Extraction of Rare Earth Metals from Geothermal Fluids using Bioengineered Microbes

Project Officer: Holly Thomas
Total Project Funding: $809,000
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Principal Investigator
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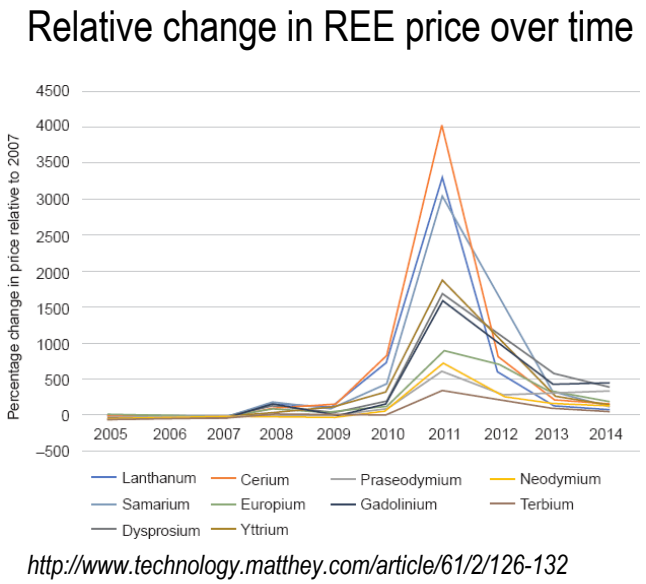
Track Two: Mineral Recovery

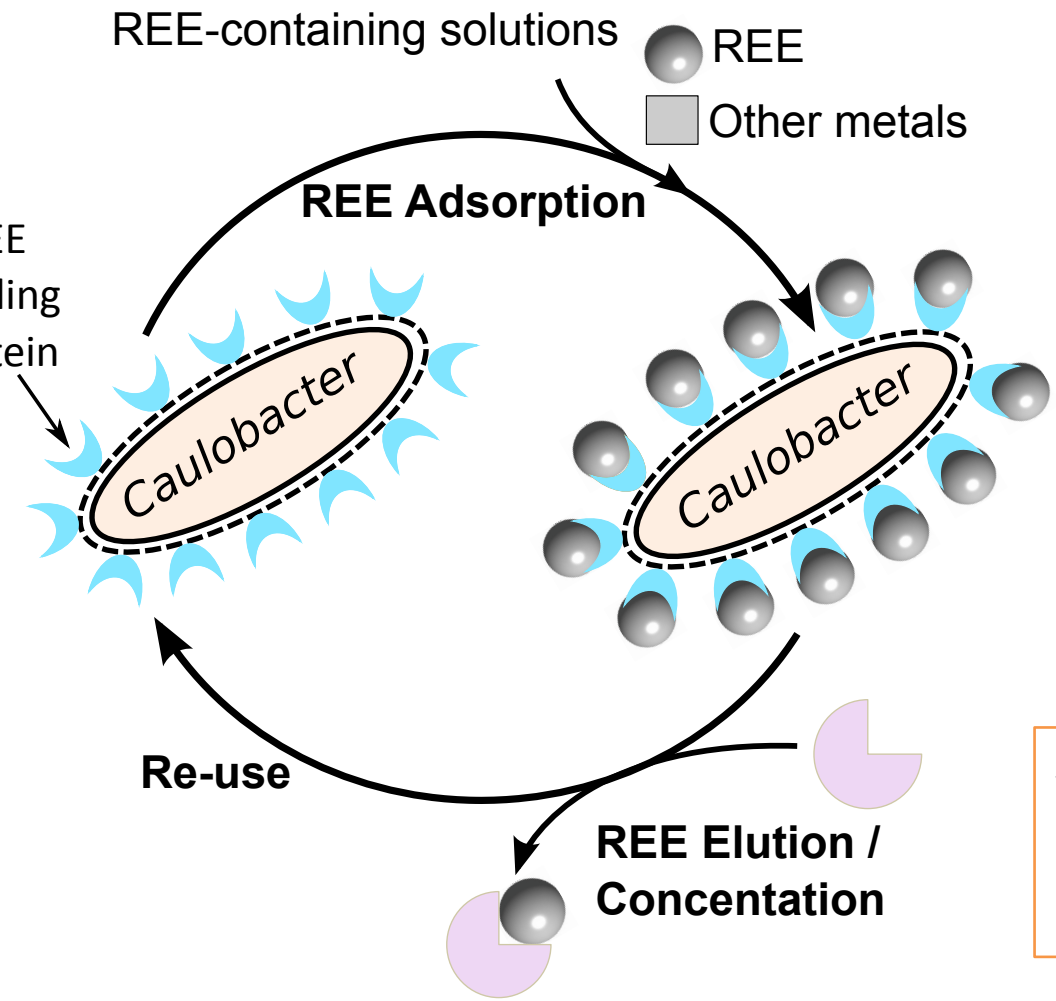
Relevance to Industry Needs and GTO objectives



http://www.technology.matthey.com/article/61/2/126-132

- Rare earth elements (REEs) are critical to clean technologies and national security but prices have been exceedingly volatile.
- Geothermal fluids are potential sources of valuable minerals and metals.
- Rare earth co-recovery with geothermal energy production could provide an additional revenue stream.
- Provides a case study into use of bioengineered microbes to extract useful elements from geothermal fluids.

