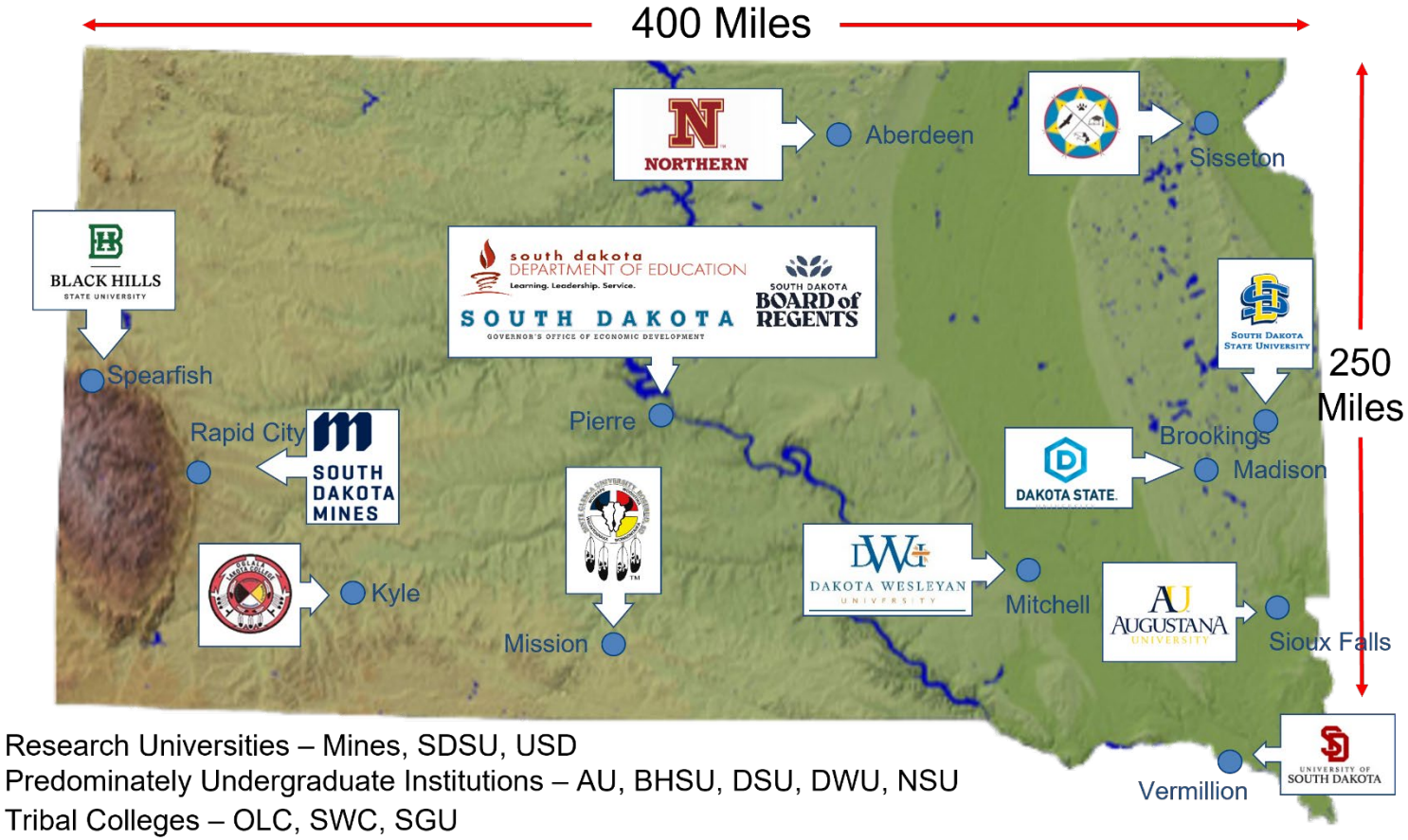
NSF EPSCoR Track-1: Beyond the 2020 Vision: Building Research, Education and Innovation Partnerships for South Dakota

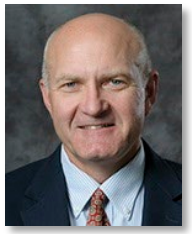
August 1, 2024
Research Symposium
Sioux Falls Convention Center
(OIA-1849206)

Participating Institutions



3 Research Universities – Mines, SDSU, USD
5 Predominately Undergraduate Institutions – AU, BHSU, DSU, DWU, NSU
3 Tribal Colleges – OLC, SWC, SGU

Leadership Team



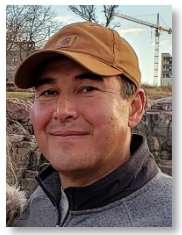
Mel Ustad (PI)
SD EPSCoR

Robb Winter
Research Lead
South Dakota Mines

Peter Hoesing
Dakota State University

Ramana Gadhamshetty
(Co-PI) Research Area 1
South Dakota Mines

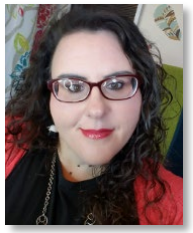
Sen Subramanian
(Co-PI) Research Area 2
South Dakota State University



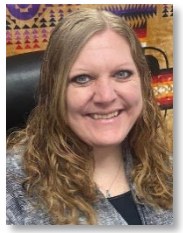
Mike Leneaugh
Sinte Gleska University

Carol Lushbough
(Co-PI) Research Area 3
University of South Dakota

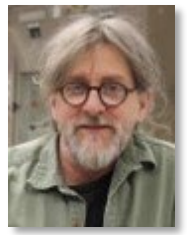
Ben Sayler
(Co-PI)
Black Hills State University



Dana Gehring
Oglala Lakota College



Kelsey Stadtler
Sisseton Wahpeton College



Jon Mitchell
Northern State University

Track-1 Project Overview

Research Focus — Biofilm/ 2D Materials/Big Data

- Thrust 1: Stress Resistant Biofilms
- Thrust 2: Microbial Resilient Biofilms
- Thrust 1-2: Biofilm Knowledge Information and Data Discovery System

