Direct-Use Profitability: The economics of direct-use geothermal systems - GEOPHIRES

Koenraad F. Beckers*, Maciej Z. Lukawski, Timothy J. Reber, Brian J. Anderson, Michal C. Moore, Jefferson W. Tester

*Email: kb447@cornell.edu

Advances in Direct-Use Workshop
Matching Low-Temperature Geothermal Resources to End-Use Demand
March 18th, 2015

Cornell University
Cornell Energy Institute

Cornell's research on low-temperature geothermal energy characterization and utilization

Thermal energy spectrum in the U.S.

Integrated use of geothermal energy & biomass for the Cornell University campus

Profitability of direct-use: The economics of direct-use geothermal systems - GEOPHIRES

Koenraad F. Beckers
kb447@cornell.edu

Cornell's research on low-temperature geothermal energy characterization and utilization

Thermal energy spectrum in the U.S.

Integrated use of geothermal energy & biomass for the Cornell University campus

Profitability of direct-use: The economics of direct-use geothermal systems - GEOPHIRES

Koenraad F. Beckers
kb447@cornell.edu

Outline

1. GEOPHIRES

- Motivation
- Overview
- History
- Implementation
  - Reservoir Simulation Models
  - Surface Plant Performance Models
  - Economic Cost Correlations and Levelized Cost Calculations

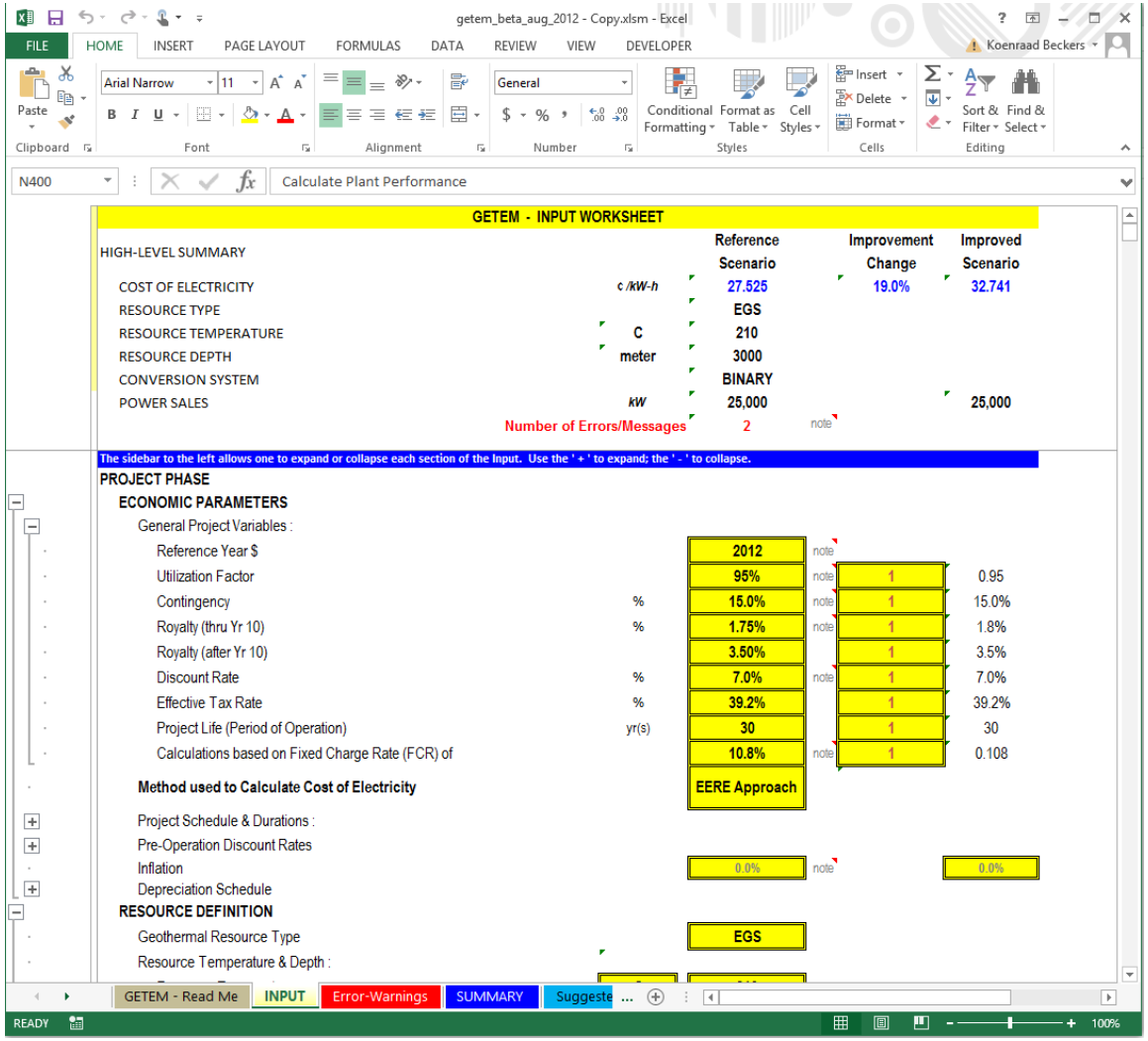
2. The economics of direct-use geothermal systems

- EGS levelized costs for 3 resource-grades and 3 levels of technological maturity
- Geothermal district heating systems in NY and PA
- Cornell geothermal-biomass district heating system

Koenraad F. Beckers
kb447@cornell.edu

1. GEOPHIRES - Motivation

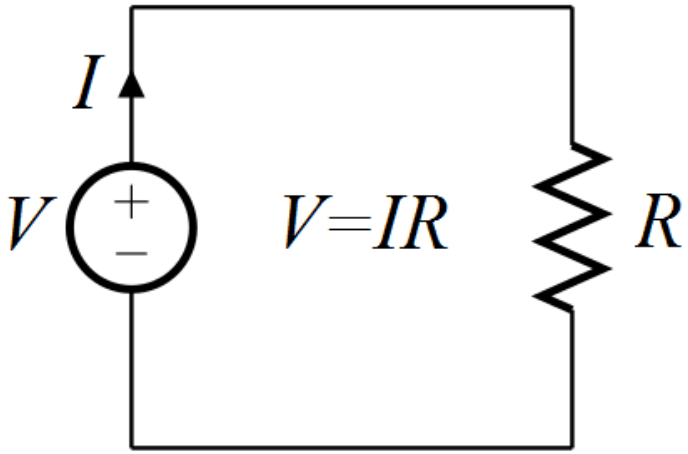
- 2011-2013 DOE study on low-grade geothermal energy between Cornell, WVU, ISU, NREL
- GETEM (Geothermal Energy Technology Evaluation Model) focusses on electricity
- Need for geothermal software to analyze direct-use heat



1. GEOPHIRES - Overview

GEOPHIRES

- "**GEO**thermal energy for the **P**roduction of **H**eat and **E**lectricity **E**conomically **S**imulated"
- Estimate LCOE and/or LCOH of EGS



Koenraad F. Beckers
kb447@cornell.edu

1. GEOPHIRES - Overview

GEOPHIRES

- "**GEO**thermal energy for the **P**roduction of **H**eat and **E**lectricity **E**conomically **S**imulated"
- Estimate LCOE and/or LCOH of EGS
- Upgrades and Expansions
  - End-use options: Electricity, Direct-Use Heat and CHP
  - New capital and O&M costs (2012 U.S. $)
  - New power plant correlations for binary cycle and flash plants
  - Other changes: 3rd economic model, 4th reservoir model, GUI in VB.net & Ramey's wellbore heat transmission model