Methods/Approach



Step 1:
Bioengineer microbes

Step 2:
Rare earth biosorption

Step 3:
Rare earth recovery

- Leverages previous work funded by EERE/CMI.

Project Overview (FY17-19)

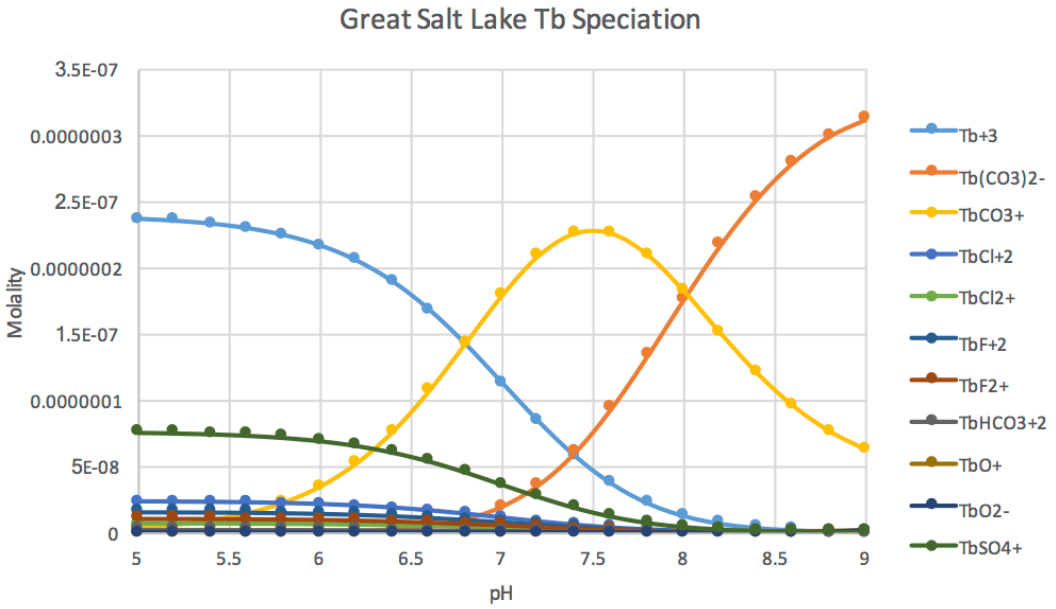
Budget period	Milestones	Go/No-Go
Year 1 - FY17	Batch scale REE adsorption/desorption and thermo-stability tests	Adsorption efficiency of >95% with a geothermal brine
Year 2 - FY18	REE adsorption in a biofilm flow through system	REE extraction efficiency of >90% and adsorption capacity more than 5 µmol per m^2 under continuous flow
Year 3 - FY19	Test REE recovery in a bioreactor	Demonstrate extraction efficiency of 1g total REEs/ 3 days for a 10-L bench-scale bioreactor.

Year 1 (FY17) proposed activities and achievements overview

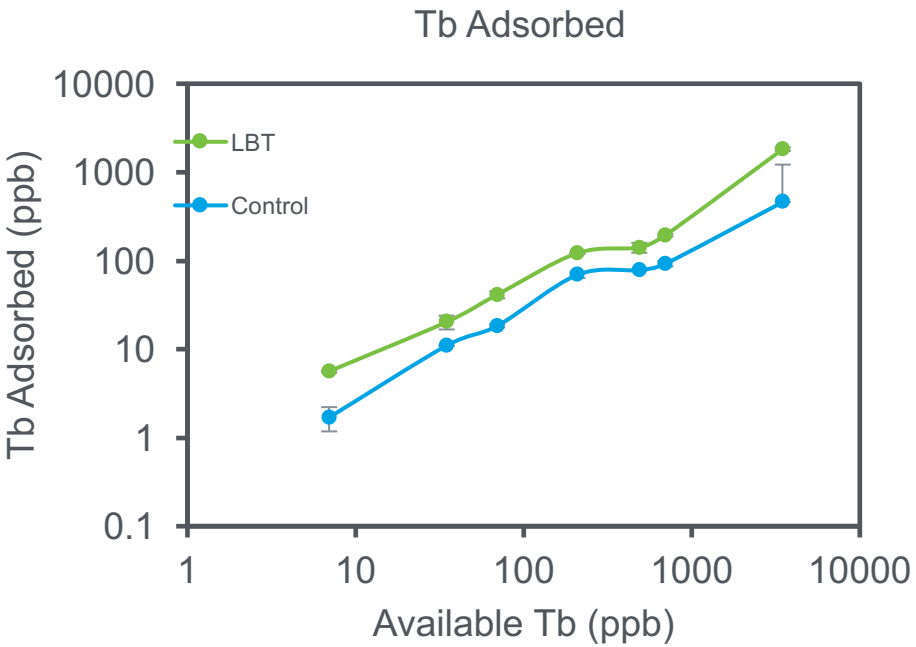
Miles tones	Proposed activity	Accomplishment	% completion
1.1	Brine characterization	Great Salt Lake REE solubility and speciation were modeled	100%
1.2 G/NG	REE adsorption and themo-stability	REE adsorption efficiency of 87% was achieved, with an increase with increasing temperature up to 70°C	100%
1.3	REE desorption	EDTA, citrate and oxalate acids were compared for desorption efficacy	100%
1.4	Reactor design consultation	An air lift bioreactor was designed	100%
1.5	Surface complexation model	A surface complexation model of *E. coli* was set up	100%
1.6	Techno-economic analysis (TEA)	TEA based on biosorption was calculated with economics compared among feedstock	100%

