s/L	0.15 MPa s/L	<0.15 MPa s/L
Temperature loss in production well	15°C	15°C	15°C
Water loss/total injected	2 %	2 %	1 %
Drawdown parameter (Armstead and Tester, 1987)	0.000119 kg/s·m^2	0.000119 kg/s·m^2	0.000119 kg/s·m^2
Well deviation from vertical	0°	0°	0°
Well separation	500 m	500 m	500 m
Geofluid pump efficiency	80 %	80 %	80 %
Capacity factor	95 %	95 %	95 %
Fluid thermal availability drawdown threshold before rework	20 %	20 %	20 %
Injection temperature	40°C	40°C	40°C
Well casing inner diameter	7"	7"	7"
Inflation rate	3 %	3 %	3 %
Debt rate of return	5.5 %	6.4 %	8.0 %
Equity rate of return	N/A	17 %	17 %
Fraction of debt/equity	100/0	80/20	60/40
Plant lifetime	30 years	30 years	30 years
Property tax rate	2 %	2 %	2 %
Sales tax	6.5 %	6.5 %	6.5 %
Drilling contingency factor	20 %	20 %	20 %

Tester et al., 2006

Economic Analysis
production cost / kWh – determining factor

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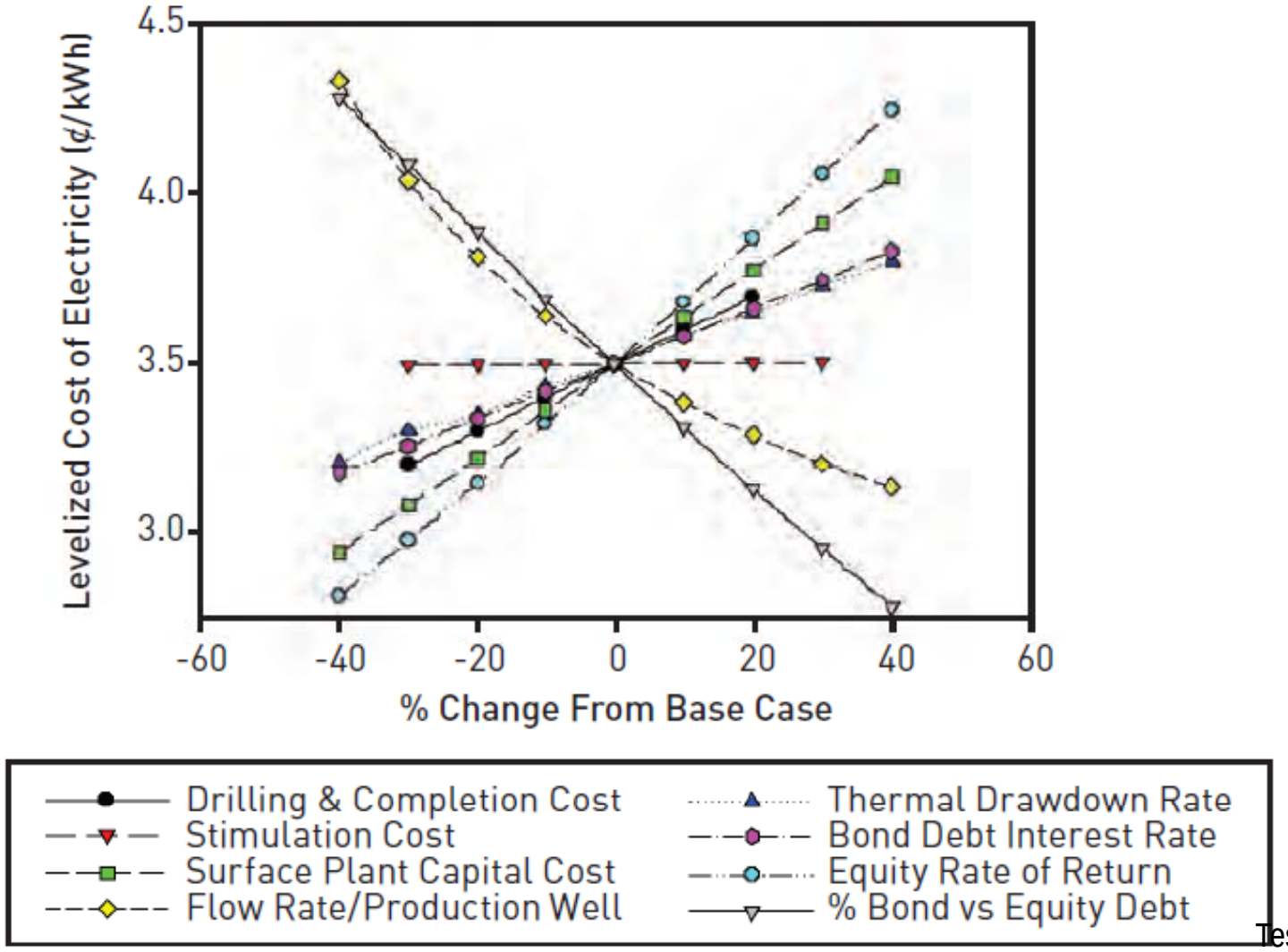

