GEOTHERMAL ENERGY OVERVIEW

STATE-OF-THE-ART and GROWTH POTENTIAL

Prepared for a general audience

Norris Geyser Basin, Yellowstone NP WY

Hottest geothermal basin in the park. No, ***nobody is proposing geothermal development*** in Yellowstone National Park … but it is a beautiful location where the energy is palpable!

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PRESENTATION OUTLINE

Electricity Generation – state-of-the-art, growth potential

Direct Heat – potential, case studies

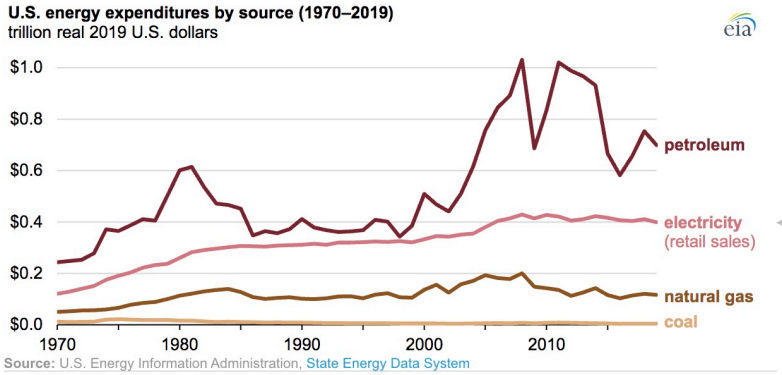
Geothermal Heat Pumps (GHP) – state-of-the-art, vendors

Hudson Ranch triple-flash geothermal power plant, Imperial Valley CA

GEOTHERMAL IN THE DOMESTIC ENERGY MARKET

small with upside!

Total 2019 energy expenditure, $1.2T, 5.7% GDP (low*)



- 2019 electricity consumption, 3.95T kWh (2018 peak, 4.0)
- Petroleum $699B, electricity $399B

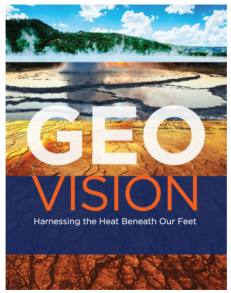
***50-year avg ~8% (range 5.5% to 13%+ in 1980)**

Geothermal role in today's energy mix

- Contributes to baseload electricity output (0.4% capacity)
- Small, niche, regional (CA/NV)
- Domestic GHPs making inroads

But…

- **Geothermal non-intermittent, small surface footprint**
- **Technology improving**, especially with O&G adoption
- **Scope for increase in baseload electricity power**, prompted by Renewable Portfolio Standards (RPS) requirements
- **Scope for increase in direct residential/industrial heat**
- ***Geothermal like wind/solar 20 years ago?***



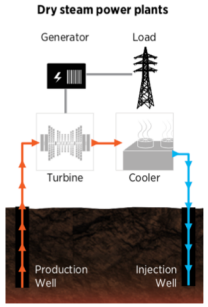
DOE GeoVision Report (2019) *CAVEAT – written by geothermal industry enthusiasts!*

- **Roadmap to increased market share for geothermal renewable energy by 2050**
- Identifies technical/non-technical blockers and enablers to meet ambitious targets
  - ✓ 16-fold increase in electric generating capacity, to 60 GW (~5% of anticipated installed capacity)
  - ✓ District-heating installation increase from 21 to 17,500
  - ✓ 14-fold increase in Geothermal Heat Pump (GHP) installations, to 28 million households

BASELOAD ELECTRICITY GENERATION, heat + water + permeability

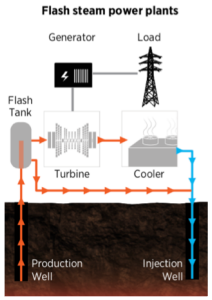
Technology evolution

Localized near subduction zones, rift volcanism, regional extension. High geothermal gradients.