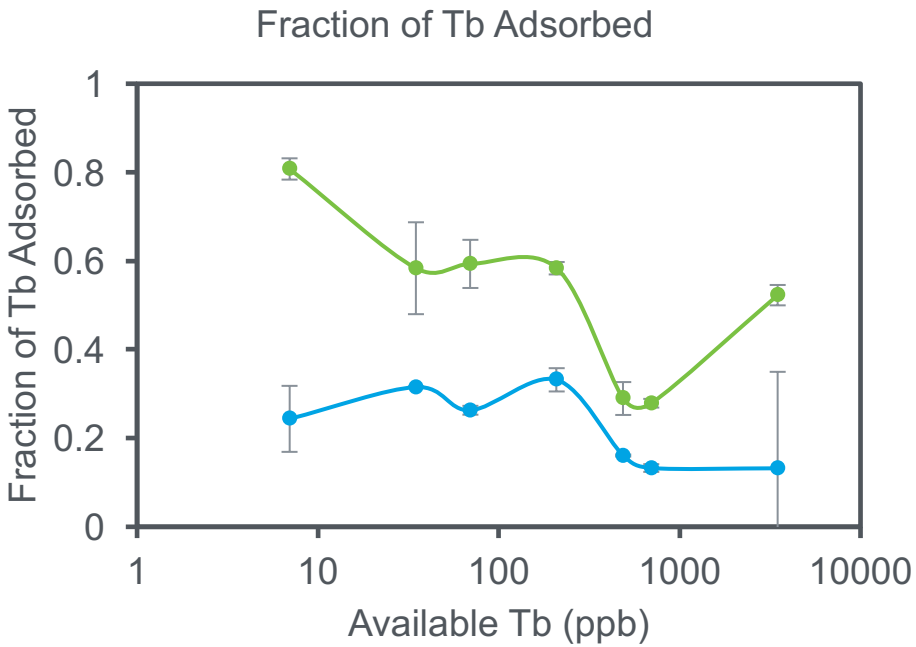
M1.1 Synthetic Great Salt Lake composition and REE speciation analysis and modeling

Simple brine	Concentration	Unit
Temperature	21	°C
pH	~6	
Na+	19000	ppm
Ca++	200	ppm
Mg++	100	ppm
K+	700	ppm
Ba++	20	ppm
Cl-	30600	ppm



