ENERGY GeO Hackathon

Society of Petroleum Engineers

2024 SPE Europe Energy GeoHackathon

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Geothermal Field Development Plan

Tim Lines

Geothermal Wells LLC, Texas (‘GTW’)

FDP Executive Summary

- Project location, infrastructure and settlements
- Project objectives
- Brief description of developer
- Illustrated description of subsurface & surface development and connection to customers, e.g.: CGS/EGS/AGS; no of wells to TVD/MD; production temperatures, field flowrates, grid connection/private wire, steam/heat pipeline
- P90-P50-P10 project metrics (table?), e.g. initial, and field-life-average, electric & thermal export power; field-life electrical & thermal sales energy produced; recovery factor; Gantt chart and energy sales start date; capex & phasing; post-tax IRR & NPV10
- Status of community engagement and of support / objections; action plan
- Status of anchor-load customer commitment (PPA, HPA, LoI etc); % of sales capacity sold
- Annual supply / committed demand profiles (graph)
- Identity of working interests in the project and (depending on jurisdiction) in the licence
- Status of funding and cornerstone equity / debt investors
- Status of surface rights and subsurface heat rights
- Planning and other permissions
- Risk register; principal quantified sensitivities to IRR

Who is interested in a Geothermal Project?

- The developer's board
- The press, NGOs, environmental groups and the public
- Local council: co-investor, land-owner, energy customer, planning authority, HSE, building control..
- Equity and debt investors, and insurers
- Regional politicians, regional authority, central government, energy regulator, well regulator
- Heat, power & zero-carbon customers: public, private, residential
- The heat network developer
- The private wire developer
- The distribution network operator, transmission grid operator,
- The water authority
- Local employers, universities and colleges, and oil and gas workers
- Oil and gas service companies

The Field Development Plan must consider them all …

GTW
Enhancing Geothermal Energy

Press and Community Engagement

- Next Generation EGS
  - Technically and economically feasible in UK granites
  - Engagement with Press, Public
    - 30-year decarbonisation benefits
    - Safe and controlled stimulation
    - Television documentary on major network?
  - Engage NGOs to support and lobby for geothermal
- 4 wells: 70,000 tonnes pa carbon savings (35,000 diesel cars)

Heat customers

- High capex and long lead-times for heat network in built-up area
  - £4m / km for main supply pipe
  - Dig up roads and install flow and return pipes to each heat consumer
  - For heat network to achieve investable IRR
    - Anchor loads to achieve early revenue
      - Slow ramp up to full capacity (one team only 500 existing houses pa)
    - Very low price for geothermal heat
  - Volatile daily and seasonal demand = lower capacity factor and annual energy sales
  - Competitors on energy price
    - Natural gas boiler (already installed and new build)
    - Air source heat pump (retrofit)