STEM Education /Workforce Development

- Rural and Native Communities Focus
- Develop more Native Faculty

Economic Development

- Internships, Entrepreneurship, and Collaboration

2 Dimensional materials for Biofilm, Engineering, Science and Technology – 2D BEST

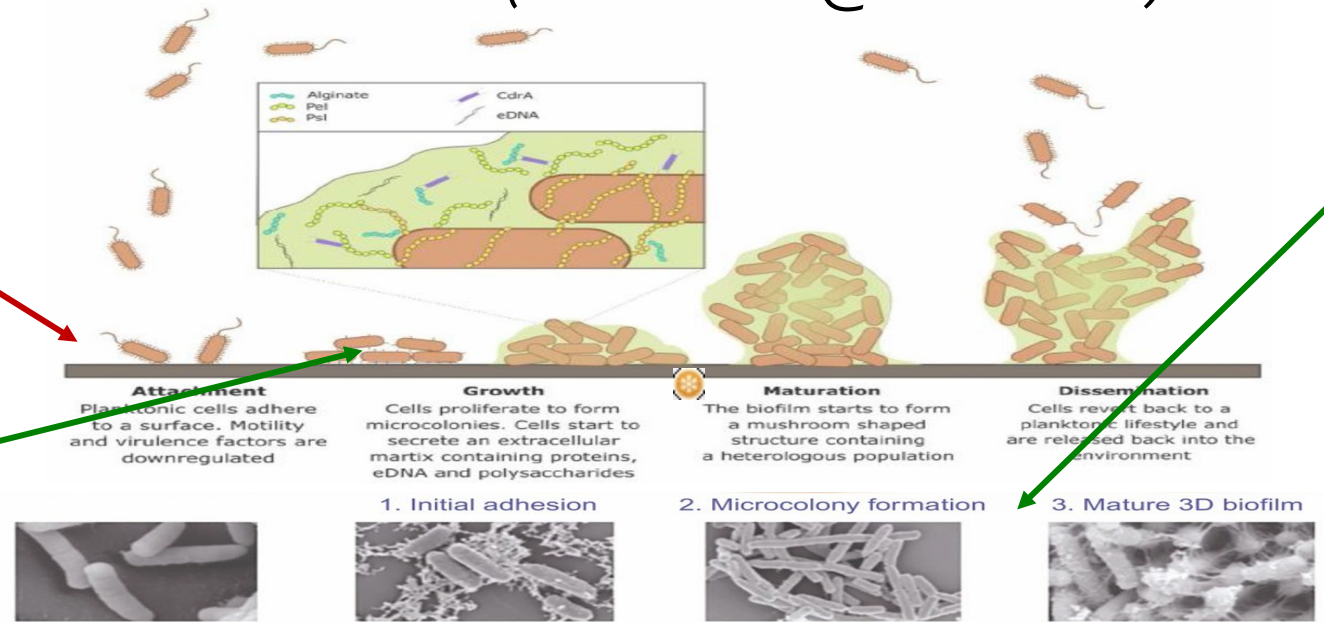
Robb Winter (robb.winter@sdsmt.edu)

Rationally designed 2D/nano surface properties

Chemistry
Engineering (AgE, ChE, EnvE, Met E)
Physics
Data Sciences

Bacterial 'omics'
Genome to Phenome

Biology
Life Sciences
EnvE, ChE
Data Sciences



Biofilm imaging

Biology
Engineering
Physics
Life Sciences
Data Sciences

Where are biofilms found?
Natural environment
Manufactured materials and systems
Living creatures (e.g. humans)
(can be beneficial or detrimental)

https://www.sciencedirect.com/topics/engineering/bacterial-biofilm
Maunders and Welch (2017) FEMS Microbiology Letters

Predictive Modeling & Big Data Discovery

S. Rauniyar

Area 1: R. Gadhamshetty, R. Sani, B. Jasthi, K. Benjamin, S. Dhiman, A. Lipatov, T. Walker
C. Lushbough, E. Gnimpieba, G. Sereda, Z. (J.) Gu, S. Subramanian, N. Butzin

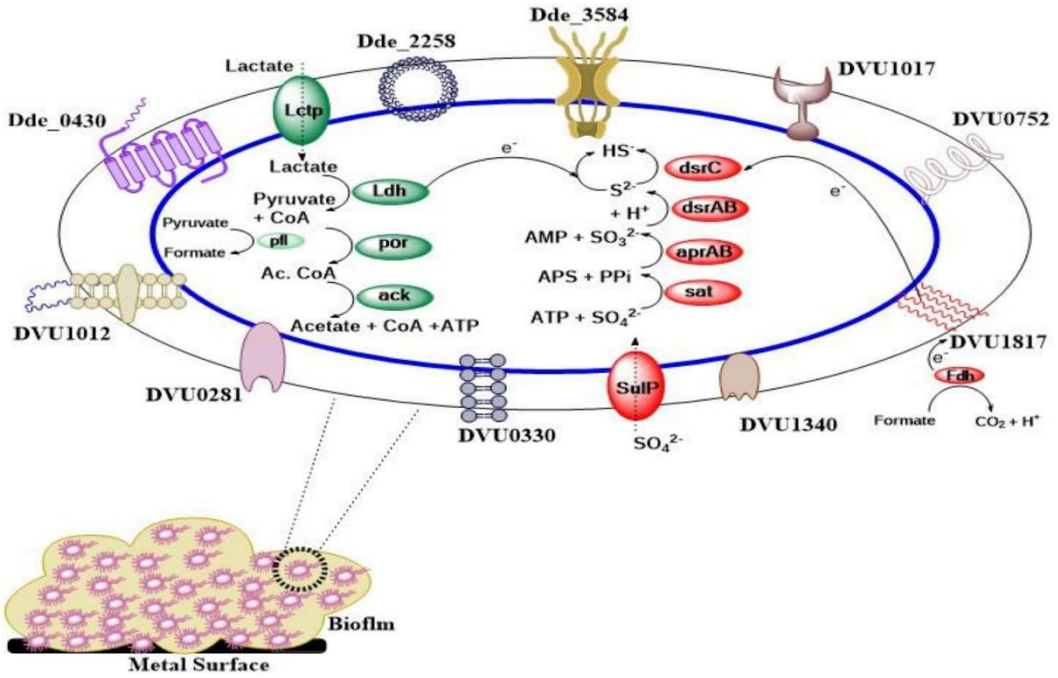
Fig. Pipeline Corrosion, Billion-dollar microbial corrosion issue, S. Simper, World Pipeline, Aug 2022.

Problem: Microbiologically influenced corrosion (MIC) causes significant challenges and economic loss in water, oil and gas metal infrastructure.

Solution/Goal: Understand genetic and biofilm phenotypic responses to 2D material; ultimately rationally design 2D materials to protect metal infrastructure from MIC

Addresses Engineering Grand Challenges of food, energy and water

Area 1 - Hypothesis



Tripathi, A.K.,Sani, R.K., et al., *Frontiers in microbiology*, p.3120.

Atomic-scale defects in 2D materials used to modify metal surfaces will provoke molecular mechanisms that induce stress resistance, biocorrosion, and microbe communication in sulfate reducing biofilms.