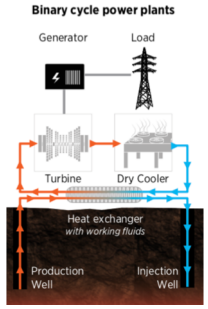
Dry steam

- Larderello IT (1913); world's first commercial geothermal power plant(s), Tuscan hills
- Geysers CA (1960), operated by Calpine. World's largest geothermal power generating facility
- 24% of global installed capacity, dominated by Larderello/Geysers
- Older technology, depletes more rapidly



Flash steam

- First implementation, Wairakei NZ (1958)
- 43% of installed capacity (2016), avg 28 MW; typical plant 5-6 production wells, 2-3 injection wells
- Hot fluid separated at surface to liquid + steam, cylindrical pressure vessel
- Double-flash, triple-flash variants more costly but more power output



Binary Power Plants

- a.k.a. Organic Rankine Cycle (ORC)
- Secondary organic fluid with lower boiling temp (pentane) drives turbines, <= 150°C reservoirs are feasible
- Most newbuilds today
- Allows for more efficient reservoir management, closed loop with no vapor losses

USA Domestic – ~3.75 GW capacity

- Focused on CA/NV Basin-and-Range, Imperial Valley
- Ormat, Calpine, BHE/Renewable leading operators

International – 12 GW capacity

- Indonesia, Philippines, Turkey, Iceland, Italy, New Zealand, Kenya, Mexico, and others; 12 GW

Case Study – Ormat McGinness Hills

Lander Co, NV

- Phases 1/2, 2*45 MW (2012, 2015)
- Phase 3 69 MW (2021) total capacity 160 MW
- PPA Los Angeles Dep't of Water and Power, 100% for 25 years

- Largest project on BLM land; 4.3 x 1.2 km dev't footprint
- Crustal thinning, basin-and-range. Production/injection in 2 grabens, linked by intersecting faults within brittle basement (blind system).
- Binary power plant, $600MM CAPEX for all phases
- 15 production wells, 7 injection wells; 170°C from 3 permeable fault zones; 30"/22"/16" casing strings, 9 5/8" liner to 1100 m

Case Study – Sarulla

North Sumatra, Indonesia

- Phases 1-3, 3*110 MW (2018)
- $1.7B, $1.6B financed by syndicate of banks, 4 year development with 16-yr repayment.
- 30-yr sales contract to state power provider PT PLN, 20-year guarantee

- World's largest single-contract GT plant, Sarulla Operations Ltd. (Medco Energi, Inpex, Itochu, Kyushu Electric Power, Ormat)
- Great Sumatran Fault, strike-slip fault system; Quaternary igneous extrusive reservoir (rhyolite-dacite), surface fumaroles
- Hybrid flash steam + binary/ORC configuration; 23 production wells, 11 injection wells

CHALLENGES … OPPORTUNITIES, ELECTRICITY GENERATION

Technical challenges
- More local variation than 'competing' renewable energy sources wind/solar
- Exploration for geothermal resource, with no surface expression
- Reduce drilling costs, large wellbores in crystalline rock
- Maximize water recycling/re-use
- Downhole sensors, steam conformance (innovation from SAG-D heavy oil industry), very high temperature requires insulation

Non-technical challenges
- Financial hurdles, up-front drilling costs and higher risk
- Streamline regulatory approval for quicker payback and lower financing costs
- Perception of induced seismicity plagued European EGS

Outsource technical challenge to GFS … Geothermal Field Service, if you will

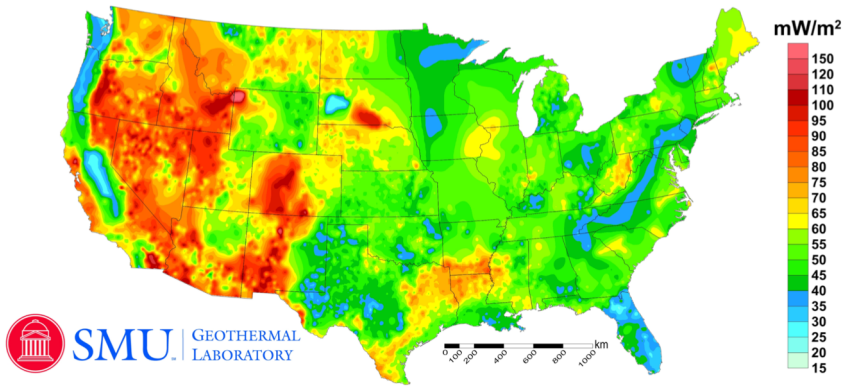
Integrated solutions
- OFS (BakerHughes, SLB/Geothermex, NOV drilling solutions, HAL)

