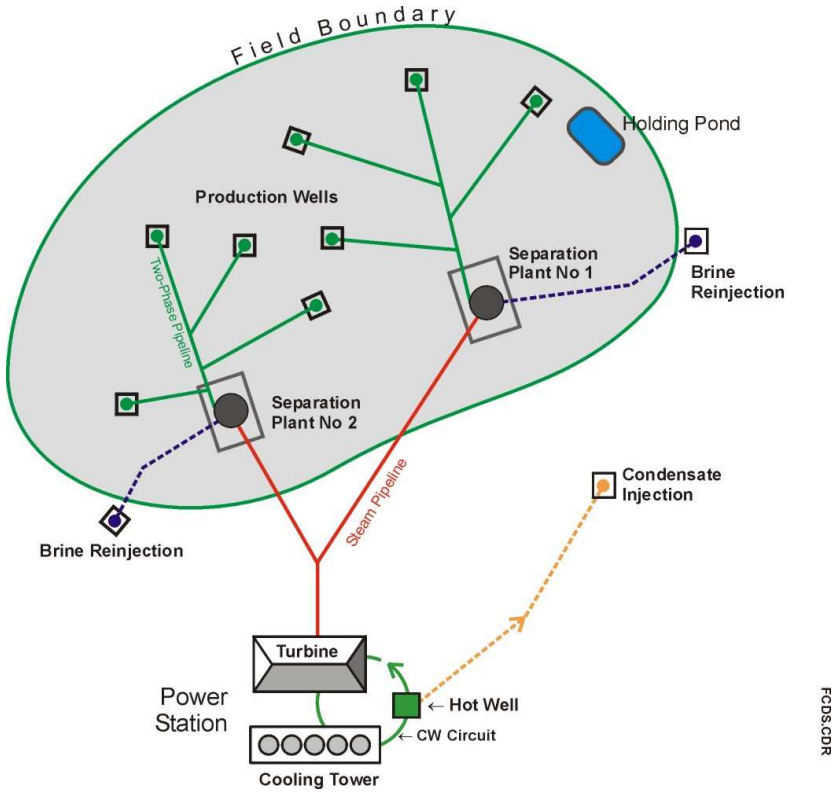

What Is the End Point for Geothermal Developments?

Allan Clotworthy
Sinclair Knight Merz

Introduction

- Any resource assessment is based on the assumption that there is a limit to extraction of the resource - otherwise the assessment would be infinitely large

  - > This means a resource assessment should take into account what is the end point of the extraction
  - > The end point may not simply correspond to energy depletion - it may be due to another *and predictable* "failure mode" of the project
  - > Correct identification of the likely failure mode may lead to a different resource assessment from simple depletion

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Introduction

- What Is the End Point For A Geothermal Development?
  - It is economically determined
  - Should be taken into account when determining the recovery factor used in resource assessments
  - Consideration of the possible failure modes also identifies the Modifying Factors which need to be taken into account in moving from Resources to Reserves
  - One major failure mode is likely, but cumulative and indirect effects also contribute to failure

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Introduction

- Implicit in any resource assessment is one or both of two assumptions:
  - The total resource capacity is infinite (i.e. totally renewable), but there is practical limit to the **rate** at which it can be extracted
  - The resource capacity is finite (i.e. partially or non-renewable) so there is limit to the **total amount** that can be extracted, and the rate is determined by dividing the total amount by the assumed project life
  - Geothermal resource assessments based on stored heat assume the latter
  - Geothermal resource assessments based on dynamic reservoir modeling fall somewhere between these two extremes