- *Beckers et al., "Introducing GEOPHIRES v1.0: Software package for estimating levelized cost of electricity and/or heat from Enhanced Geothermal Systems", Proceedings, 38th Workshop on Geothermal Reservoir Engineering, Stanford University (2013).*
- *Beckers et al., "Levelized Costs of Electricity and Direct-Use Heat from Enhanced Geothermal Systems (EGS)", JRSE 6, 013141 (2014)*

Koenraad F. Beckers
kb447@cornell.edu

1. GEOPHIRES - History

LANL (1970's)

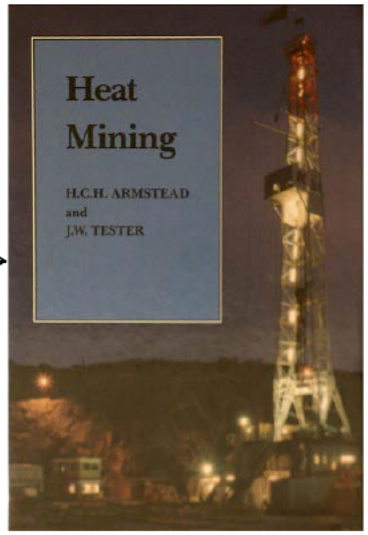
HDR Model (1982)

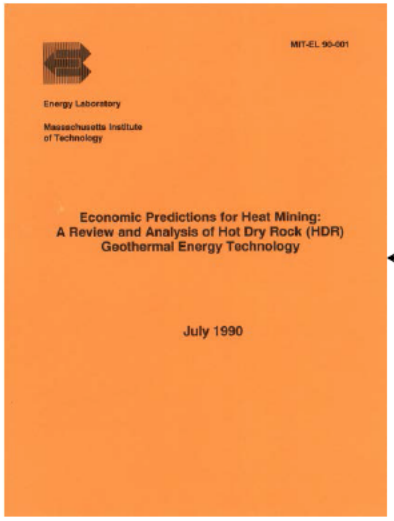
MIT-HDR Model (1990)

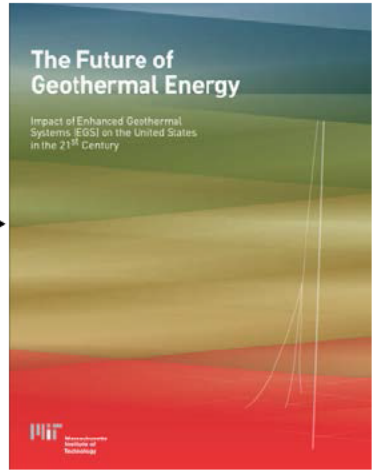
EGS Modeling for Windows (2000)

MIT-EGS Model (2006)

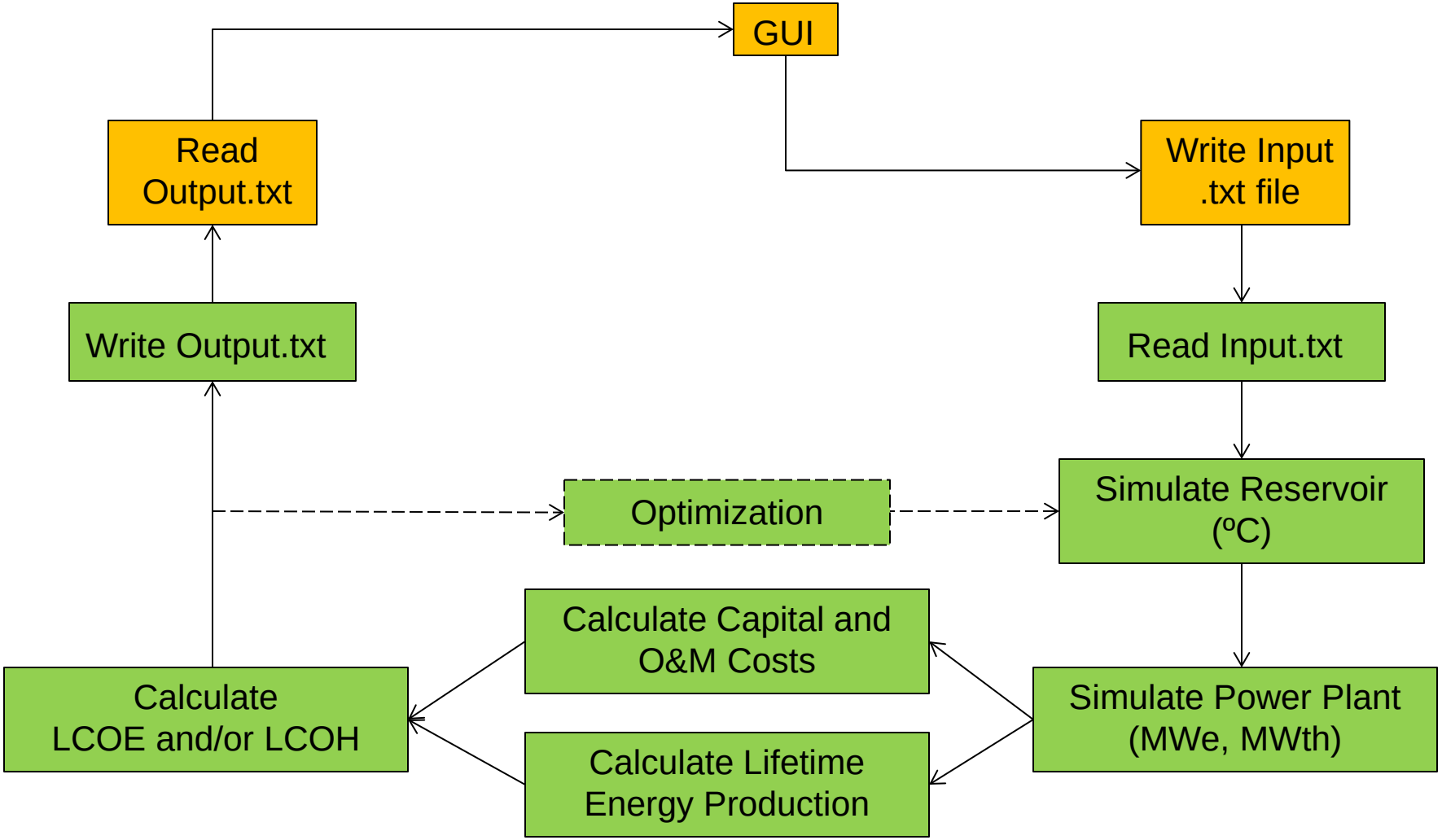
GEOPHIRES (2013-2015)