Pre-FEED technical work
- Exploration and opportunity screening
- Advances in computational techniques for EGS, fracture modeling design, reservoir geomechanics
- Subsurface simulation with emphasis on fracture permeability

Drilling solutions
- NOV, Nabors prominent; Kenai leading contract driller

Surface equipment
- ORC units, turbines, steam scrubber, cooling towers, chillers

SMU Geothermal Laboratory Heat Flow Map of the Conterminous United States, 2011



Reference: Blackwell, D.D., Richards, M.C., Frone, Z.S., Batir, J.F., Williams, M.A., Ruzo, A.A., and Dingwall, R.K., 2011, "SMU Geothermal Laboratory Heat Flow Map of the Conterminous United States, 2011". Supported by Google.org. Available at http://www.smu.edu/geothermal.

Upside 1 – Enhanced Geothermal Systems (EGS)

- a.k.a. hot dry rock, much larger areas with insufficient groundwater; **induced fractures**
  - Cycle 'imported' water through induced permeability system, alternative for 'brownfield' redevelopment of existing reservoirs (Geysers NW)
  - Soultz-sous-Forêts, Rhine Graben - shut down, induced seismicity
  - FORGE DOE project, UT; drilling technology incubator, long timeline

horizontal drilling & hydraulic fracturing)
+
GCCU and/or ORC for optimal reservoir management
+
HVDC long-distance transmission

Upside 2 – Ground loops

- No induced fractures, **lengthy loops maximize reservoir contact**
  - Eavor (backed by BP, Chevron); -lite (Canada), -2 (Germany) designs. Prominent at Geothermal Rising '21 conference

Upside 3 – Supercritical water

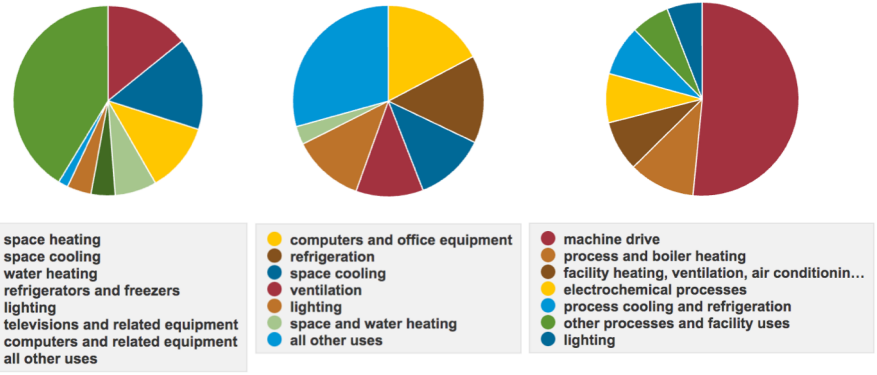
- Higher energy density. Requires innovative technology – 374°C, 3200 psi
  - Much greater depths, 5-10 years off?

Upside 4 – Repurposed oil & gas wells

- Oil wells too narrow, not designed for volumes, durations
- Sage Geosystems targeting gas wells including shallow offshore

DIRECT HEAT USE - INDUSTRIAL AND/OR DISTRICT HEATING

Big % of US electricity consumption is heating/cooling!
.48*.38 + .3*.36 + .25*.26 = 35+%