M1.2 Comparison of rare earth biosorption by bioengineered and control strains



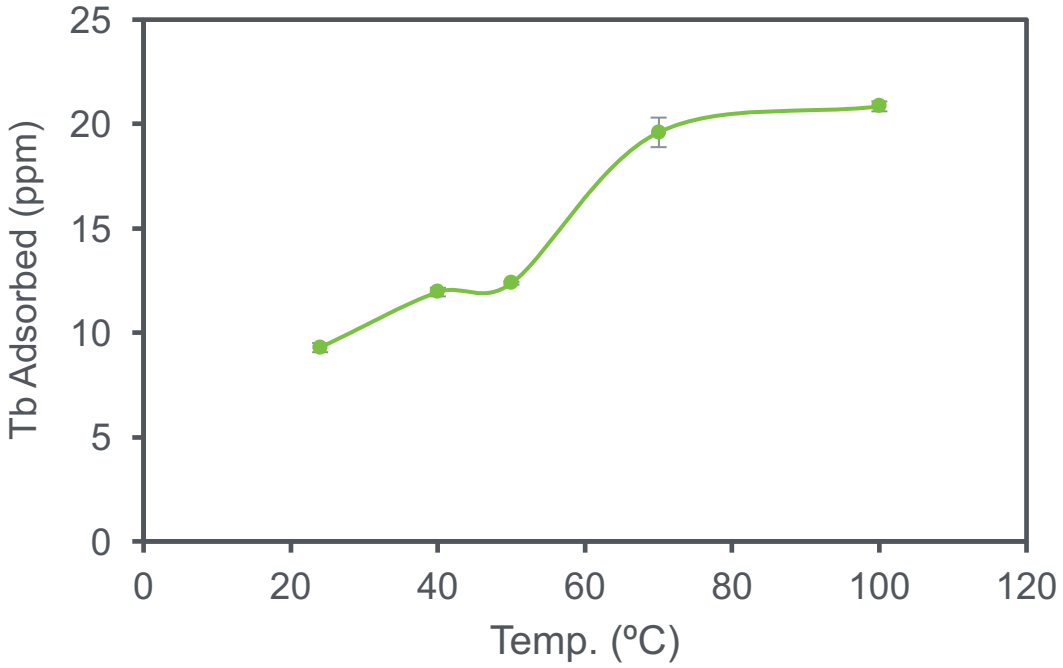


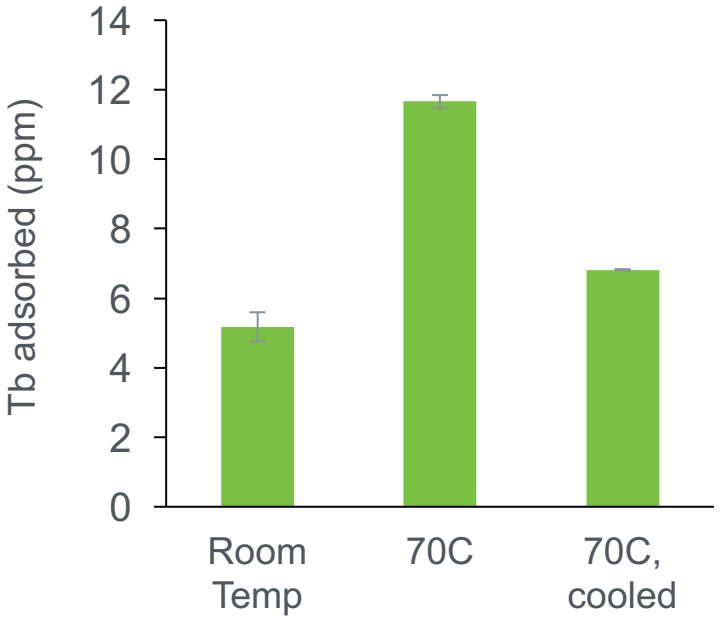
M1.2 Rare earth biosorption/desorption process significantly increases REE purity

Non-REEs	Initial (ppm)	Final (ppm)	% retained
Na	48761.4	31.0	0.1
K	3909.8	5.4	0.1
Mg	4909.6	1.3	0.0
Ca	320.6	0.3	0.1

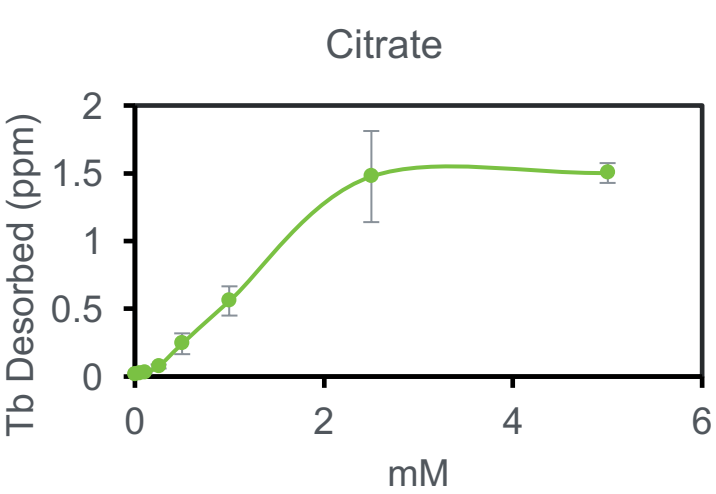
Tb initial (ppb)	Tb adsorbed (ppb)	Adsorption efficiency (%)	Initial Tb purity (%)	Final Tb purity (%)	Concentrating factor (fold)
10	8.7	0.87	1.7E-05	0.0	548
100	71.7	0.72	1.7E-04	0.1	764
1000	497.7	0.50	1.7E-03	0.7	419
5000	3338.0	0.67	8.6E-03	1.6	186