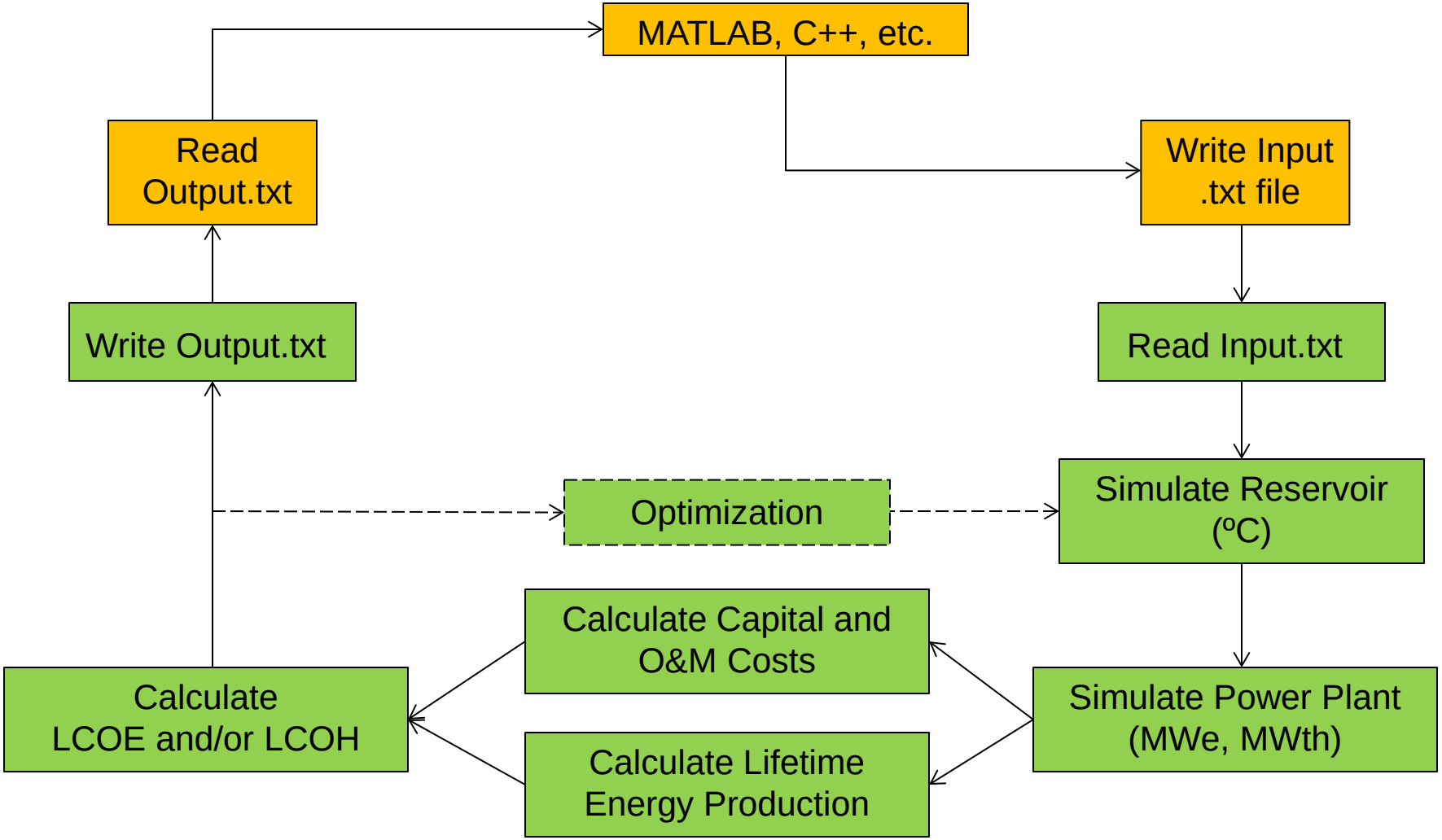


1. GEOPHIRES - Implementation



Koenraad F. Beckers
kb447@cornell.edu

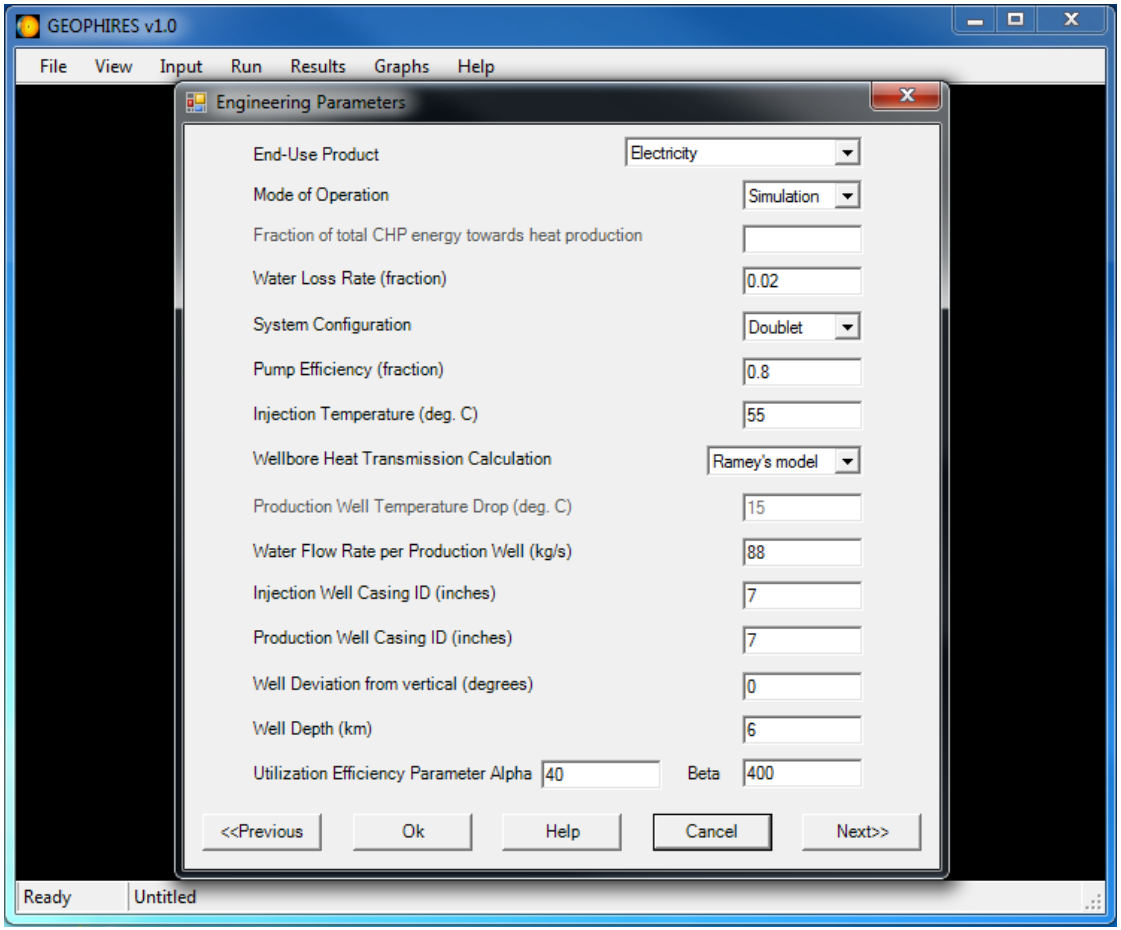
1. GEOPHIRES - Implementation



Koenraad F. Beckers
kb447@cornell.edu

1. GEOPHIRES - Implementation

- GUI in VB.net
- Simulations in Fortran
- 96 input parameters
  - Resource characterization
  - Engineering parameters
  - Reservoir model
  - Economic parameters
  - Capital costs
  - O&M costs
  - Optimization parameters