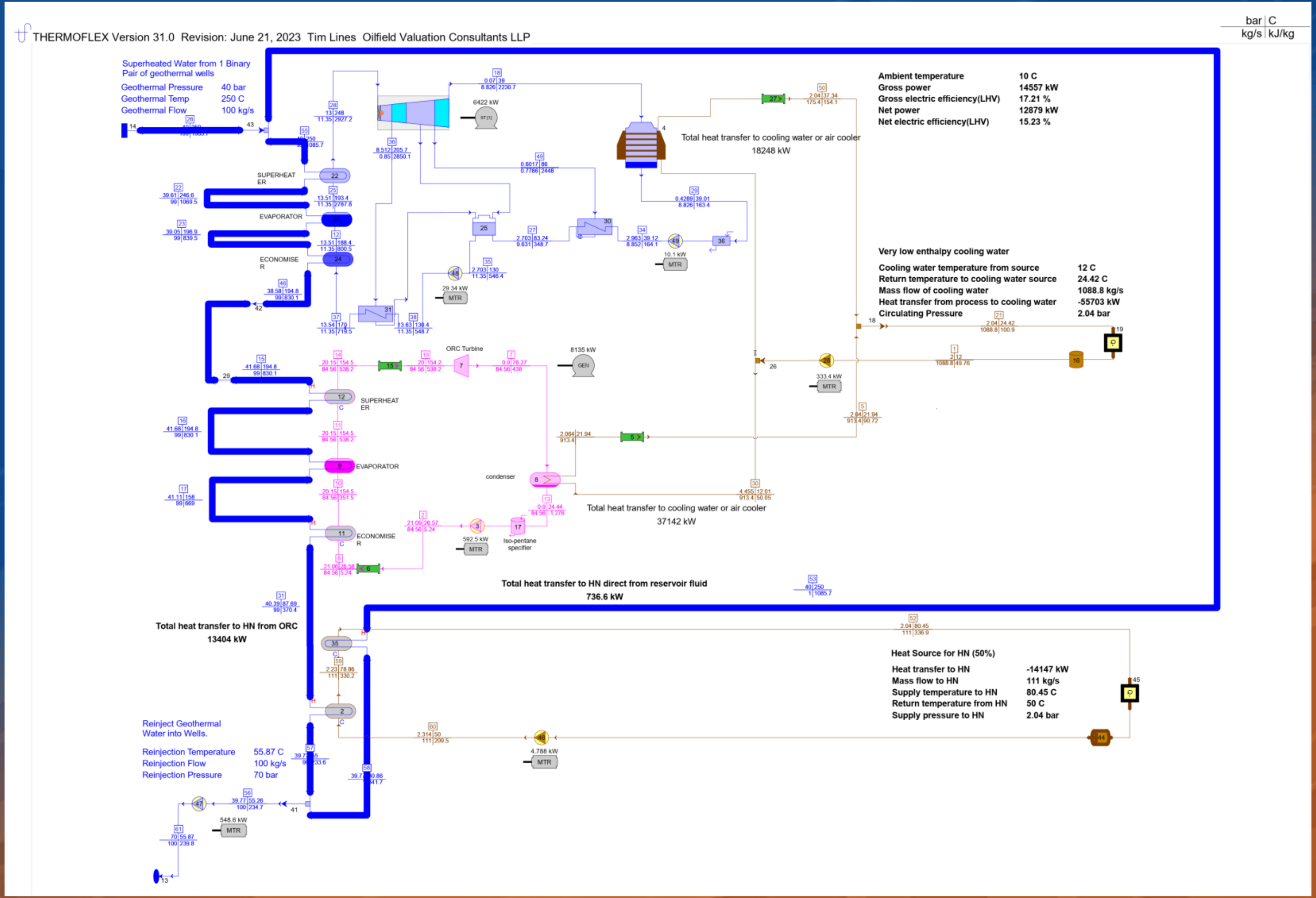
Electricity customers

- (Power) Distribution Network Operator (DNO)
  - Power grid entry-capacity constraints
  - DNO markup from price paid to geothermal developer and price charged to consumer
    - Pricing opportunity for Private Wire?
- Private wire
  - Capex
    - >£1m / km; 6-12 months to build
    - Backup storage for power generation upsets
    - Substations; switchgear at each customer
  - Gross revenue
    - Higher prices than from DNO by sharing with customer:
      - DNO’s markup
      - Carbon credits
    - But volatile daily and seasonal demand = lower capacity factor and annual energy sales
  - Micro grid operator and system aggregator role
    - **Need whole new skill set (joint venture?)**

Surface Location –competing needs

- Community support – social license to operate
  - Minimise noise, vibration, traffic disruption to residential
  - Planning
- Proximity to
  - Heat customers
  - Electricity customers (different location) by grid or private wire
  - Deep wells, preferable to drill vertically then turn the bit at lateral depth
  - Highways and Rail
  - High-pump capacity 24 MWe, high volume water supply (350,000 m3 / injector), high volume cooling water (1 mega litre/s /injector)
  - Land-owners willing to lease
    - 5 acres for drilling and completion; 3 acres for cogeneration plant; 10 acres for pond for several injectors (total 18 acres =7.5 hectares)

Facilities Design – Cogeneration of power & heat



Description and Observations / Injector:

100 kg/s of 250°C Superheated Water, reinjected at 56°C. Energy transferred to turbine working fluids by shell and tube heat exchangers.

~13 MWe +
14 MWth at 80°C for Heat Network, returned at 50°C (111 kg/s)

Steam and Organic Rankine Cycles

Water cooled condensers rather than air: 1 Mega-litre/s of 12°C water discharge 24°C.

Cooling water can be reconfigured for agro-industry, swimming pools, etc

Subsurface imaging data

- Gravity - depth to granite
- Seismic – depth to granite; faults; stratigraphy
- Magnetic – not normally useful in granite but complements MTA survey (below)
- Offsite borehole data – stratigraphy, drilling hazards
- Magneto Telluric Array - depth to granite; conductive fractures to avoid
- Cooperative inversion of Gravity, Seismic, Magnetic, Borehole and MTA
- Seismicity records – baseline for human-induced seismicity