Approach: Oleidesulfovibrio alaskensis G20 (OA-G20) as sulfate reducing bacteria (SRB); Technologically Relevant Materials: Copper (Cu) and Nickel (Ni); 2D coatings: graphene (Gr) and hexagonal boron nitride (hBN); CVD: Chemical vapor deposition; PLD: Pulse laser deposition

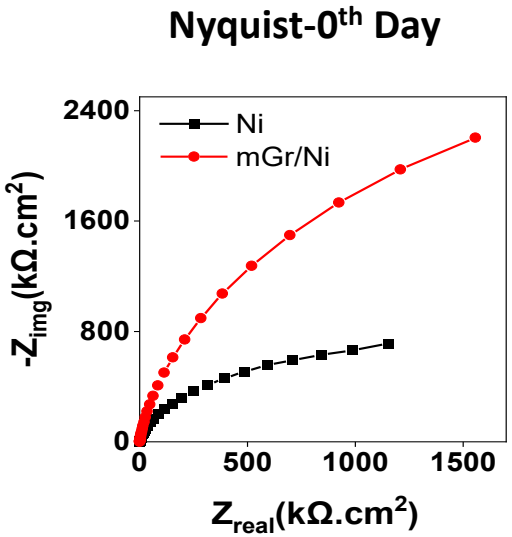
Area 1 - Approach

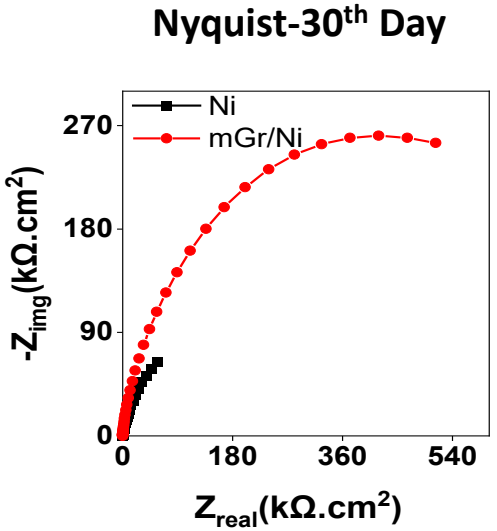
1) Determine the genes and metabolic networks that govern biofilms in response to changes in atomic-scale features (point defects and grain boundaries) and the corresponding barrier and galvanic properties of 2D coatings;
2) Match each parameter to molecular markers and biofilm phenotypes (stress resistance, extracellular electron transfer capabilities, corrosion ability; adhesion, morphology and structure); and
3) Apply new mechanistic knowledge to design and create a new class of 2D materials to block microbial influenced corrosion.

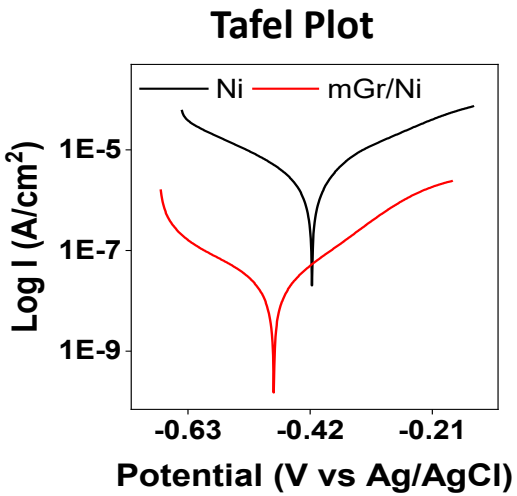
Highlight: Task 1.1.3 Tune barrier properties to influence the phenotypical and genotypical response of underlying substrates exposed to OA-G20 and axenic cultures

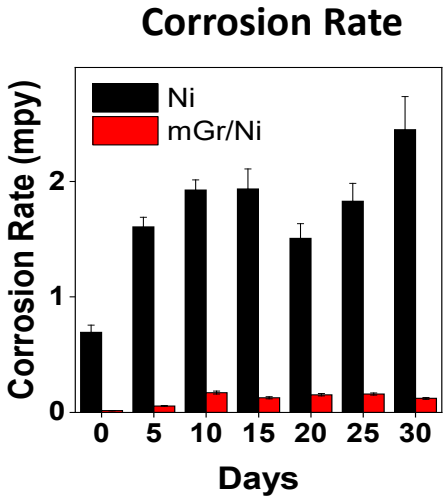
- Task significance: Design a tunable 2D graphene surfaces for controlling phenotypical responses of OA-G20
- Hypothesis/Expectation: 2D coatings can be used to control genotypical and phenotypical (adherence state, corrosion and bifouling resistance) and responses
  - multi-layered graphene (mGr) on polycrystalline (PC)-Nickel (Ni) tested with pure *Oleidesulfovibrio Alaskensis* (OA-G20) (60 days) and field conditions (30 days)

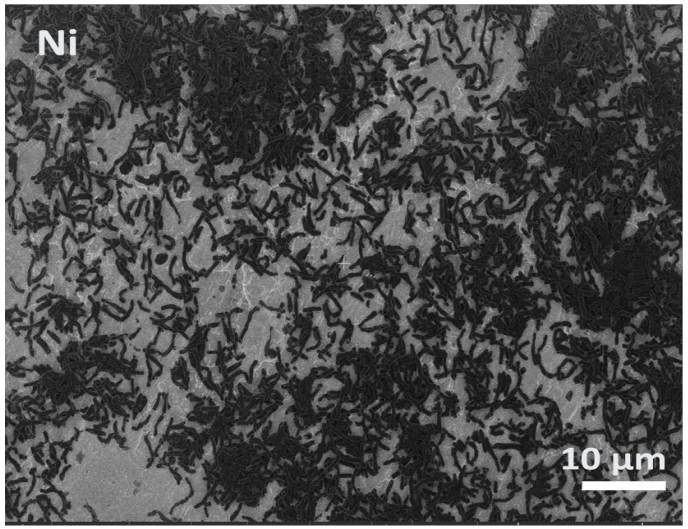
mGr/PC-Ni: Corrosion (left panel) and fouling resistance (right panel)