Koenraad F. Beckers
kb447@cornell.edu

1. GEOPHIRES – End-Use Options and Reservoir Models

End-Use Options

1. Electricity
   (LCOE: cents/kWh)
2. Direct-Use Heat
   (LCOH: $/MMBTU)
3. Cogeneration
   (LCOE, LCOH, LCOE&LCOH)
   - Topping cycle
   - Bottoming cycle
   - Parallel cycle

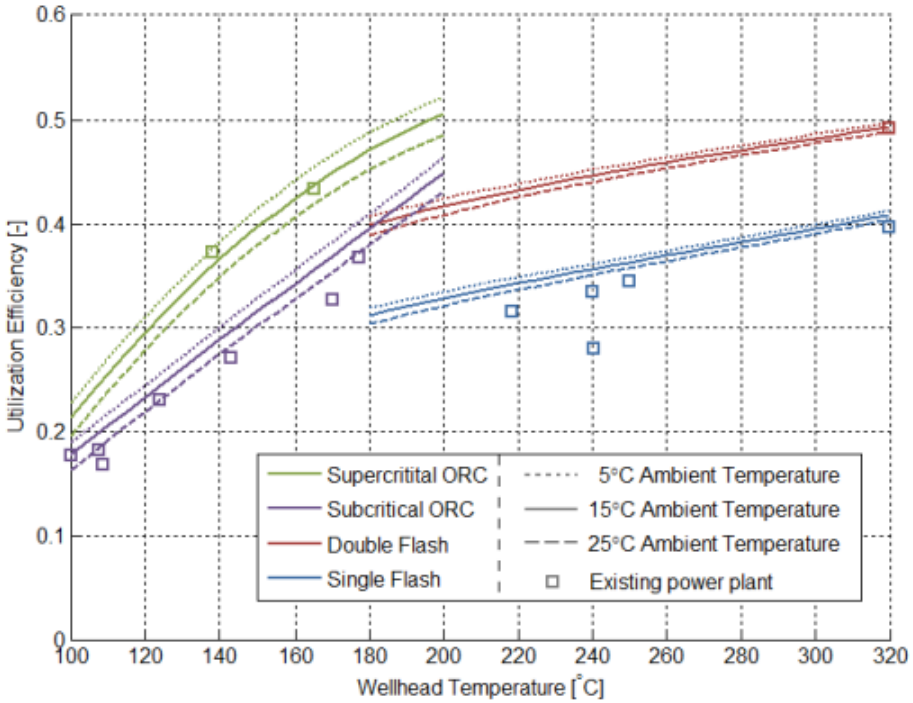
Reservoir Models

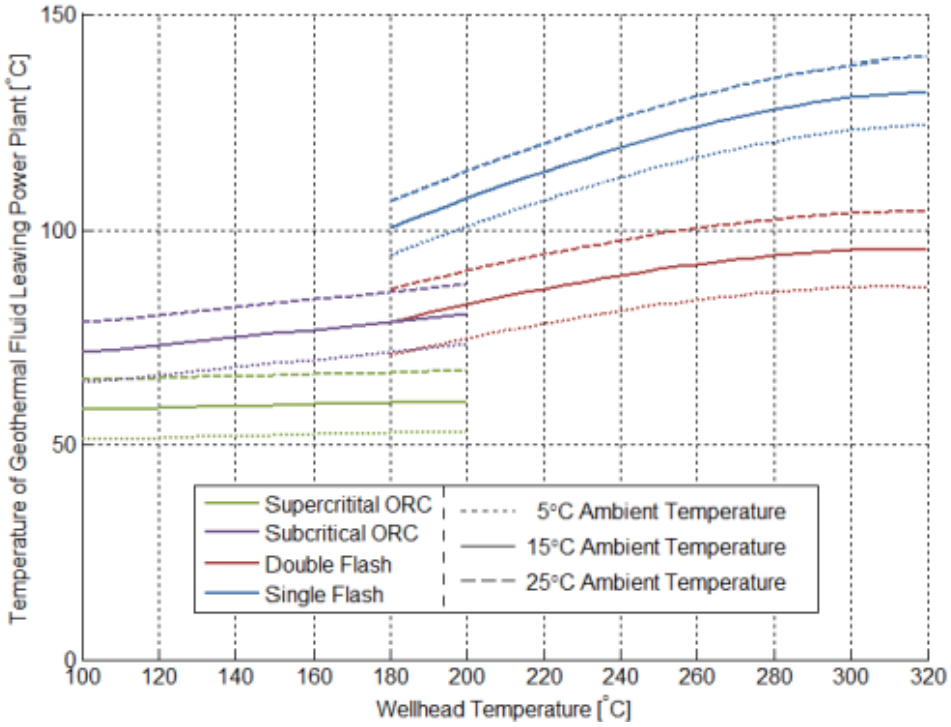
1. Multiple Parallel Fractures
2. 1D Linear Heat Sweep Model
3. $\dot{m}/A$ Drawdown Parameter Model
4. Annual Percentage Thermal Drawdown Parameter Model