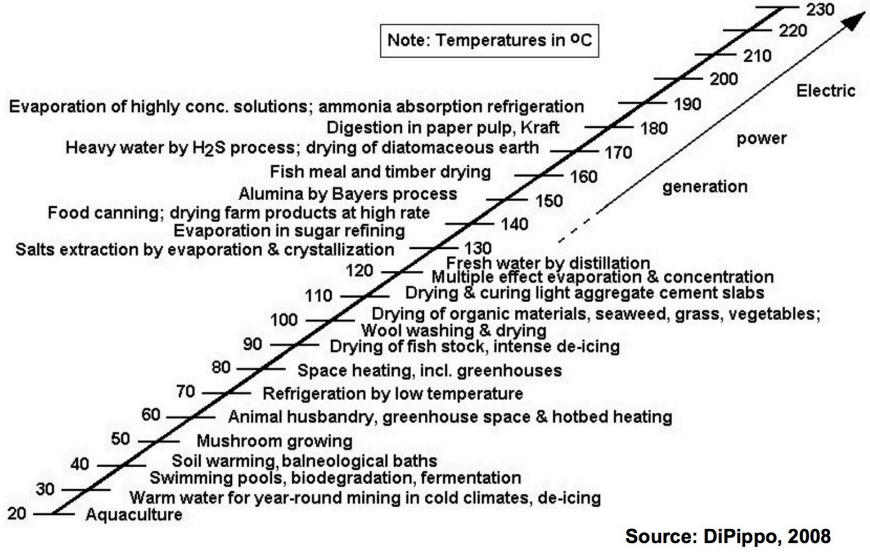


48% of residential demand (38%)

30% commercial demand (36%)

25% industrial demand (26%)

2019 EIA data, total US consumption 3.95T kWh
Retail sales 3.81T kWh, remainder direct use (industrial)



Numerous uses for industrial heat, as low as 20°C

EGS, closed loop potential here too

Size of domestic market

- Currently 21 district-heating systems installed
- GeoVision predicts 17500 district heating applications by 2050
- Could satisfy demand of 45 million households

Challenge – retrofit costly, newbuild focus

- Property developers, master-planned communities
- New light municipal industrial zones
- Factory one-offs

Case Study – Reykjavik, Iceland

Easy to dismiss as special case near active volcanism; Reykjavik Energy uses lower-temperature reservoirs.

- < 150°C at 1000 m depth
- 1300 km pipeline network serves 170,000 customers
- Exporting technology worldwide

Case Study – Boise ID

Edge of Snake River Plain, older portion of Yellowstone hot spot track with widespread flood basalts

- Began 1890s, revived 1980s
- Today 92 buildings with 6M ft^2 CRE
- Operated by Boise public works
- 80°C water circulated in pipes

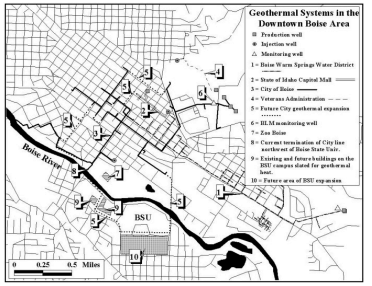
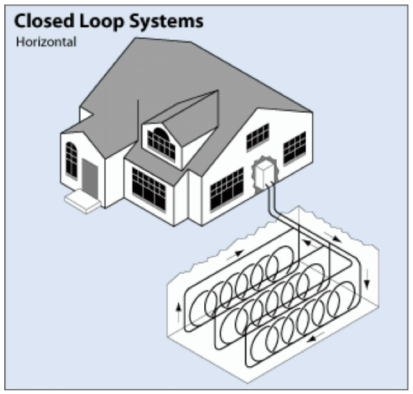


Figure 2. Map of the four geothermal district heating systems within the City of Boise (source is the City of Boise Public Works Department).

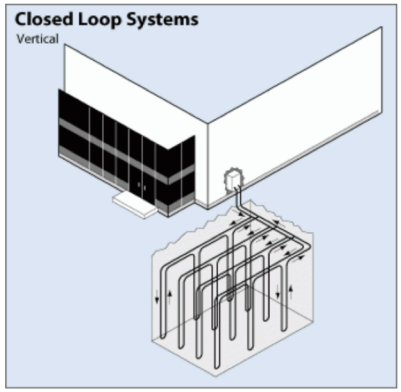
CLOSED-LOOP RESIDENTIAL HEAT PUMPS (GHP, an HVAC system)

Premise – use shallow underground ambient temperature to equilibrate surface fluctuations

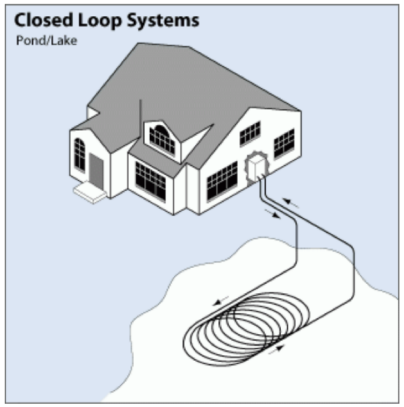
- Ubiquitous, deeper than 10m temperature near-constant near year-round
- In US, heating/cooling residential/commercial building contributes 11% of CO_2 emissions