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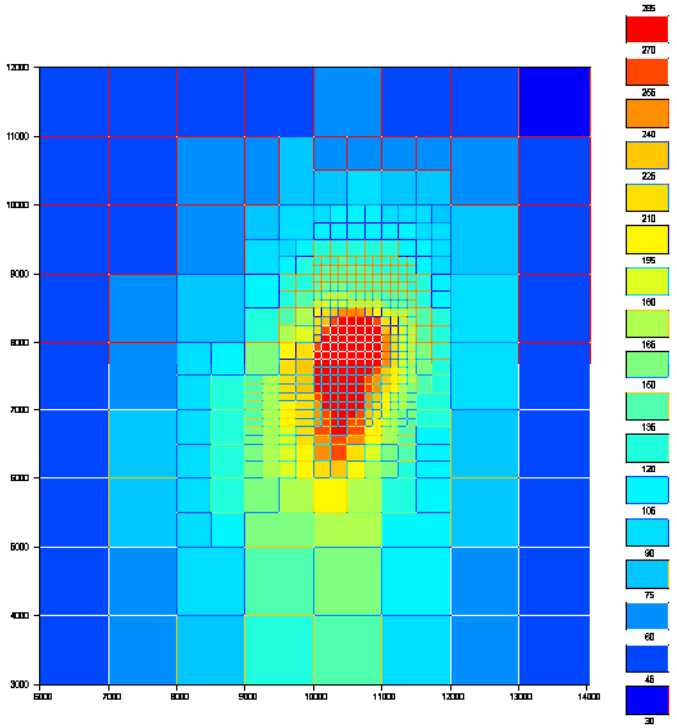
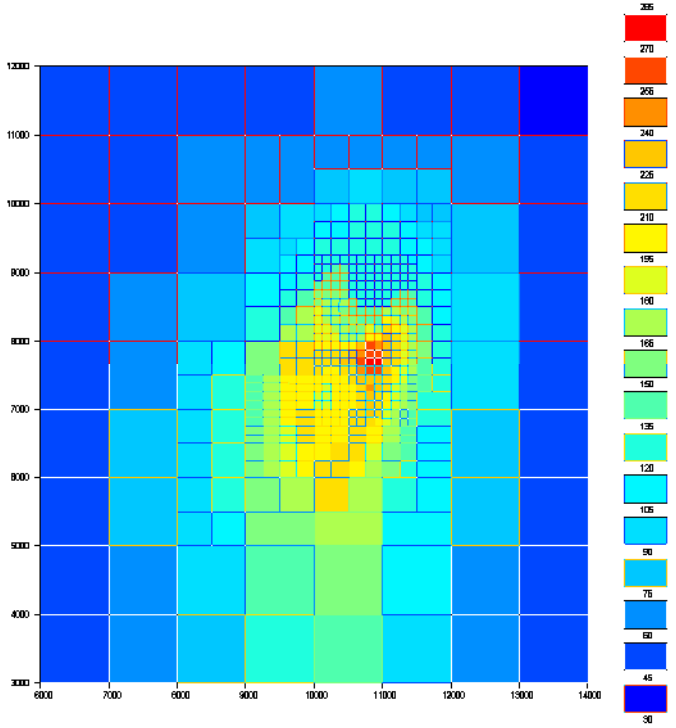
Modelling of heat loss in convective geothermal reservoirs
Inferno Project – Fictitious SKM Example