Koenraad F. Beckers
kb447@cornell.edu

1. GEOPHIRES – Surface Equipment Performance

Aspen PLUS and MATLAB used to simulate ORC and flash power plants

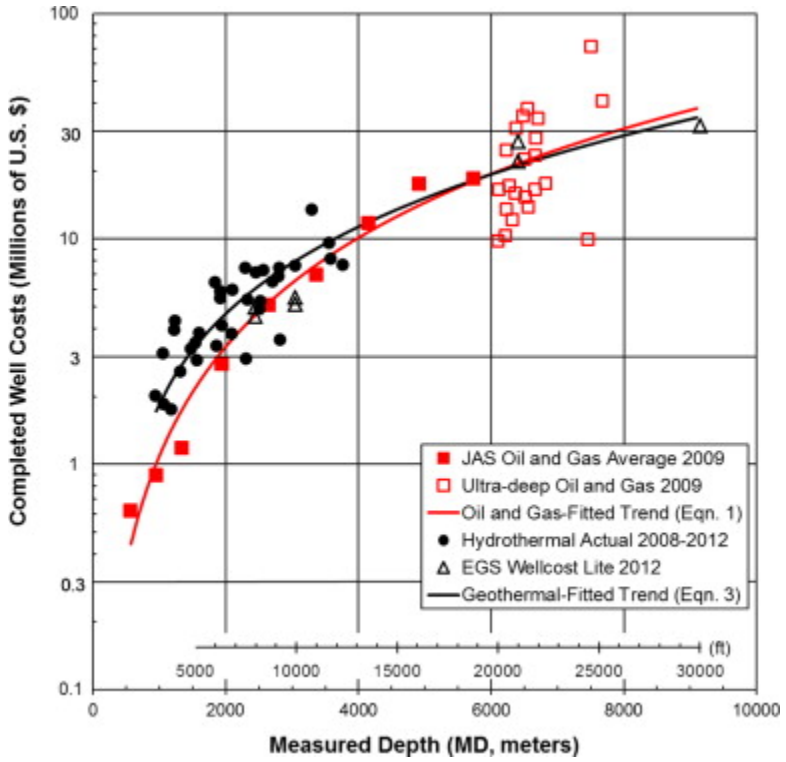


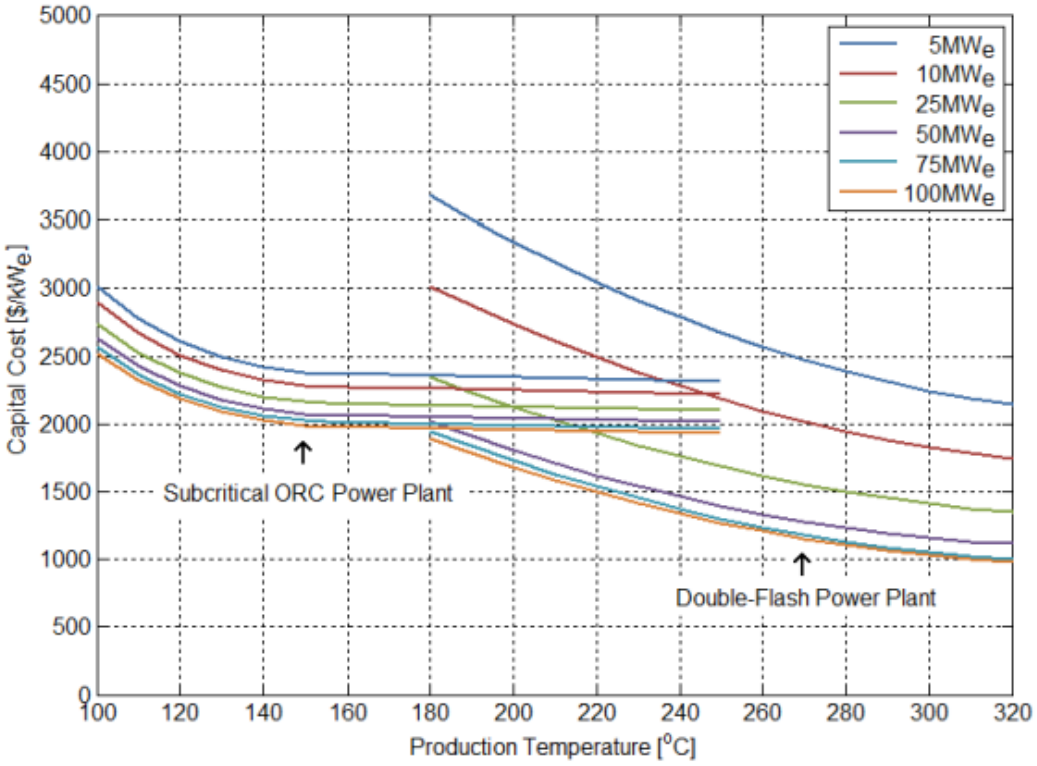


All correlations can be found in online supplemental material

Koenraad F. Beckers
kb447@cornell.edu

1. GEOPHIRES – Cost Correlations



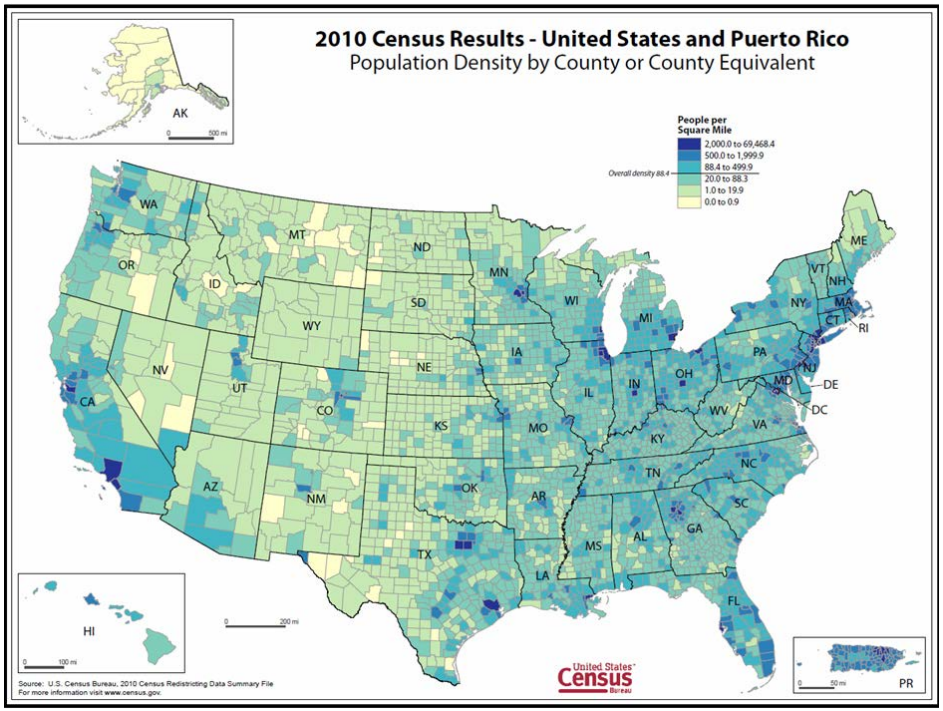


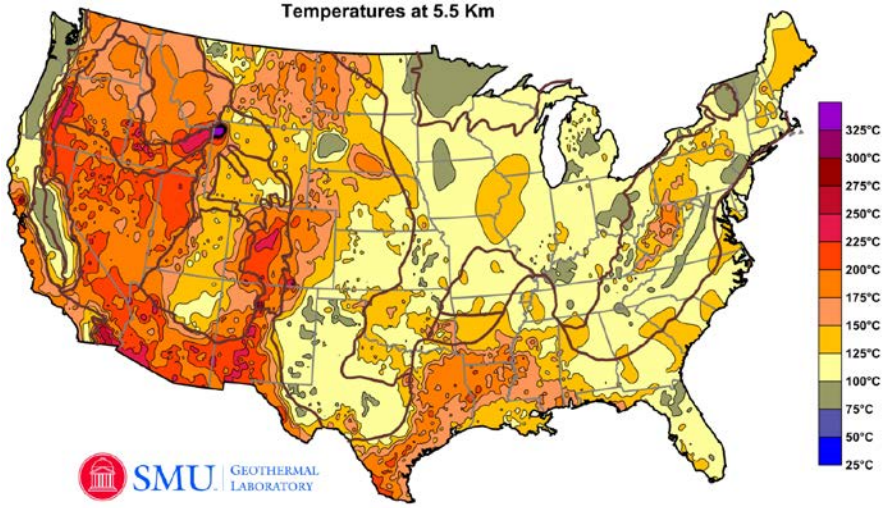
Lukawski et al., "Cost Analysis of Oil, Gas, and Geothermal Well Drilling", Journal of Petroleum Science and Engineering, 118, 1-14, (2014)