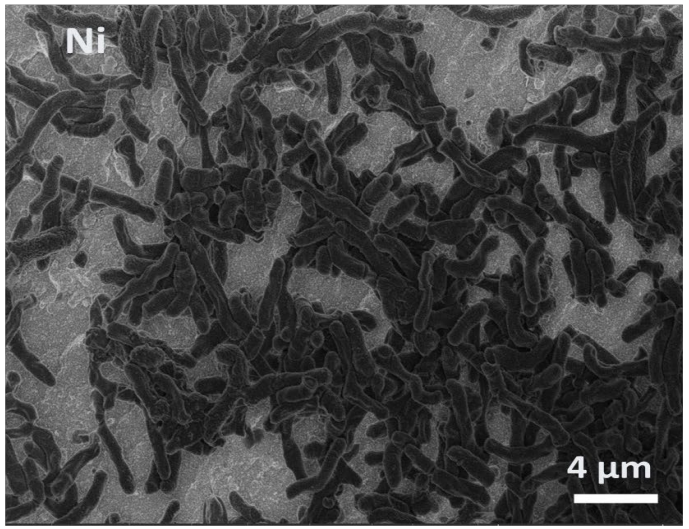


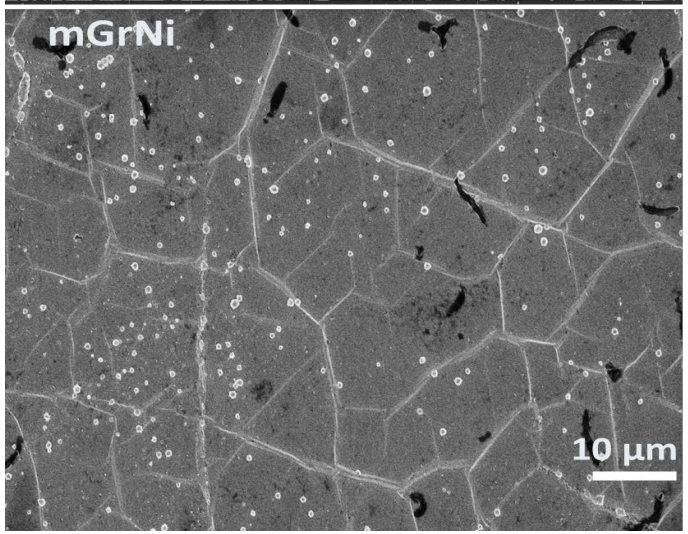


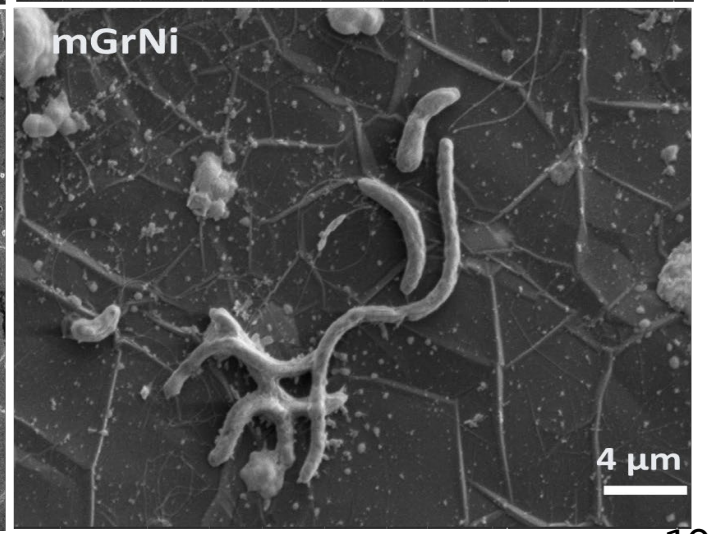




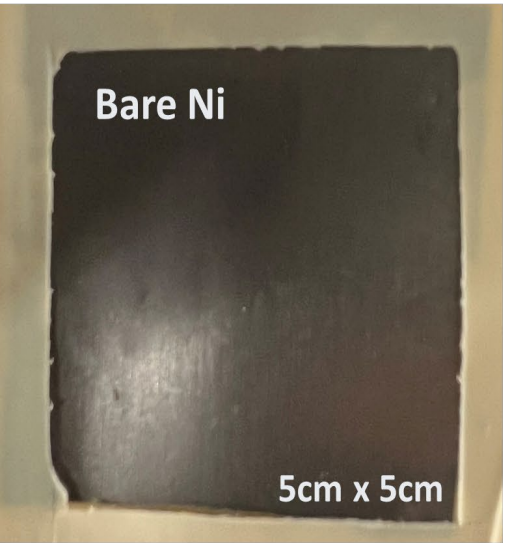


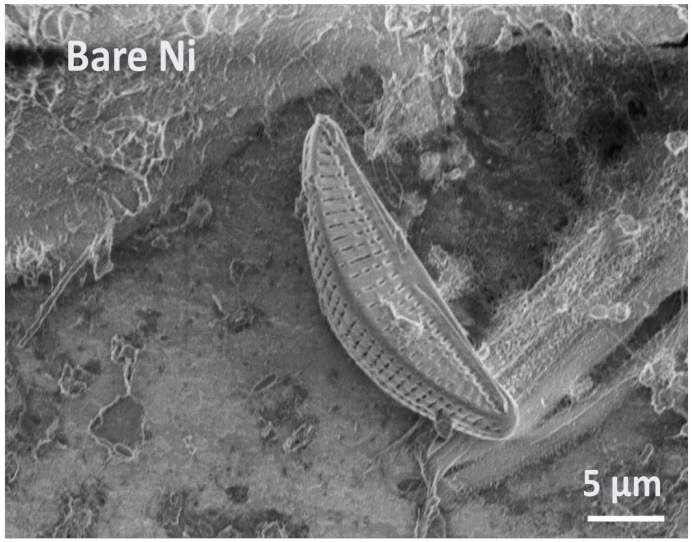


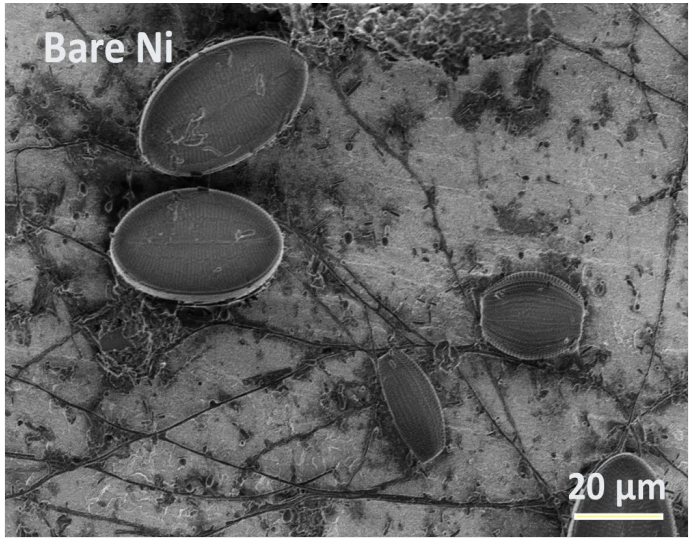


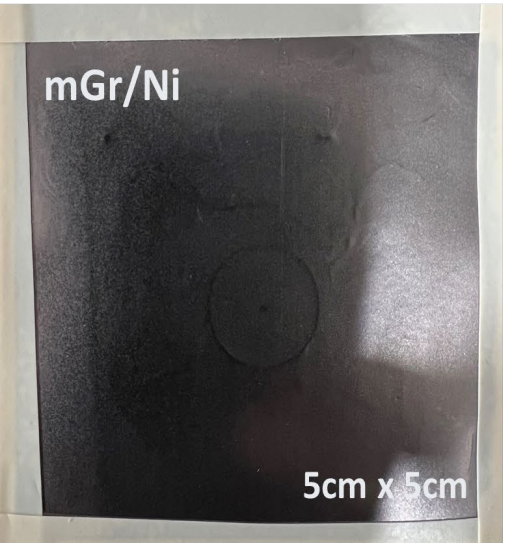


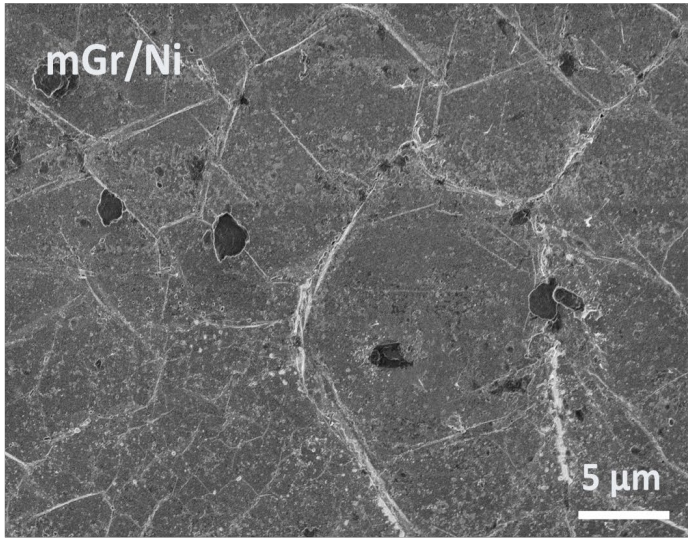
Can mGr/Ni offer fouling resistance under field conditions?

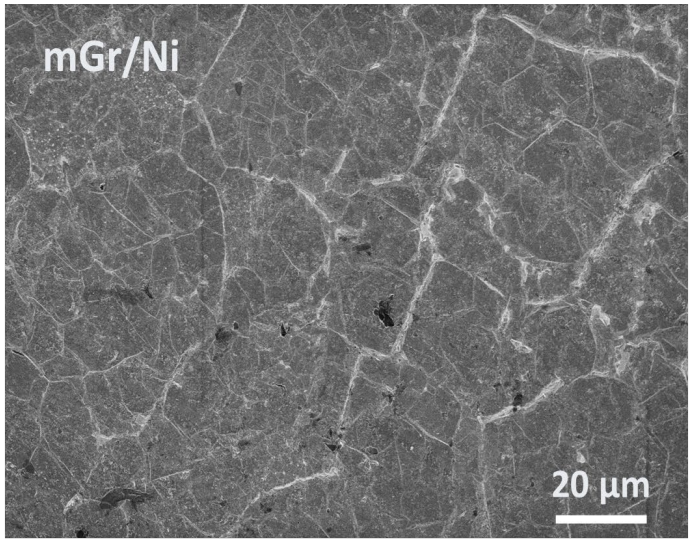






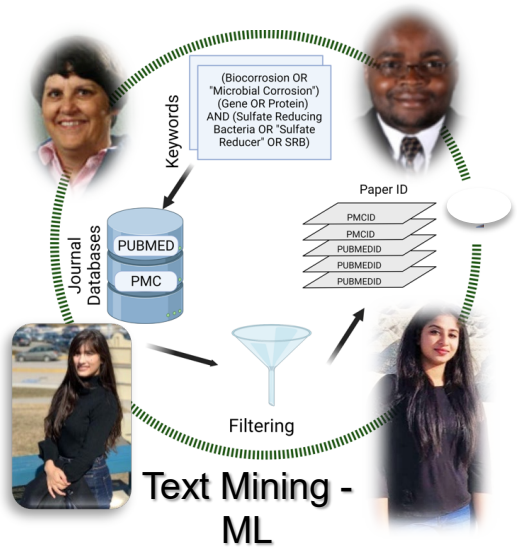






- Freshwater reservoir; 30 days exposure
- mGr/Ni discouraged adherence state of prokaryotes and eukaryotes