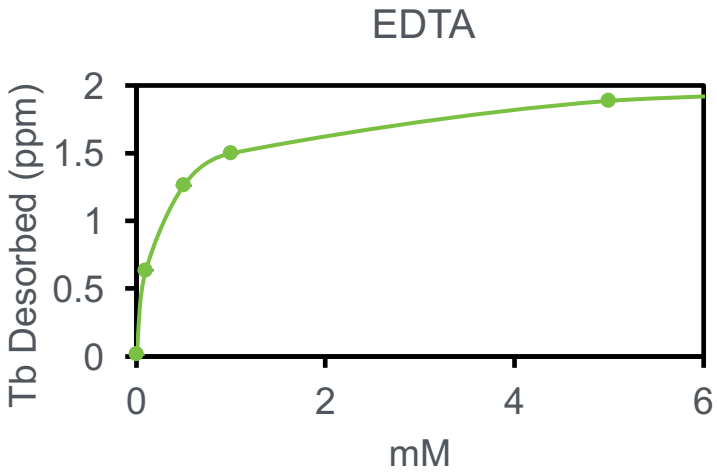
M1.2 REE adsorption capacity improves with increasing temperature up to 70ºC

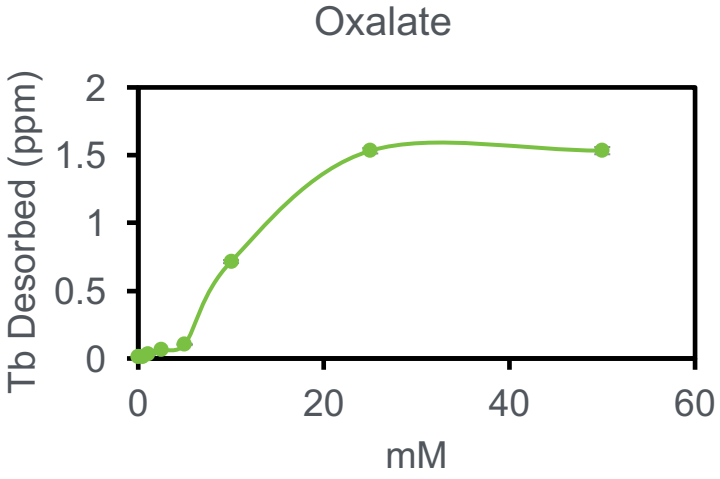




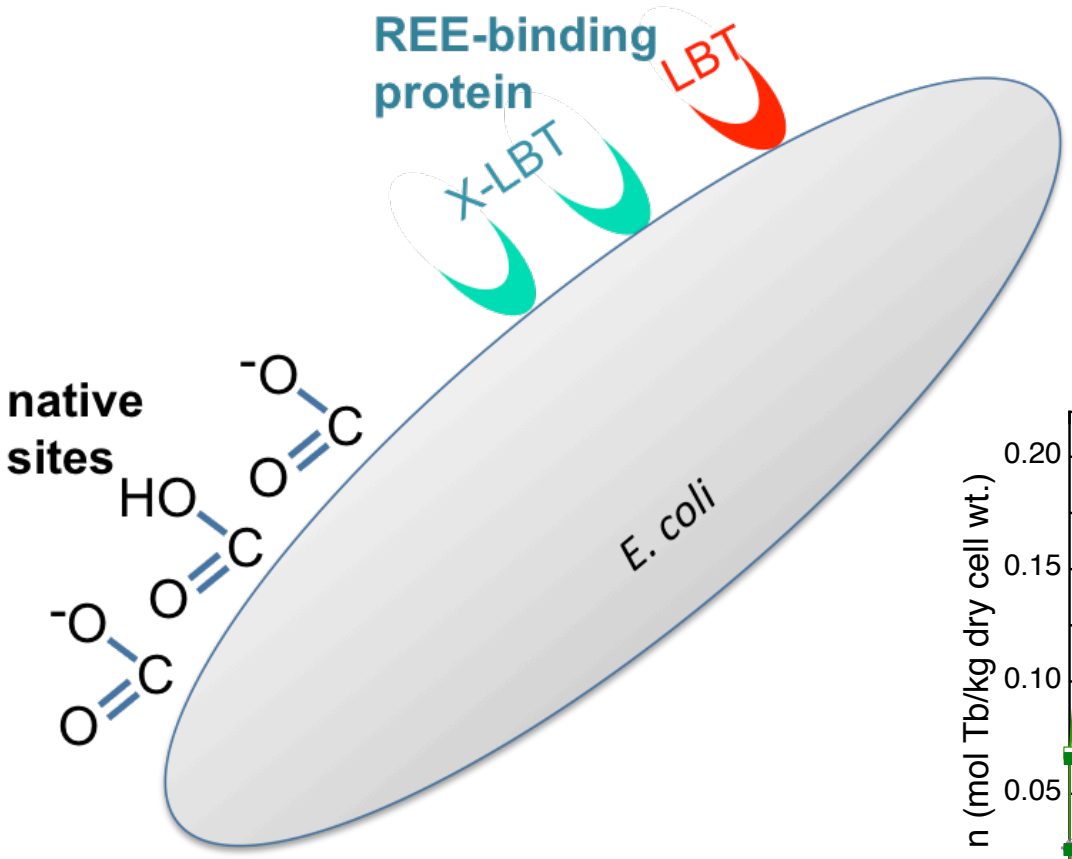
M1.3 Comparison of desorption efficiency with different chemicals methods