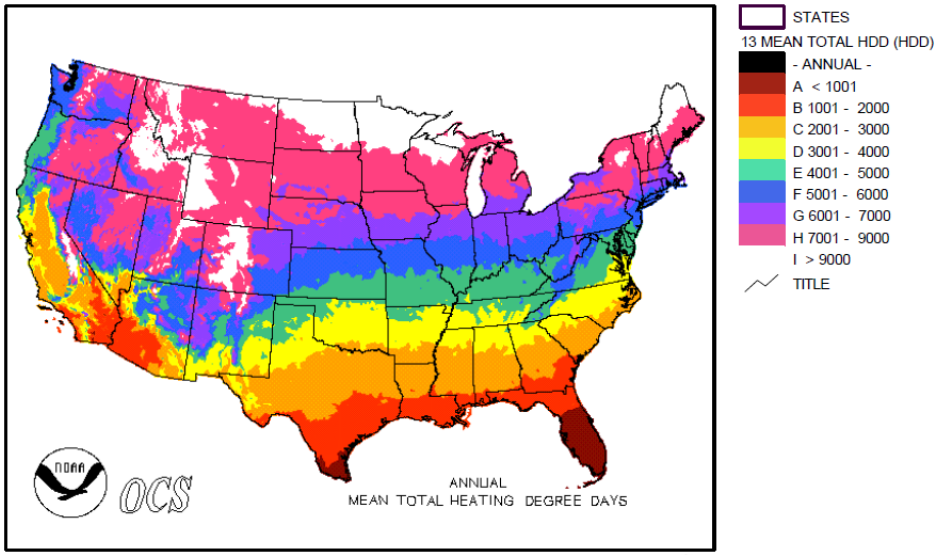
Other cost correlations can be found in supplemental material

Koenraad F. Beckers
kb447@cornell.edu

2. Economics of Direct-Use Geothermal Systems: Case-Studies







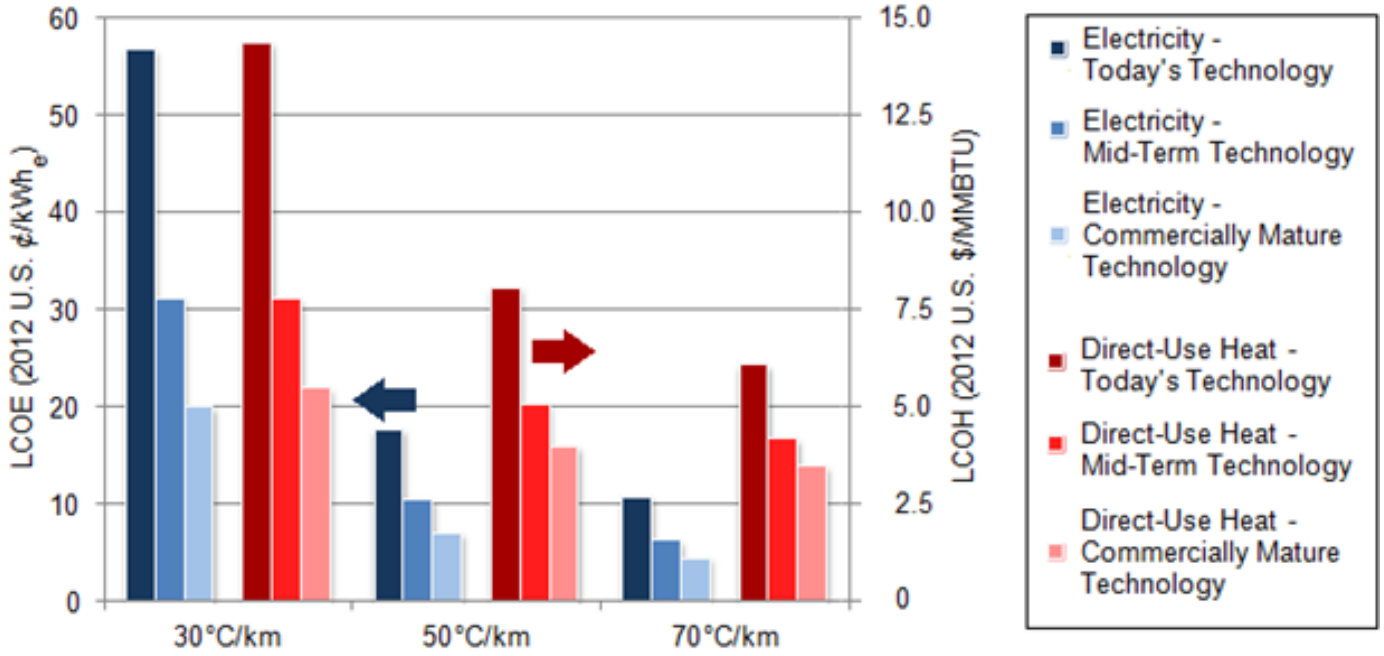
2. Economics of Geothermal Electricity and Direct-Use Heat

3 resource-grades:

- 30ºC/km
- 50ºC/km
- 70ºC/km

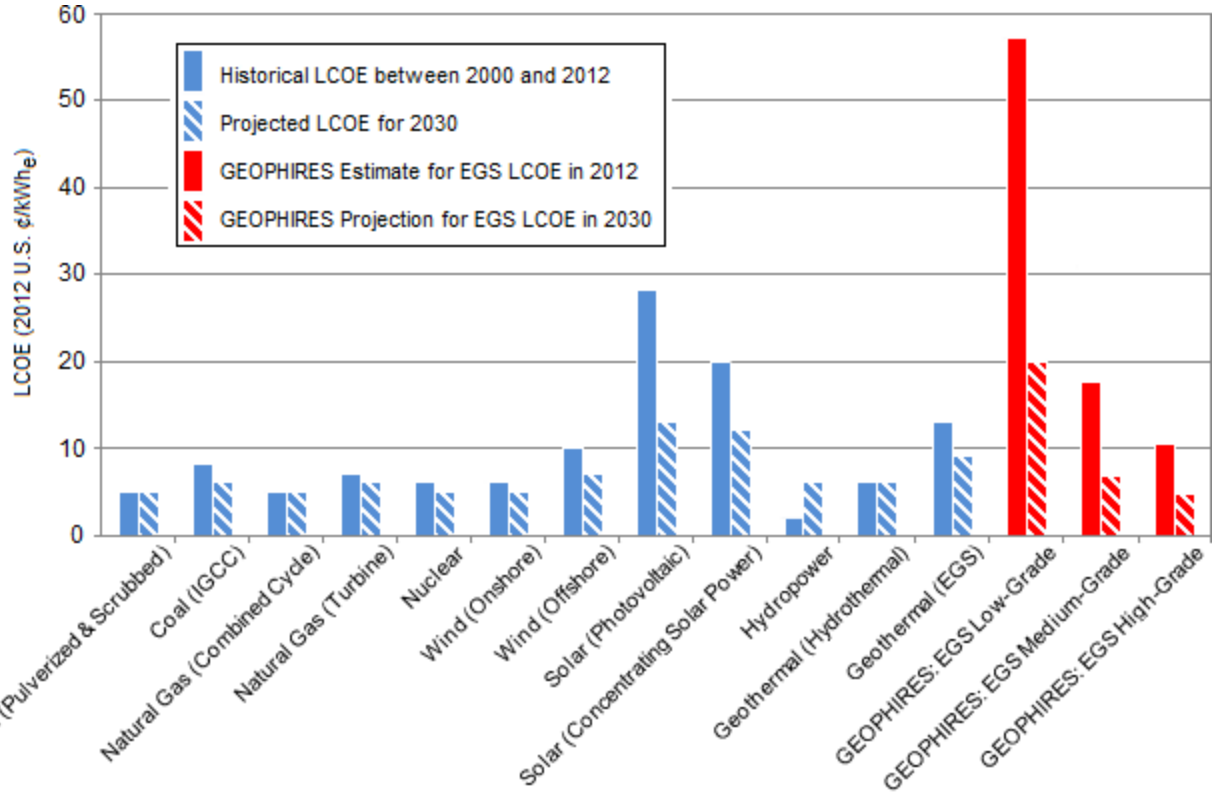
3 levels of technological maturity:

- 30kg/s & 1.5%/yr drawdown
- 50kg/s & 1.0%/yr drawdown
- 70kg/s & 0.5%/yr drawdown



Koenraad F. Beckers
kb447@cornell.edu

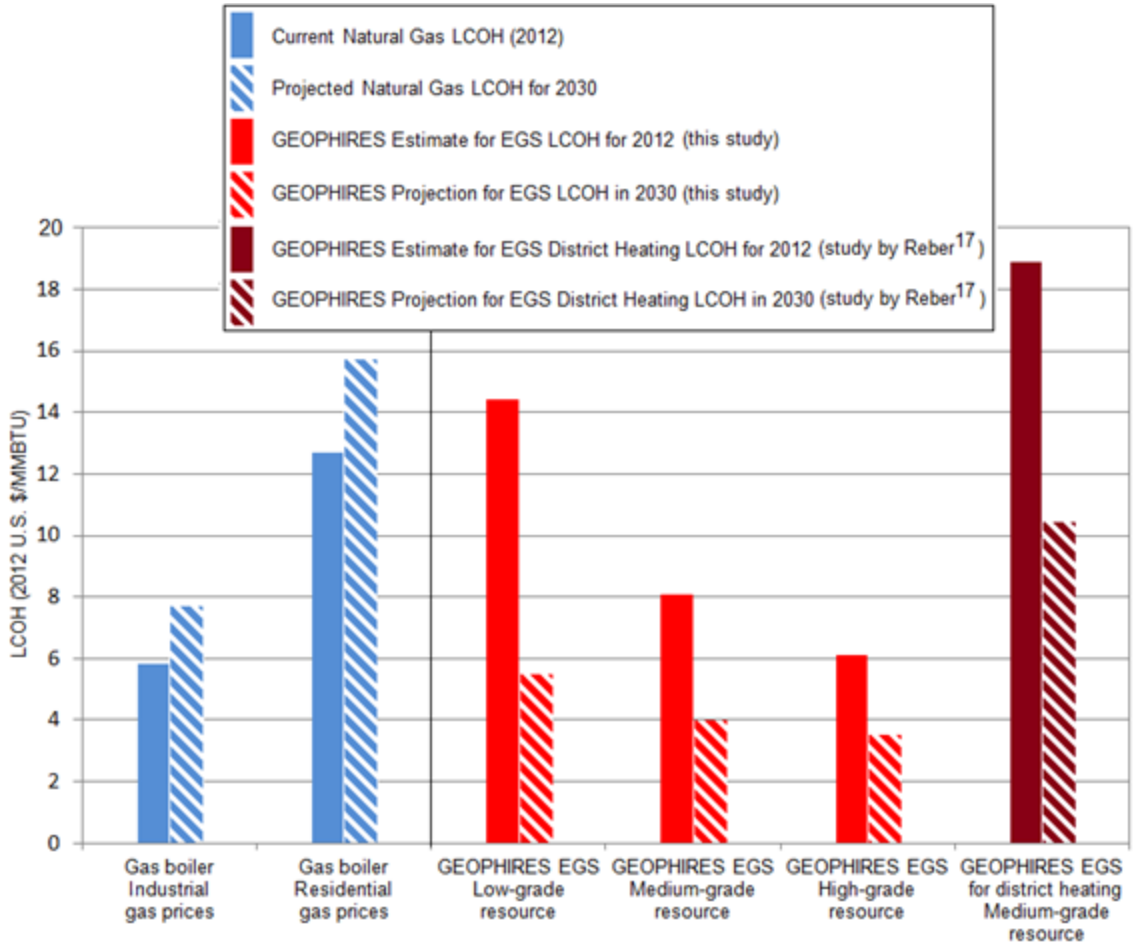
2. Economics of Geothermal Electricity



→ Low-grade geothermal electricity is expensive

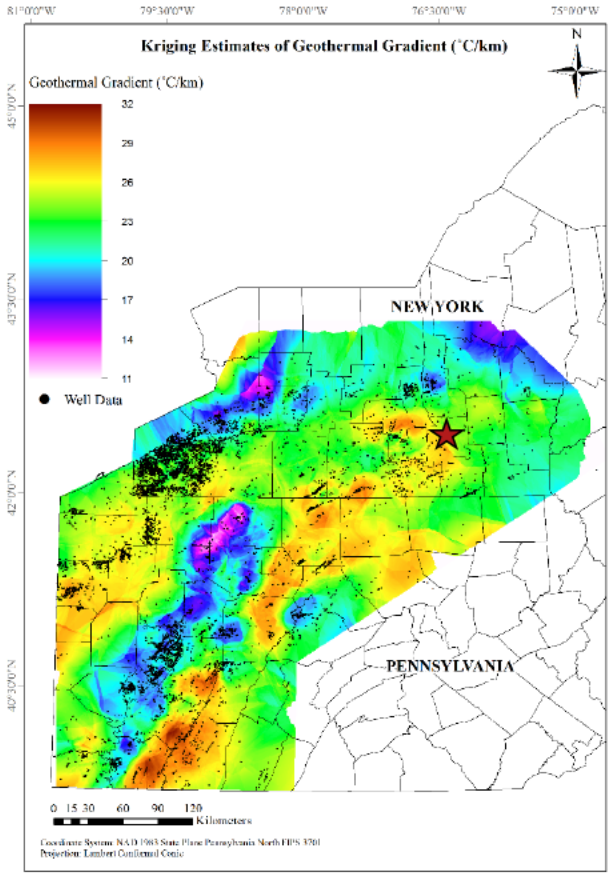
Koenraad F. Beckers
kb447@cornell.edu

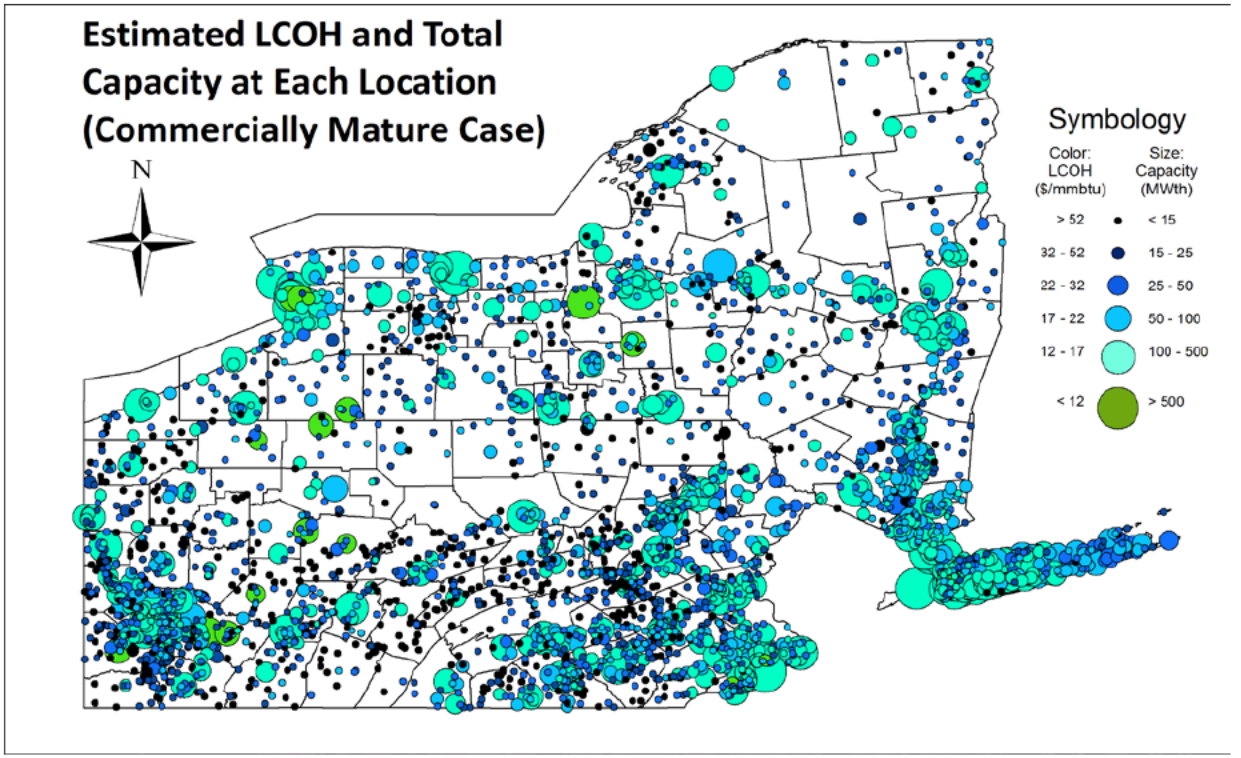
2. Economics of Geothermal Direct-Use Heat



Koenraad F. Beckers
kb447@cornell.edu

2. Economics Geothermal district heating systems in NY and PA



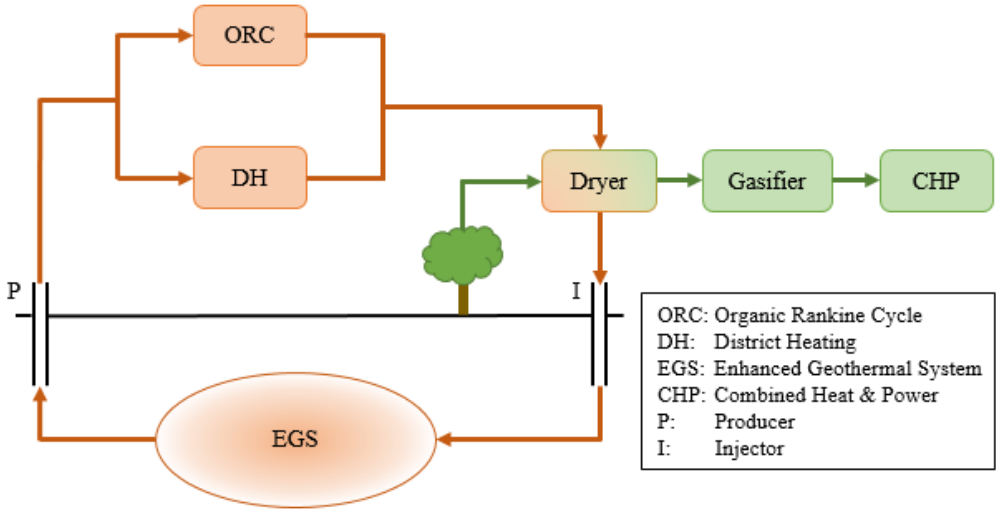


Aguirre G. A., "Geothermal Resource Assessment: A Case Study of Spatial Variability and Uncertainty Analysis for the State of New York and Pennsylvania", A Master of Science Thesis presented to the Faculty of the Graduate School of Cornell University, (2014)

Reber et al., "The Transformative Potential of Geothermal Heating in the U.S. Energy Market: A Regional Study of New York and Pennsylvania", Energy Policy, 70, 30-44, (2014)

2. Economics of direct-use: Hybrid Geothermal-Biomass Co-Generation System for the Cornell University Campus

- Low-Grade EGS (25ºC/km) for base-load heating and summer electricity & Gasified willow for peak-load heating
- MATLAB using GEOPHIRES as subroutine & published biomass data



- ➢ Pilot project (20%):
  - $ 47M
  - 17.3 $/MMBtu
- ➢ Full-scale project (98%):
  - $ 217M
  - 15.9 $/MMBtu

Beckers et al. "Hybrid Low-Grade Geothermal-Biomass Systems for Direct-Use and Co-Generation: from Campus Demonstration to Nationwide Energy Player", Proceedings, 40th Workshop on Geothermal Reservoir Engineering, Stanford University (2015)

Koenraad F. Beckers
kb447@cornell.edu

Conclusions

- GEOPHIRES is program to analyze technical and economic performance of geothermal systems for electricity and direct-use heat

- First developed in 2011 and continually being updated