- Ongoing studies to validate the role of pseudomagnetic effect (40-100 Tesla)
- Future studies to broaden the applicability and expand the scalability

Highlight: Task 4.3.2-1a Elucidate molecular mechanisms involved in SRB biofilm formation



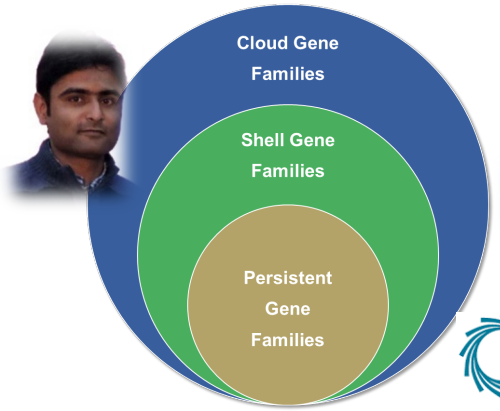
Text Mining - ML

"Rules of Life" in SRB biofilms

OMICS

- Transcriptomics ATLAS
- Epigenomics
- Phenomics
- Regulome (non-coding RNAs)

- Genes and Gene Families
- Gene Clusters
- Presence/Absence Matrix
- Rarefaction Curves
- Gene Ontology
- Pathways and Enzymes
- Protein Interactions; E.g., Network Analysis of Exact Core genome
- Phylogenetic Analysis