Heat in Place Determination

- P90 Assumptions
  - No influx of heat beyond cylinder of rock stimulated (300m radius of which 200m propped; 3000m length)
  - Rock volume: ~0.2 km3
  - Reservoir Temperature Range: 265 Deg C to 180 Deg C (cogeneration surface simulation)
  - Heat Capacity: 774 J/kg/C; Density: 2600 kg/m3
  - Useful Heat in Place for cogeneration:
    - 49 peta-joules or
    - 13.6 TWth.hrs or
    - Average 52 MWth for 30 years (100% Capacity Factor)

Reservoir Development - Modelling

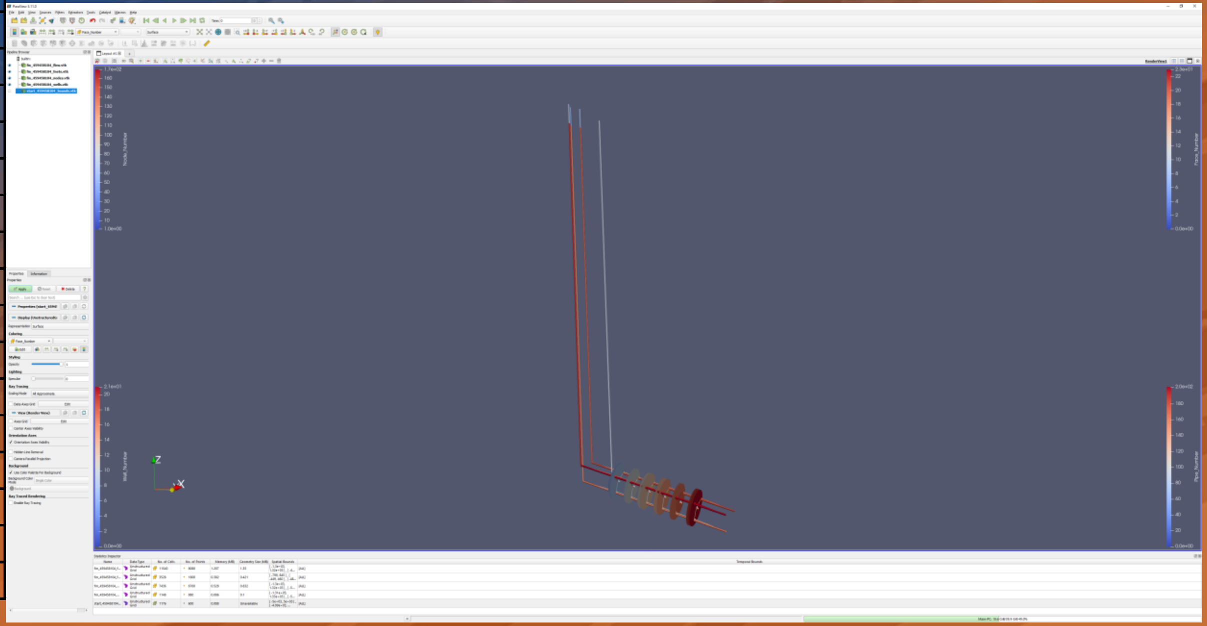
- Configurations
  - 1 Injector: 1 producer; 2 producers; 3 producers; 4 producers
  - Minimum separation of injectors to avoid interference?
  - Modelling more complex configurations

- Models
  - Open-source GeoDT pseudo 3D model which creates a mesh of pipes to represent 3D hydraulic connectivity (ref Luke Frash / Los Alamos)
  - Open-source Geophires Laplace domain solution of Gringarten's 1975 parallel fractures model for rapid 'reality check' modelling (ref Beckers / Augustine)
    - Key variables: stimulated area (min 4 km2); volume of rock within stimulated area; temperature difference between injected and produced water; rate of extraction

Incremental Economics of Well Configuration

Injector Producer Lateral Separation	Increase Injection Flowrate	Increase No of Producers per Injector	Increase spacing (metres) between Injector and Producer Laterals
metres	100 kg/s - 60 kg/s	(E.g.) 100 kg/s	(E.g. 60 kg/s)
	Incremental 10% Discounted Gross Revenue exc parasitic losses £m		
			100m-> 150m
100 m	£130		£45
150 m	£90		**150m-> 200m**
200 m	£123		£26
		1P-> 2P	**100m-> 150m**
100 m	£189	£118	£43
150 m	£141	£109	**150m-> 200m**
200 m	£181	£111	£22
		2P-> 3P	**150m-> 200m**
100 m	£215	£64	£28
150 m	£147	£29	**150m-> 200m**
200 m	£172	£13	£21
		3P-> 4P	**100m-> 150m**
100 m	£219	£13	£24
150 m	£196	£55	**150m-> 200m**
200 m	£220	£42	£9