M1.5 Surface complexation model of REE-adsorption



REE complexation reactions

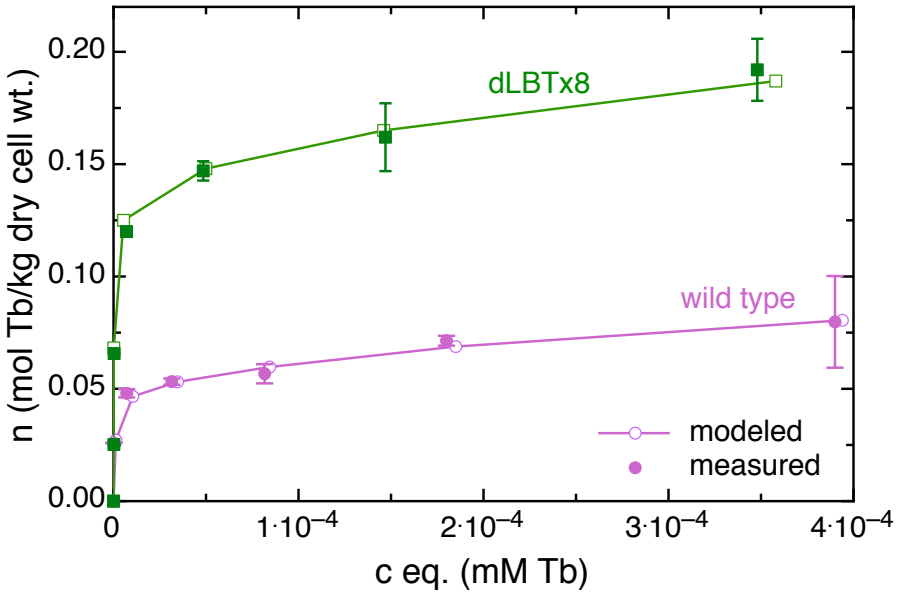
wild type

$>COOH + Tb^{3+} \rightarrow >COOTb^{2+} + H^{+}$

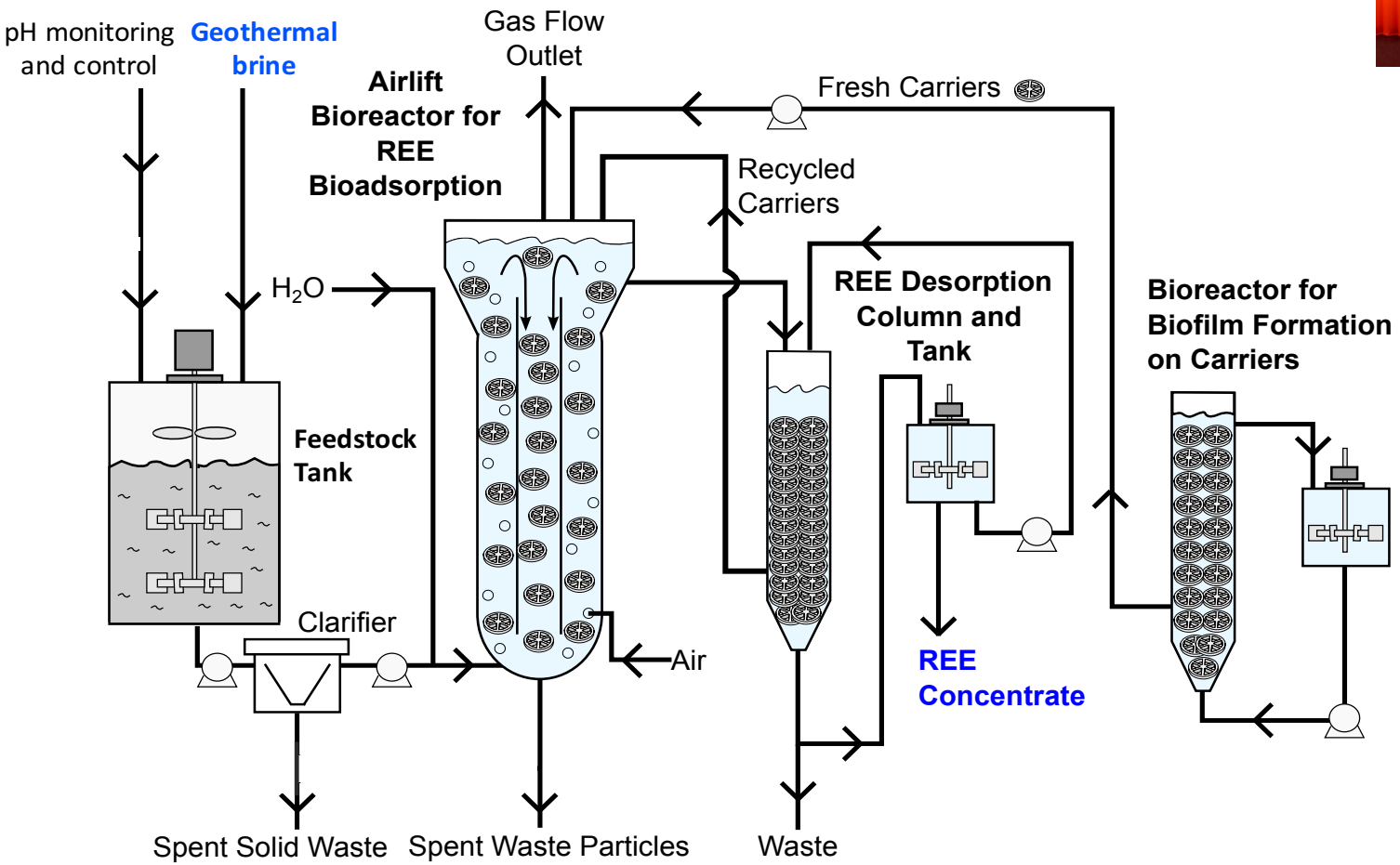
$>POH + Tb^{3+} \rightarrow >POTb^{2+} + H^{+}$