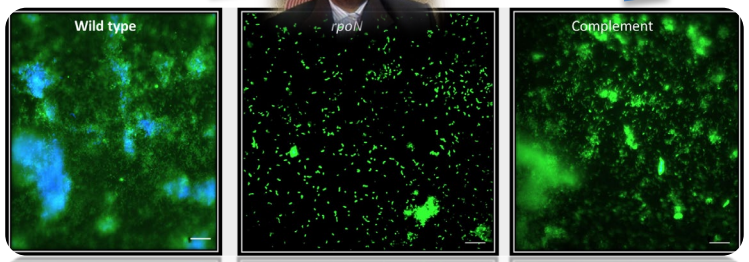


Pangenome

JSR Life Sciences

Oxford NANOPORE Technologies

Validation

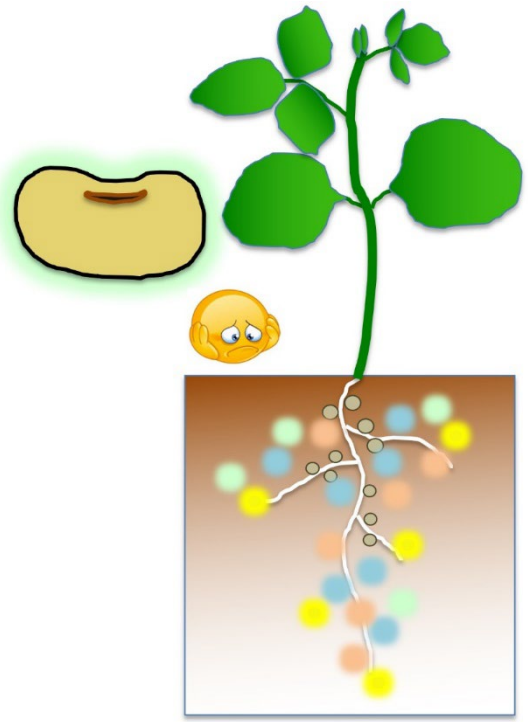


Wild-type | Mutant | Complement

- **Discoveries and Impacts:**
  - Insights about hypothetical proteins, New functions
  - Why SRB are SRB?
- **Publications: 5 (9 under Prep)**
- **Several new hypotheses for proposals**
- **2 PhD transition to employment**

NUPROBE

Area 2: S. Subramanian, Z. (J.) Gu, V. Brozel, N. Butzin, J. Gonzalez, M. Sher, R. Gadhamshetty, R. Sani, S. Dhiman, K. Benjamin, E. Gnimpieba, C. Lushbough, G. Sereda

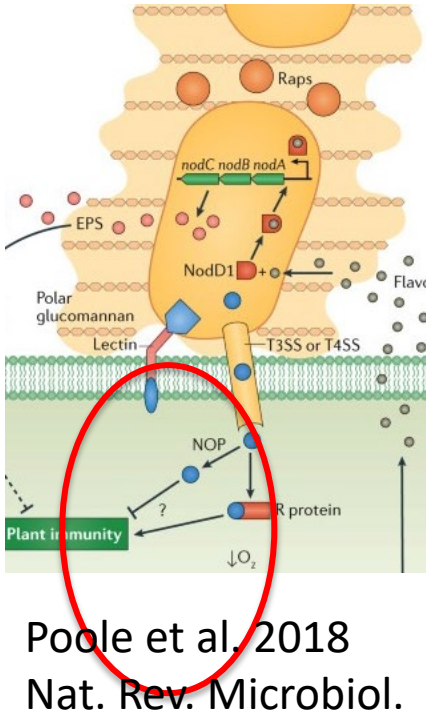


Problem: Poor competitiveness (low resilience) of high efficiency nitrogen fixing bacteria in occupying root nodules leads to less-than-optimal nitrogen fixation in soybean

Solution/Goal: To increase soybean root nodule occupancy by high efficiency rhizobia, enhancing microbial resilience

Addresses Engineering Grand Challenges of food, energy and water

Area 2 – Hypotheses and *Approach*



Poole et al. 2018
Nat. Rev. Microbiol.

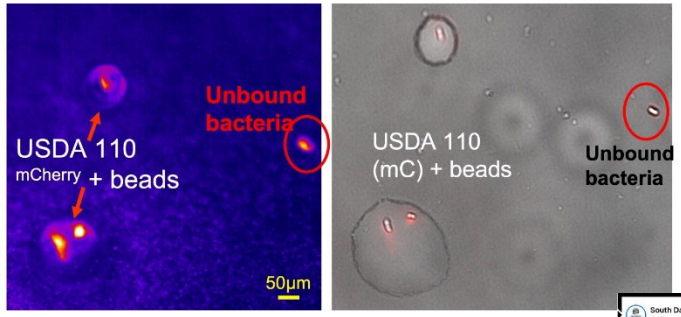
- Designer lectins (attachment proteins) with higher specificity to desirable (high nitrogen fixing) bacteria will enhance their root attachment, nodule occupancy and thus increase nitrogen fixation capacity
- Increased attachment will elicit the activation of distinct bacterial and plant pathways associated with biofilm resilience against competition

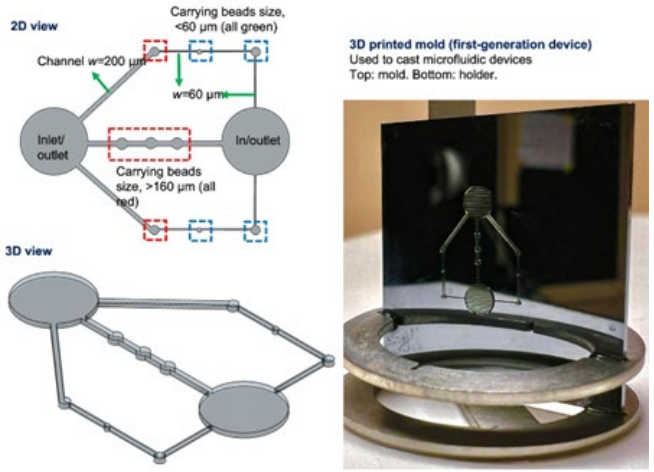
1) *use rational protein engineering to design lectins with better specificity,*
2) *decorate soybean root surface with these lectins using 2D material technology, evaluate root attachment using microfluidics enhanced microscopy,*
3) *determine key plant and bacterial pathways using omics analyses and use the resulting knowledge to develop strategies to enhance nodule occupancy by desirable rhizobia.*

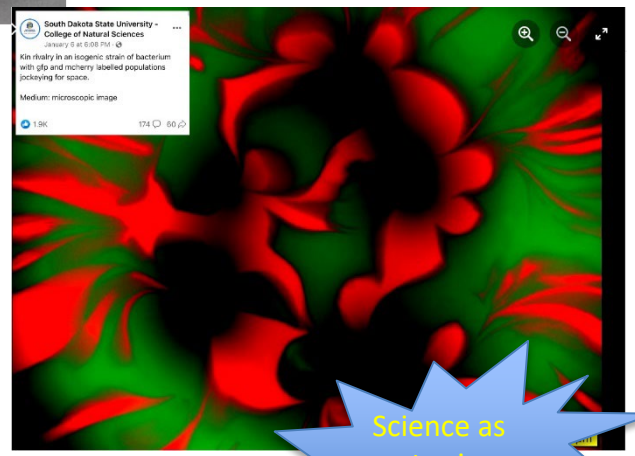
Highlight: Task 4.3.4-5 Design microfluidic chambers for root microbe imaging

- Task significance: Ability to image dynamic binding of *Bradyrhizobium* cells to lectin under competitive environment will help determine the role in selective binding and enrichment of desirable strains
- Hypothesis/Expectation: Selected lectins will promote resilient attachment and propagation of desirable *Bradyrhizobium* strains
  - Design a microfluidic device to evaluate attachment and propagation under competition