  → Beta version (v1.3)

- Using GEOPHIRES:
  - Low-Grade geothermal electricity: 20-60 ¢/kWh
  - Low-Grade geothermal direct-use: 6-14 $/MMBtu

Koenraad F. Beckers
kb447@cornell.edu

Thank you! Questions?

Collaborators:

Dr. Brian Anderson (West Virginia University)
Manish Nandanwar (West Virginia University)
Xiaoning He (West Virginia University)
Kelydra Welcker (West Virginia University)
Dr. David Blackwell (Southern Methodist University)
Maria Richards (Southern Methodist University)
Zachary Frone (Southern Methodist University)
Dr. Chad Augustine (NREL)
Dr. Bill Livesay (Sandia)
Louis Capuano, Jr. (Capuano Engineering Company)
Louis Capuano III (Capuano Engineering Company)
Dr. Michal Moore (University of Calgary)
W.S. 'Lanny' Joyce (Cornell Facilities)
Steven Beyers (Cornell Facilities)

Acknowledgements:

U.S. DEPARTMENT OF ENERGY
IGERT Integrative Graduate Education and Research Traineeship
Cornell University David R. Atkinson Center for a Sustainable Future
Cornell University Cornell Energy Institute

Contact Information:

Jefferson Tester
jwt54@cornell.edu

Maciej Lukawski
mzl8@cornell.edu

Koenraad Beckers
kb447@cornell.edu

Full Simulation Results for 2015 Cornell Case-Study

Pilot Project (20%)

Geothermal EGS Energy Output
- Heat = 73 GWh_{th}/yr
- Electricity = 0.5 GWh_e/yr

Biomass Energy Output
- Heat = 3.3 GWh_{th}/yr
- Electricity = 1.9 GWh_e/yr

Overall Results
- **CAPEX = $47M**
- **LCOH = 17.3 $/MMBtu**
- Avoid. CO_2 emissions = 19,000 metric tons/year

Full Conversion (98%)

Geothermal EGS Energy Output
- Heat = 363 GWh_{th}/yr
- Electricity = 5.7 GWh_e/yr

Biomass Energy Output
- Heat = 16.3 GWh_{th}/yr
- Electricity = 9.5 GWh_e/yr

Overall Results
- **CAPEX = $217M**
- **LCOH = 15.9 $/MMBtu**
- Avoid. CO_2 emissions = 94,000 metric tons/year

Current Campus System: 218,000 metric tons CO_2/year

Koenraad F. Beckers
kb447@cornell.edu