Observations
Increasing flowrate from 60 kg/s to 100 kg/s large increase in gross discounted revenue excluding parasitic losses and incremental capex (GDR)
Increasing no of producers surrounding an injector increases GDR. Note: risk of higher temperature losses in producer wellbore
Increasing separation between injector and producer (s) increases GDR



Well data gathering

- Logging While Drilling (LWD) incorporating mud chillers and coated drill pipe to control bottom hole circulating temperature within equipment specifications
- Oriented Core
  - Fracture orientation
  - Core analysis: unconfined compressive strength; Youngs Modulus; Poisson's ratio; fracture toughness
- Incorporate Gyro surveys at casing setting points and real time survey correction to reduce ellipse of uncertainty separation distance of laterals
- Full open hole logging suite including caliper for borehole breakout, and borehole imaging
- Mini frac (fracture parameters and direction of laterals)

Optimising Vertical Casing,

Dimension	Internal Diameter	Flowrate to /from TVD	Flowrate to /from TVD	Frictional head loss / pressure to/from TVD: hL=fD*(L/D)*(V^2/2g)	TVD	Frictional Pressure Drop to TVD	Hydraulic Power	Shaft Power, assuming efficiency of: 0.7
	m	bpm	m3/s	psi/1000 ft	ft	psi	hp	hp
7", 35 lb	0.153	7.7	0.020	3.6	21116	77	14	20
7", 35 lb	0.153	11.3	0.030	7.9	21116	166	44	63
7", 35 lb	0.153	22.6	0.060	31	21116	656	349	498
7", 35 lb	0.153	30.0	0.079	54	21116	1148	808	1155
7", 35 lb	0.153	38.0	0.101	87	21116	1838	1639	2342
9 5/8", 53.5 lb	0.217	22.6	0.060	5.0	21116	105	56	80
9 5/8", 53.5 lb	0.217	30.0	0.079	8.7	21116	183	129	185
9 5/8", 53.5 lb	0.217	38.0	0.101	13.9	21116	293	262	374
13 3/8", 83 lb	0.309	22.6	0.060	0.8	21116	17	9	13
13 3/8", 83 lb	0.309	30.0	0.079	1.4	21116	29	21	29
13 3/8", 83 lb	0.309	38.0	0.101	2.2	21116	46	41	59

Observations
Parasitic losses in 7” too high for injector (60-100kg/s) . Good for 2 or 3 Producers / Injector (20-30 kg/s per producer)
9 5/8” good for 60-80 kg/s for injector and single producer, tolerable for 100 kg/s. Too large for 2 or 3 producers / Injector because temperature losses increase up wellbore due to low superficial velocities = higher residence time.
13 3/8” ok for 100 kg/s or more for injector

Optimising 3km lateral casing – parasitic load vs capex at 6.5km TVD

Injector Flowrate		7" Casing Length	5 1/2 " Casing Length	4 1/2" Casing Length	Frictional Pressure Loss	Hydraulic Power	Shaft Power, assuming efficiency of: 0.7		Price of electricity sale forgone	Capacity Factor	Electricity Sales Foregone pa	10% Discounted Electricity Sales Foregone over field life	Incremental 10% Discounted Cost over field life
m3/s	BPM	ft	ft	ft	psi	hp	hp	kWe	$/kWe	%	$ mln pa	$ mln	$ mln
0.06	22.64	10000	0	0	106	57.3	82	61	0.215	95%	$0.1	$1.1	
0.06	22.64	4000	2875	3125	169	91.3	130	97	0.215	95%	$0.2	$1.7	$0.6
0.06	22.64	0	10000	0	290	157.0	224	167	0.215	95%	$0.3	$3.0	$1.3
0.06	22.64	0	0	10000	985	532.4	761	567	0.215	95%	$1.0	$10.2	$7.2
0.08	30.19	10000	0	0	188	135.3	193	144	0.215	95%	$0.3	$2.6	
0.08	30.19	4000	2875	3125	299	215.6	308	230	0.215	95%	$0.4	$4.1	$1.5
0.08	30.19	0	10000	0	515	371.1	530	395	0.215	95%	$0.7	$7.1	$3.0
0.08	30.19	0	0	10000	1747	1259.6	1799	1342	0.215	95%	$2.4	$24.0	$16.9
0.1	37.74	10000	0	0	293	263.6	377	281	0.215	95%	$0.5	$5.0	
0.1	37.74	4000	2875	3125	466	420.1	600	448	0.215	95%	$0.8	$8.0	$3.0
0.1	37.74	0	10000	0	803	723.5	1034	771	0.215	95%	$1.4	$13.8	$5.8
0.1	37.74	0	0	10000	2727	2457.3	3510	2619	0.215	95%	$4.7	$46.9	$33.1

Conclusions
For 60-100 kg/s: either 7” or telescoping 7”, 5 ½”, 4½” are optimum
Drilling team will drill 8 ½” to TD for maximum efficiency and safety regardless of completion team decision.