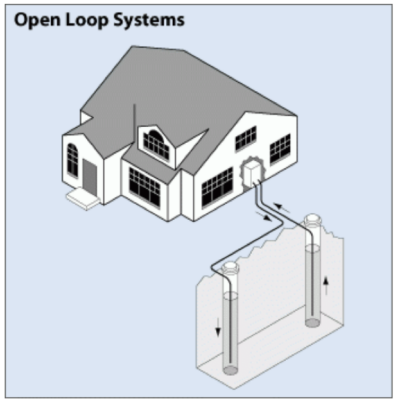
Trenches 4-6 feet deep, 'slinky' looped pipe increases length. Residential newbuilds.



Commercial buildings, schools; 4" holes drilled 20' apart to depths of 100-400'



Coiled pipe in nearby body of water (if available) at depth of 8'



Production/injection from aquifer or body of standing water

Size of market, domestic/international –

- Existing capacity 16.8 GW-thermal, equivalent to 2 million households
- Market participants –
  - Ingersoll (American Standard, Trane) – Trane Comfort Specialists
  - Bosch – Greensource Cdi, Si, i-Series
  - Carrier (original inventor of AC) – Comfort, Performance, Infinity Series
  - Dandelion Energy – pure-play GHP

Case Study – Dandelion Energy

- GoogleX spinoff, VC funding from Breakthrough Energy
- Taking aim at NE heating oil market, propane
- Cost reduced from standard $50k to $18-$25k, small bores 2" diameter
- Recycled water solution in ground-loops

PROFITABILITY OF GEOTHERMAL SUB-SECTORS

Exit timing/strategy – **proof-of-concept**, or **operating profit**?

Electricity generation

Upside

- ✓ Size of market, runway from 0.4% like wind/solar 20 years ago?
- ✓ RPS standards drive adoption, coal-fired plant retirements
- ✓ Off-grid solutions

Downside

- Utilities, highly-regulated, rate-controlled, low margins
- Penalty on heat-to-electricity conversion, Carnot's law
- High visibility, resource nationalism

District heating

Upside

- ✓ Huge industrial/residential market
- ✓ ~50% of residential electricity usage for heating/cooling
- ✓ Nascent utility, early pricing power

Downside

- Costly to retrofit older buildings
- Nascent utility
- Simple process, hard to establish IP