Temperatures at deep production level

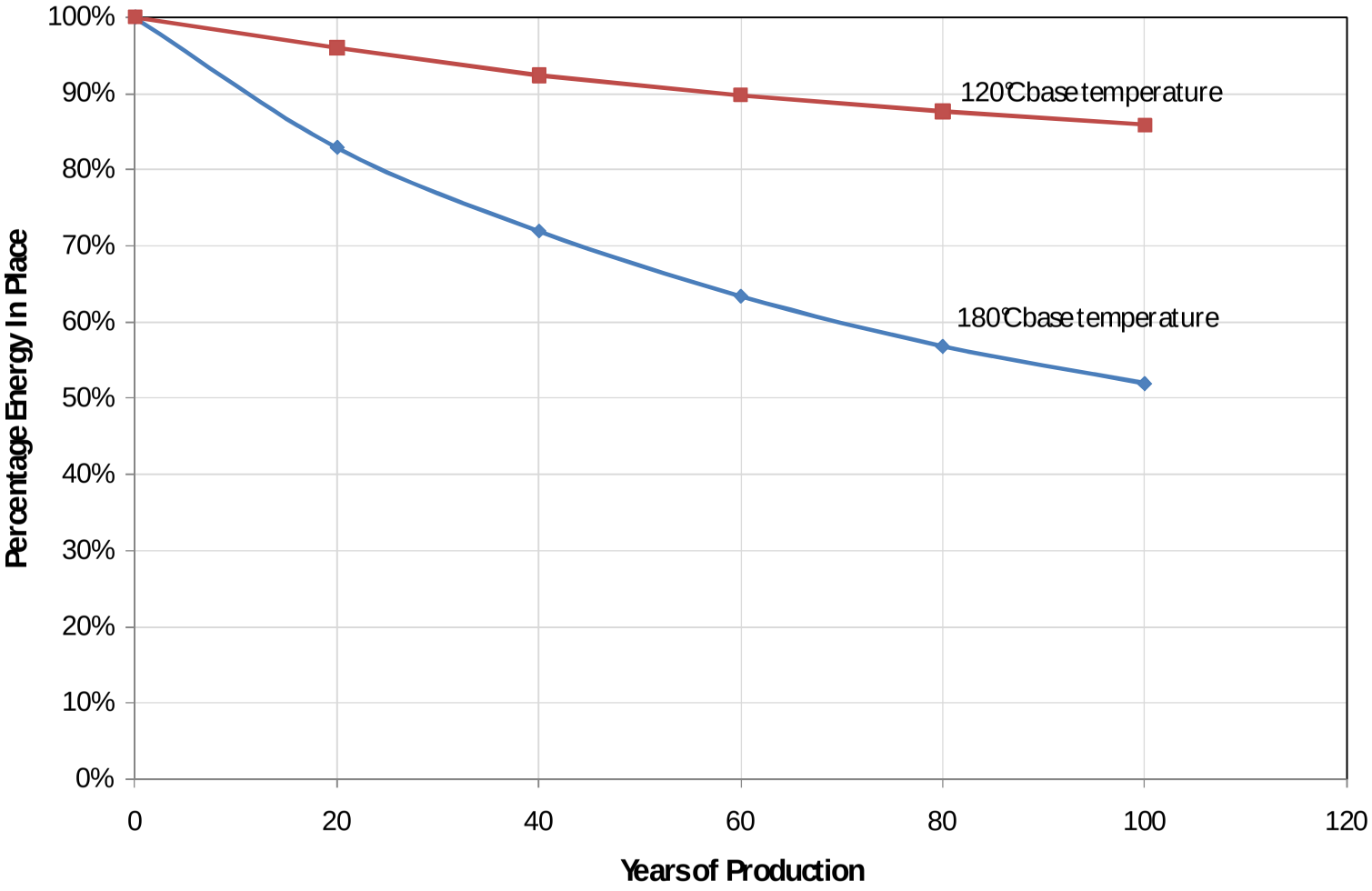


Natural State

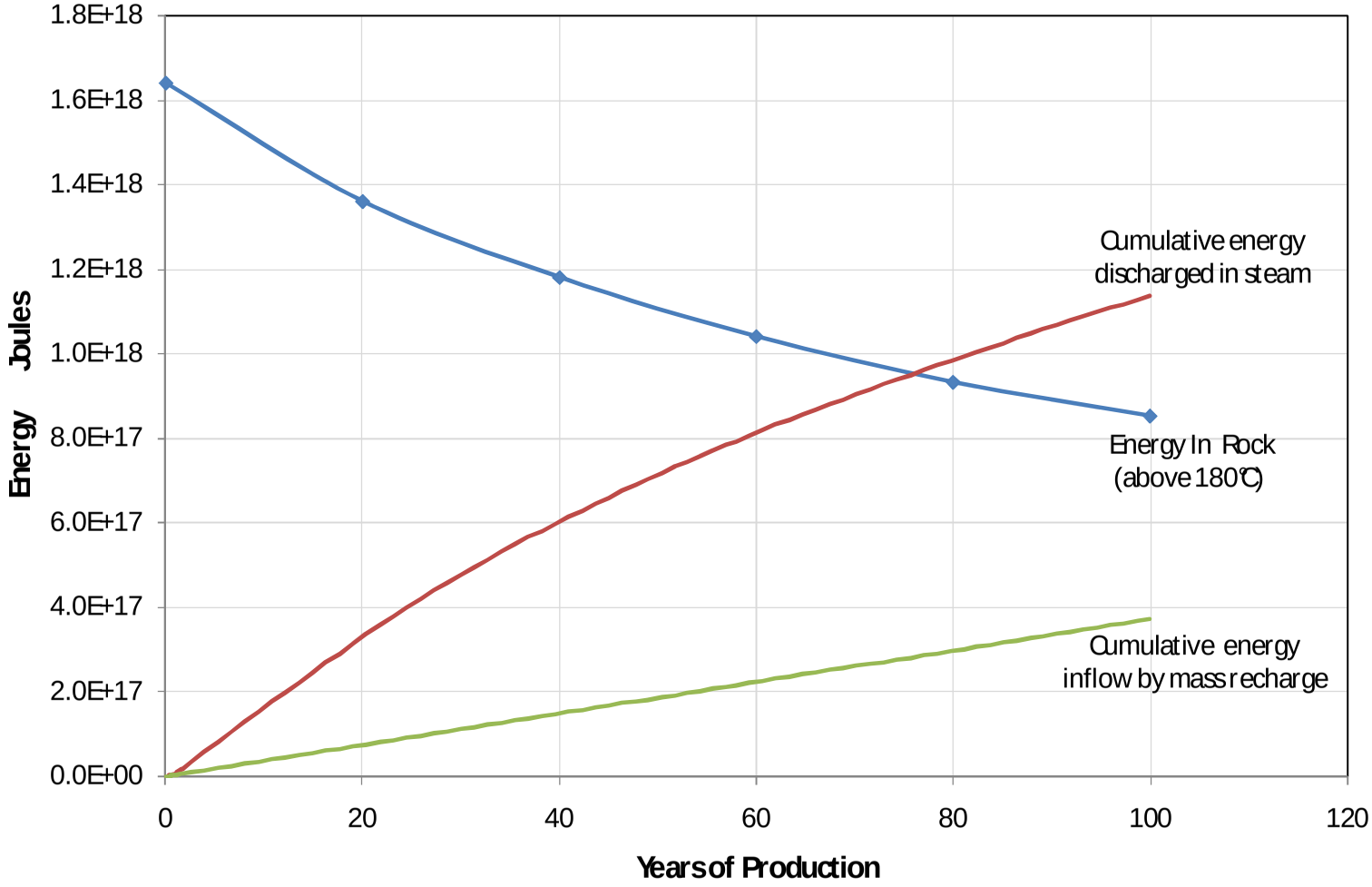


100 yr production

Modeling of heat loss in convective geothermal reservoirs
Inferno Project – Fictitious SKM Example