Live imaging attachment of Bradyrhizobium^{mCherry} to lectin-coated beads







Science as art prize winner

- Microfluidic device development (invention disclosure)
- Microscopic analysis optimized: ~2 weeks to image
- In-house image processing software to easily extract quantitative data from microscopic images
- *Bradyrhizobium* mCherry, GFP, YFP and mTurquoise strains available
- CFDA-SE Dye-set for multiple strains (no need for transformation)

Big Data Approaches to Knowledge Discovery

C. Lushbough, E. Gnimpieba
in collaboration with Area 1 and Area 2 researchers

Goals

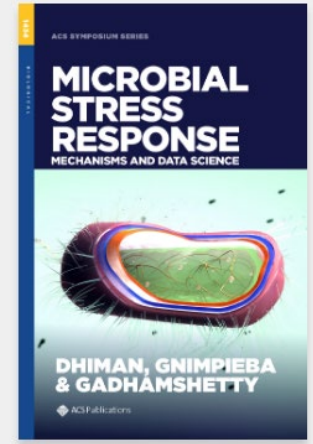
1. Develop the **Biofilm**s **K**nowledge and **I**nformation **D**iscovery **S**ystem (**Biofilm-KIDS**) to assist researchers in screening for 2D materials that withstand corrosive effects of SRB biofilms (Area 1).

   Biofilm-KIDS leverages project data and existing datasets and data mining frameworks (e.g. Material Genome Initiative-NanoMine) to develop a toolkit to predict gene-of-interest selection scores based on surface properties of 2D materials.

   Biofilm-KIDS uses Natural Language Processing, machine learning, and an AI algorithm annotation system to promote the accessibility

2. Apply data mining and machine learning approaches to predict 2D material functions, biofilm phenotypes, and bio corrosion resistance in response to surface properties (Area 1).

3. Develop an infrastructure to assist in the correlation of gene expression patterns between specific plant pathways (that enhance efficient nitrogen fixing bacteria colonization) and specific microbial pathways (Area 2).



Microbial Stress Response: Mechanisms and Data Science

Editor(s): Saurabh Sudha Dhiman[1], Etienne Z. Gnimpieba[2] and Venkataramana Gadhamshetty[3]

Volume 1434

Publication Date (Web): January 12, 2023

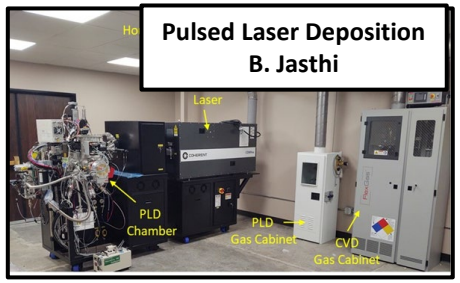
Research Output Summary

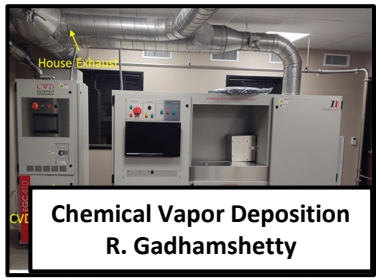
- 158 ($164 MM) Proposal, 127 Publications, 24 Books, Data sets, Software, 4 Disclosures/Patents
- External Collaborations: U of MN, Boise St U, U of NE-Lincoln, U of NE-Omaha, U of NV-Las Vegas, MT St U, U of OK, ITQB-Portugal, Max Planck Inst., PHA4GE, 5 International Biofilm Centers
- UG/G/c – 68/99, Graduations – 86, remainder in the pipeline; Post Docs – 20, 11 permanent employment
- Collaborated with Education Team to develop K-12 biofilm teaching modules
- Proposal submissions to: AEESP, AFCEC, Austin Eng., DOE, NASA, NIH, NSF, NASA, OSMRE, SD GOED, various SD crop councils, USDA
- 54 extramural grant awards ($32 MM); 30 proposals pending ($58 MM)

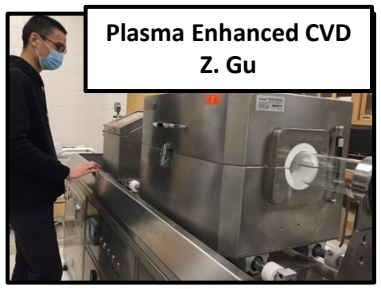
- **PENDING: NSF Gen-4, Bio-IGNITE** (mIcroBiome engineering by IntelliGeNt lIvIng maTErials) Eng. Res. Ctr. ($26MM/5yr, renewable) (SD, ND, NE, NV, MT) - OLC, BHSU, DSU, SD Mines, USD, SDSU, UNO, UNLV, MSU
  - Rational Engineering of Microbiomes to address key societal needs - Data Science – Digital Twin, Fouling resistant microbiomes, Soil nutrient enrichment microbiomes; Leveraging EPSCoR T1 and T2 grants