Heat pumps

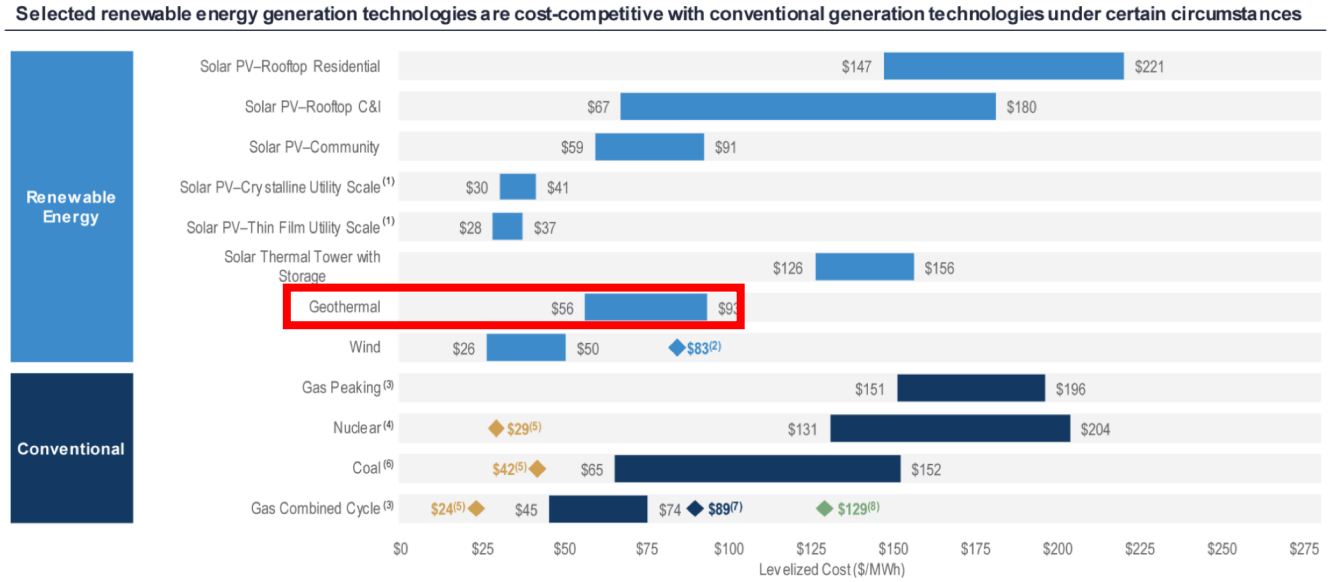
Upside

- ✓ Large market (142 million housing units in America)

Downside

- 'Commoditized' equipment
- Margin compression

Related opportunities in service sector –
subsurface, surface equipment, data, engineering advisory services



Lazard LCOE analysis 2021

- Accepted within renewable community, questioned outside*
- Competitive with conventional and other renewable resources … *especially when storage taken into account*
- Range $56-93 for new projects
- non-intermittent baseload has value

* depending on audience, not a concern

GEOTHERMAL ENERGY IN TEXAS

Premise – Can we repurpose oil and gas wells in TX to produce heat?

165,000 oil wells
85,000 gas wells
Abandoned wells?

- 29 MM population, fastest growing state in USA
- Industrial base
- **Biggest electricity market in the USA (421B kWh, 11%)**

Challenges –

- Geothermal low energy density, large water volumes
- Narrow wellbores/tubing, questionable durability
- Geothermal gradient relatively low in TX … more applicable for district heating or ORC conversion?

SAGE Geosystems

Houston-based startup, $3M Series A
WFT, RDS leadership

SAGE GEOSYSTEMS™

Toolkit for sedimentary rocks

- HeatRoot™ (hot-dry-rock application)
- HeatLoop™ (interconnected laterals)
- HeatFlood™ (secondary fluid, sCO_2)
- CO_2 Sequestration

Test well in Starr Co.
Feasibility study for 3MW geothermal plant at Ellington Field

Repurposing Human Capital

Houston global energy capital … center of excellence for technical innovation & implementation in subsurface disciplines

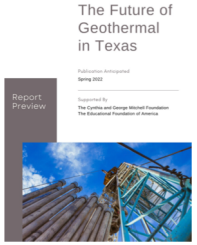
- ✓ Geoscience (exploration)
- ✓ Geoscience (development)
- ✓ Reservoir engineering
- ✓ Drilling/completions

… also energy finance

Already startups (Fervo Energy, Sage), consultancies

Geothermal Entrepreneurship Organization GEO

- UT/Austin
- Annual PIVOT Conference
- Texas Geothermal Institute newly-formed academia/industry consortium



The Future of Geothermal in Texas (Q1/2022)

- Sponsored by Mitchell Foundation
- Resource Assessment
- Roadmap for TX role in GT energy transition, leveraging O&G strengths

If US geothermal to meet full potential … center of excellence *must shift* from SoCal/Reno to TX, and utilize O&G transferable skills

TX Geothermal Energy Alliance (TxGEA) launched 1/13/2022

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INVESTMENT THEMES
(ranked by NPV*, not % return)

1A) Power production, EGS and/or closed-loop geothermal development. *Maximum reservoir contact + ORC + HVDC to distant markets*. Operator or non-op partner … domestic/international.

1B) District heating to erode electricity market share, 35% heating/cooling

3) International conventional geothermal exploration/development

4) Off-grid electricity generation for local demand, including digital mining

5) Field equipment for geothermal application – drilling/completion/monitoring (HPHT), applicable for power production and/or district heating

6) FEED engineering/consulting services – De-risk geothermal projects through application of O&G project management and tollgates. Opportunity screening and analogs.

??? Lithium mining from geothermal brine

***NPV = Net Present Value, reference to size of business opportunity (as opposed to rate of return)**

How can I help (your firm) understand geothermal energy?

- **Market studies (domestic/international focus)**
- **Competitive Intelligence (CI) assessments**
- **Opportunity Screening**

✓ **20 years experience, upstream energy production**
✓ **Member relevant industry associations, active networker**
✓ **Commercial focus**

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