dLBTx8 (additional)

$>LBTOH^{-2} + Tb^{3+} \rightarrow >LBTOTb^{0} + H^{+}$



M1.4 Design of an airlift bioreactor for REE recovery

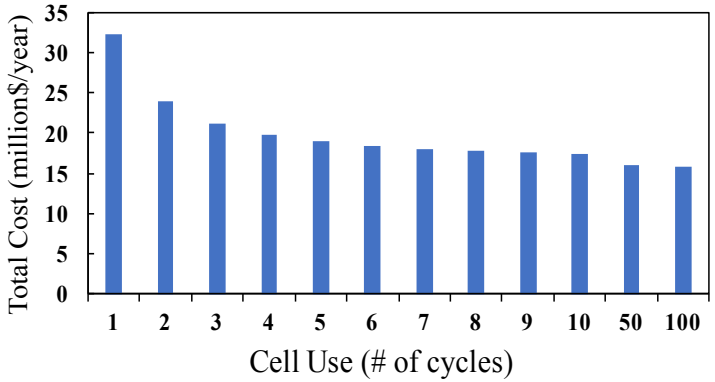


M1.6 Preliminary techno-economic analysis

Feedstock: 50 M tons/yr
REE content: 0.6-3.2 ppm

Processing Steps	Cost (M$)	Cost %
Pre-processing	0	0%
Biosorption	14.9	95%
Oxalic precipitation & Roasting	0.6	5%
Total	15.5	100%

- Geothermal brine benefits from low/no pretreatment cost and challenges are low REE content.
- Future REE price volatility could improve economics.



REE content (ppm)	0.6-3.2
Unit production cost ($/kg TREO)	132-582
Current TREO basket price ($/kg TREO)	17-22
TREO price increase required for break-even (x-times)	**8-27**

Research Collaboration and Technology Transfer

- Filed a U.S Patent application (#15400948, pending), entitled "Engineered Microbes for Rare Earth Element Adsorption"
- Collaborated with Dr. Laura Lammers at UC Berkeley for Surface Complexation Modeling of REE adsorption onto *E. coli*
- Obtained Great Salt Lake samples from INL
- Collaborated with Bioreactor Sciences for the design of an air-lift bioreactor for REE recovery
- Submitted a manuscript by Jin et al, "Techno-Economic Assessment for Integrating Biosorption into Rare Earth Recovery Process" to ACS Sustainable Chemistry and Engineering.
- Presented at the Stanford Geothermal Workshop (Stanford University, CA; 02/2017)
- Presented at the U.S. Department of Energy (DOE) California Energy Commission (CEC) and the Geothermal Resources Council forum on advancing geothermal energy (Sacramento, CA; 10/2016)
- Plan to test fluids from AltaRock Energy Blue Mountain plant in FY18.