Tester et al., 2006

Economic Analysis
Levelized electricity cost

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- Levelized electricity cost (LEC):
  - The most common basis used for comparing the cost of power from competing technologies.
  - Present value of the total cost of building and operating a generating plant over its expected economic life. Costs are levelized in real dollars, i.e., adjusted to remove the impact of inflation.

Economic models
US DOE model

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- Geothermal Electricity Technology Evaluation Model (GETEM)
- Estimate and summarize the performance and cost of various geothermal electric power systems at geothermal reservoirs
- http://www1.eere.energy.gov/geothermal/getem.html

Summary of the lecture
Objective revisited

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수업목표	This course provides an introduction to geothermal energy, which covers heat pump type application for heating/cooling and power generation including enhanced geothermal system. Students are expected to finish term papers with a topic of their own selection. On completion of this course, students should be able to understand the principles and techniques of geothermal energy utilization and identify the major issues associated with a further development of geothermal energy.

- Emphasis on fundamentals: T, H, M processes
- Open-ended problem: Homework & Term project
- Linkage with Korean Geothermal Community
- Development of thinking/writing/presentation skills

Summary of the lecture
1st half of the course

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- Week 1: Introduction to the course
- Week 2: Overview of Geothermal Energy
- Week 3: Heat Transfer (1) – conduction, convection, radiation
- Week 4: Heat Transfer (2) – Heat diffusion equation
- Week 5: Fluid flow in porous media
- Week 6: Fluid flow in fractured media
  Exploration techniques (invited lecture)
- Week 7: Fluid flow in porous media (conduction-convection problem)
  Mid-term exam

Summary of the lecture
2nd half of the course

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- Week 8: Reservoir Geomechanics
- Week 9: Reservoir Geomechanics
- Week 10: Environmental Impact/Geothermal Power Generation
- Week 11: Video (direct and indirect use of geothermal energy)
- Week 12: Enhanced Geothermal System (EGS)/Field Visit (석모도, 20 Nov)
- Week 13: Geothermal Energy in Korea (invited lecture)
  Heat Pump applications in Korea (invited lecture)
- Week 14: Report writing guide, Final Exam - take-home exam
- Week 15: Student conference (7 & 9 Dec)

Evaluation

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- Take the Course Evaluation seriously.
- Additional Evaluation about English Lecture will be conducted.
- You are completely anonymous – somebody else will compile your comment and return it after typing it.
- I will return to you with my own course evaluation report based on your feedback.

Geothermal Energy

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- Final word

Today

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- (very brief) Economic Analysis
  - ✓ Cost categories
  - ✓ Determining factor in cost/kWh
- Summary of the course
- Take-home exam (2 Dec 2009)
  - ✓ to be submitted within a day via eTL (09:00 Thursday 3 Dec 2009), late submission with 20% penalty (09:00 Saturday 5 Dec 2009)
  - ✓ Will take about 2-3 hours

References

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- Hagan P & Mort P, 2007, Report Writing Guide for Mining Engineers, Mining Education Australia (MEA)
- MIT, 2006, The future of geothermal energy - Impact of Enhanced Geothermal Systems (EGS) on the United States in the 21st century, US Department of Energy, http://www1.eere.energy.gov/geothermal/future_geothermal.html
- Enhanced Geothermal Network of Europe, WP5 Deliverable D35, Economic Analysis of geothermal energy provision in Europe