Inclining Laterals; Buoyancy Effects

Well	Depth	Temperature	Water Density	Hydrostatic pressure	Hydrostatic Pressure Difference (Gain +; Drop -)	Frictional Pressure Drop	Bouyancy Heel-Surface	Net Pressure (Gain +; Drop -)
	m	Deg C	psi/ft	psi	psi	psi	psi	psi
Injector Heel	6200	75	0.423	8597				
Injector Toe	6400	75	0.423	8874	277	-193	0	84
Producer Toe	6400	265	0.336	7065				
Producer Heel	6200	257	0.342	6954	-112	-255	1643	1277

Issues
How to establish stable flood front when casing pressure higher at heel than toe? Incline about 200m over 3km so hydrostatic head balances pressure drop
Hydrostatic head and frictional pressure drop in producer is secondary to 1643 psi buoyancy (siphon)

Conceptual Well Design

GEOTHERMAL WELLS LLC
CONCEPTIUAL WELL DESIGN
DURHAM UK

Well Design			Age	Formation	Top Depth (TVDm	Lithology
String	Description	Depth				
				Pennine Middle Coal Measures	Surface	SST, mudstone, coal
				Pennine Lower Coal Measures	161	SST, mudstone, coal
				Namurian	318	SST, siltstone, mudstone, very coarse SST at base
			Yordale	Stainmore	376	Cyclic succession of SST, Siltstone, mudstone coarsening upwards with thin LST beds and COALS
				Gt Limestone	670	
Surface Casing	24" TBD	700		Alston	686	Cyclic sequences of LST, mudstone, siltstone, SST with Coals. LSTs generally thickest
				Fault Zone	*860*	10%-30% dolerite, sequentially changing LST, Coal, SST and silstone
				Tyne Limestone	928	Sandstone = mudstone = limestone
Intermediate 1 (Contingency)	18 5/8" Weight and Grade TBD	As/If Required	Border	Fell Sandstone (Asbian/Holkerian)	1,419	Sandstones, silstones, micaceous silstones
			Cement-Stone	Lyne Formation (Arundian / Chadian)	1,795	Cement stones, Siltstone with sandstone, dolostones and anhydrites (latter beds <4m thick). More marine character than Ballagan
9 5/8" Liner Top		3300		Ballagan Formation (Arundian/ Chadian/ Courceyan)	3000	Cement stones; calciferous sandstone measures: alternating silstone and argillaceous dolostones, the latter generally less than 1 m thick
Intermediate Casing	13 3/8" Weight & Grade TBD	3500			3300	
			Kelso Volcanics Formation (Courceyan)		3500	Kelso Volcanics Formation (Courceyan)
			U Devonian	Kinnesswood / Tayport (Courceyan / Famenian	3650	Thick hardpan calcrete horizons
				Stratheden / Buchan (Famenian / Frasnian)	3800	Reddish brown, fine- to medium-grained sandstone, interbedded with thin beds of siltstone and mudstone. An increase in silt and mud content with depth.
			L Devonian	Basement Rocks	5000	The depth of top Weardale Granite varies
	9 5/8" Weight & Grade TBD					
Intermediate Liner	6900 mMD					Measured Depth
		6500 mTVD			6500	9500+
						7" Weight & Grade TBD

Logistics

- Automated super-rigs – US
- 15000 psi stimulation fleet – US/Europe
- 50,000 tonnes intermediate strength proppant –China (or UK?)
- Casing and tubulars – Japan or China?
- Multiple products and services - Aberdeen and UK

Staffing

- Drilling, completion, high temperature specialists – US, UK and Canada
- Granite geologists and R&D staff - UK universities
- Subsurface modelling – US with UK collaboration
- Legals, Planning – UK
- Surface design and engineering – UK
- Procurement staff – UK
- Surface construction, commissioning & support services – UK
- Operations - UK

Capital Structure

- Equity for engineering and other works to Final Investment Decision
- 25% / 75% equity / debt for construction
- Post-Tax equity IRR > 15%
- Equity payback 6 years after main equity drawn-down

- Equity and debt investors: UK and USA
- Insurances: Europe

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#DatafyingEnergy

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