Key activities in FY18

Immobilize cells on solid surface and characterize REE extraction under flow:

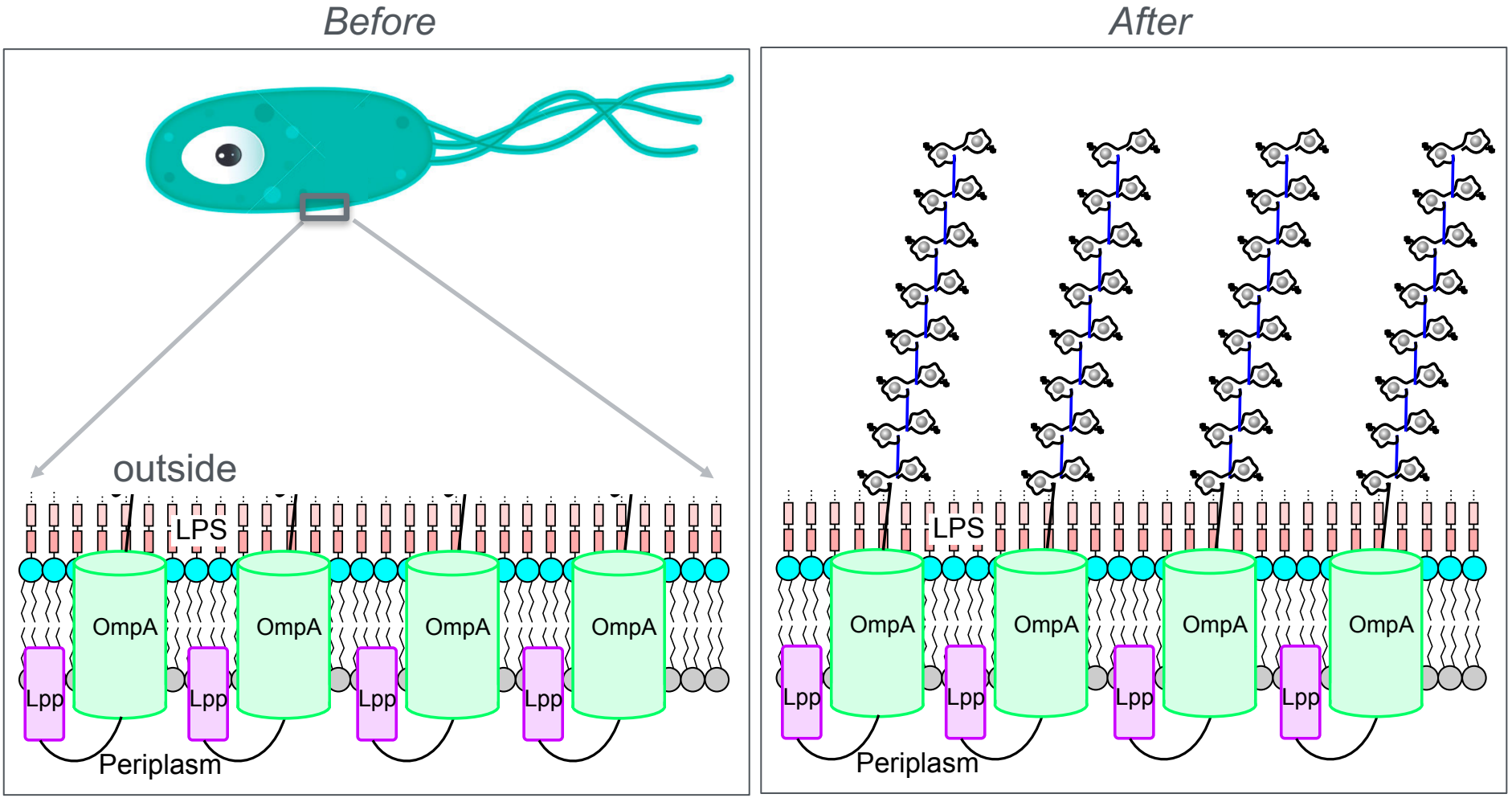
- Achieve robust biofilm formation on solid substrates (glass and plastic)
- Test biofilm thermo-stability
- Characterize REE adsorption and desorption under flow
- Build a reactive transport model

Milestone or Go/No-Go	Status & Expected Completion Date
Biofilm formation and thermo-stability	Milestone (3/18)
Demonstrate REE extraction efficiency of >90% and adsorption capacity more than 5 µmol per m^2 under continuous flow	Go/No-Go (9/18)
Add metal competition and flow to surface complexation model	Milestone (9/18)

Summary

- REE recovery from representative brine is feasible with 87% adsorption efficiency.
- Bioengineered strain outperforms the native strain by 2-3 fold in REE adsorption capacity.
- Bioengineered strain showed high selectivity toward REE with very little contaminating cations observed, yielding a REE concentrating factor up to ~750 fold.
- REE adsorption capacity increases with increasing temperature – condition well suited for geothermal fluids.
- Established a REE surface complexation model for *E. coli.*
- An air-lift bioreactor has been designed.
- Initial TEA analysis indicates that the REE price needs to be increased by 8-27 fold to break even.
- Demonstrates that biosorption using bioengineered microbes are effective at treating geothermal fluids and may be useful for other elements.

Methods/Approach



Display lanthanide binding tags on cell surface, with ~1,600,000 copies LBT / cell