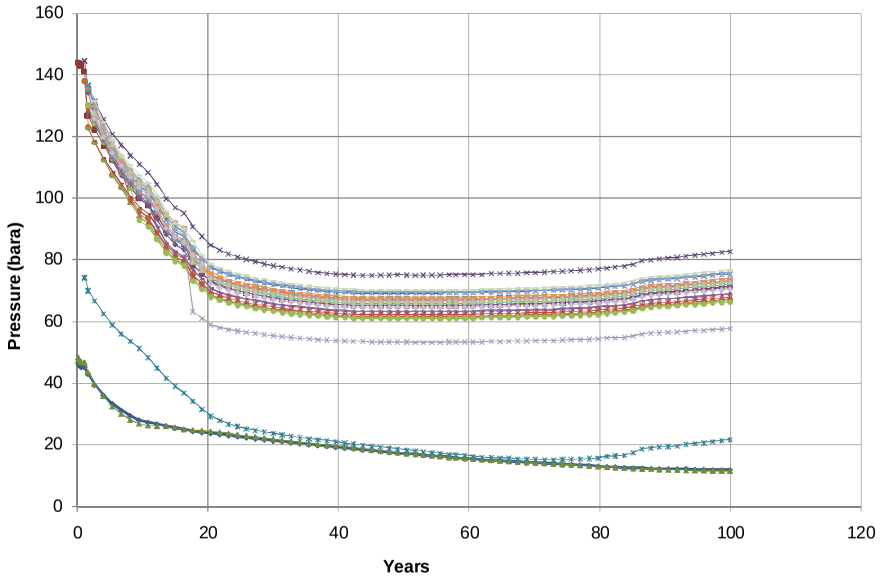


Modeling of heat loss in convective geothermal reservoirs
Inferno Project – Fictitious SKM Example

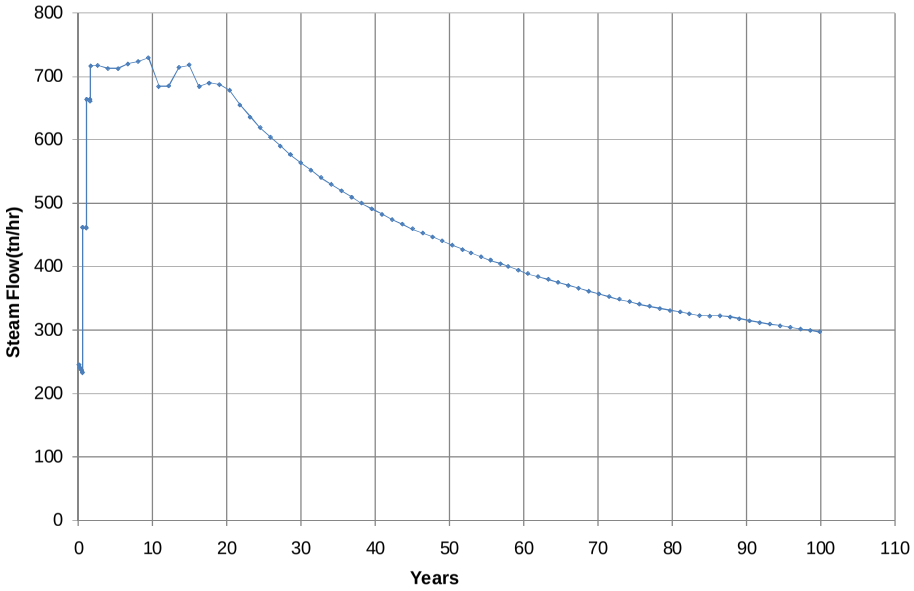


Energy In Place – 100 Years Production (base temperature = 180°C) and energy discharged in steam

Fluid loss – pressure decline even with full reinjection– Inferno Project example



Pressure trends – 100 years



Steam flow trend

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Experience with Convective Geothermal Developments

- Major failure modes often involve interaction with the external environment:
  - > Cool inflows from sides of the reservoir
  - > Cool downflows from overlying groundwater
  - Cooling by rapid reinjection returns usually overcome by moving injection wells further away
  - Fluid depletion (pressure decline) can occur in liquid-dominated systems where natural recharge is low

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Dynamic modeling of long term depletion

- Dynamic modeling should give reasonable prediction of different failure modes:
  - For operating fields modeling should be used for resource assessments to estimate remaining reserves
  - Modeling can be used to refine the recovery factor used in stored energy assessments
  - Modeling may not predict the extent of cooling by cooler groundwater inflows
  - Natural hot recharge is a complicating factor with convective systems, but should not be a factor with EGS

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Conclusions

- A resource assessment is an estimate based on implicit assumptions about how a project operates and why it eventually stops
  - > Proving Reserves requires that the assumptions are made more explicit and are justified
  - > Stored heat assessment is appropriate for Inferred Resources, but an implicit assumption is always that the project ceases through temperature depletion
  - > This assumption may well not be correct in many cases
    - Other failure modes may lead to premature cessation
    - Recharge may add to the available energy
  - > Dynamic reservoir modeling offers more opportunities to address alternative end points

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