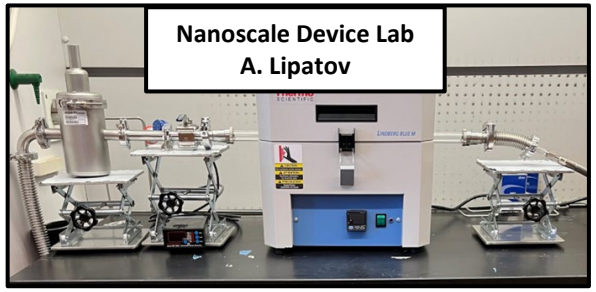
Major Research Tools Acquisitions

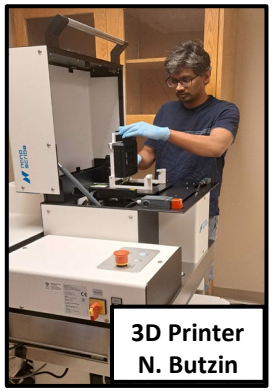
Materials



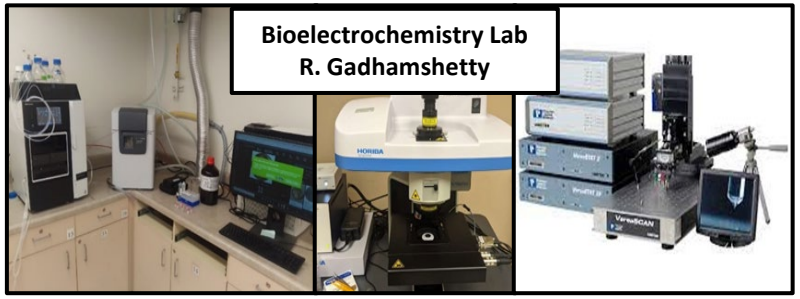


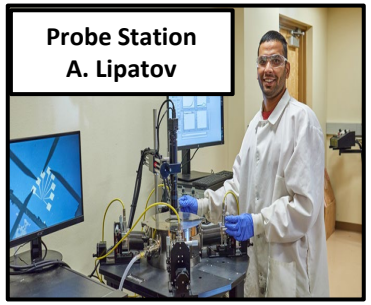


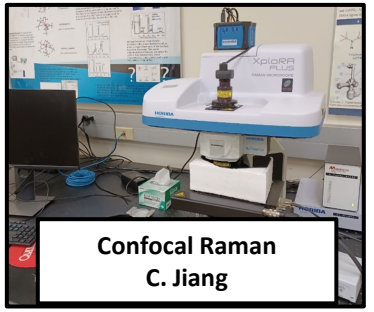


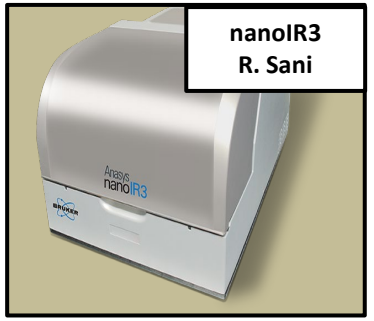


Analysis

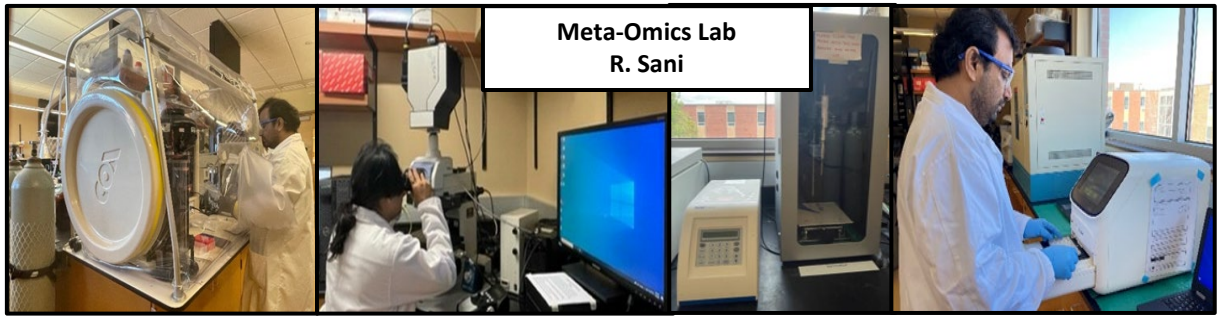


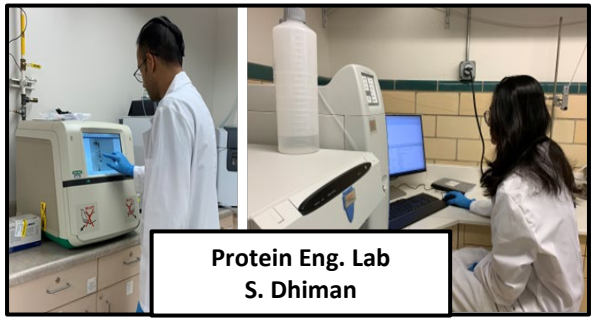






Omics





Education & Outreach

Primary Goals

- Support K-12 teachers of science, especially within rural and tribal communities
- Support students' transition from high school to post-secondary in STEM

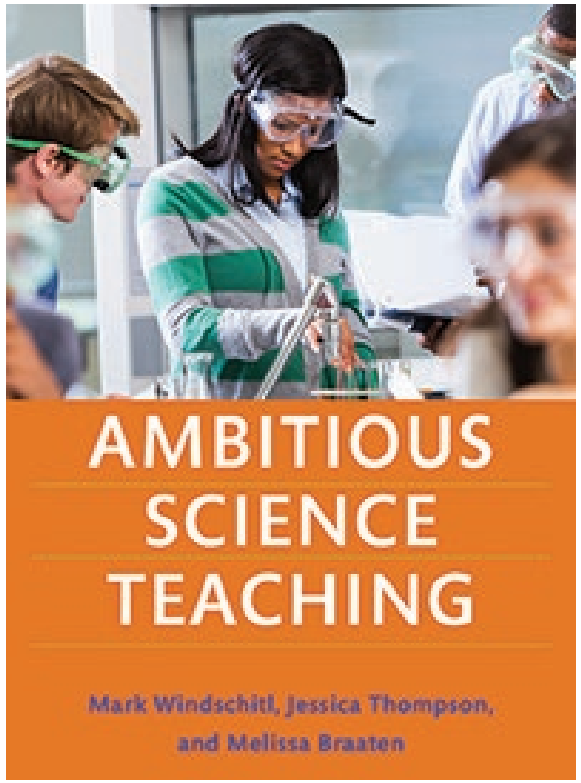
Key Activities

- Development of Biofilm-related curriculum modules
- K-12 teacher workshops that showcase the curriculum modules
- Education research on the impact of teacher supports
- Bridge programs at Oglala Lakota College, Sinte Gleska, & Sisseton Wahpeton

Teacher Workshops

- Created three 15-hour courses (1 graduate credit each)
- Typically offered in 3-day format during summers, but also offered options during academic year
- Entirely virtual in Years 1 and 2 due to pandemic
- Mix of virtual and face-to-face in Years 3, 4, and 5
- Offered to undergraduate teacher education majors
- Facilitated with support from K-12 teacher leaders

Ambitious Science Teaching



- Figuring out vs. learning about
- Carrying out investigations
- Strengthening science identity
- Supporting arguments with evidence
- Science & Engineering Practices
- Cross-cutting concepts (e.g., patterns, cause & effect, systems)

Curriculum Modules

- Elementary Unit #1: Pond Scum
- Elementary Unit #2: What's in My Water Bottle?
- Middle School Unit #1: Stuck Like Glue — Stuck On You
- Middle School Unit #2: Dead Zones
- High School Unit #1: Water Quality
- High School Unit #2: Biofilms in the Human Body

Teacher Participation

Courses	
Fundamentals of Effective Science Instruction	297
Student Discourse and Sense-Making	139
Making Student Thinking Visible	96
Curriculum Unit Explorations	66
Teacher Leader Capacity-building	32
TOTAL	**633**

Education Research

- Led by School of Education faculty at University of South Dakota.
- Graduate courses were successful in building teachers' confidence in teaching science, increasing familiarity with effective teaching practices, and building community.
- Face-to-face and virtual formats were similarly effective.

Bridge Programs

- Opportunities for high school students and first-year undergraduates to earn college credit in the summer.
- Intensive field and laboratory components
- Primarily focused on environmental science
- Culturally relevant and responsive

Foundation for New E-CORE from NSF

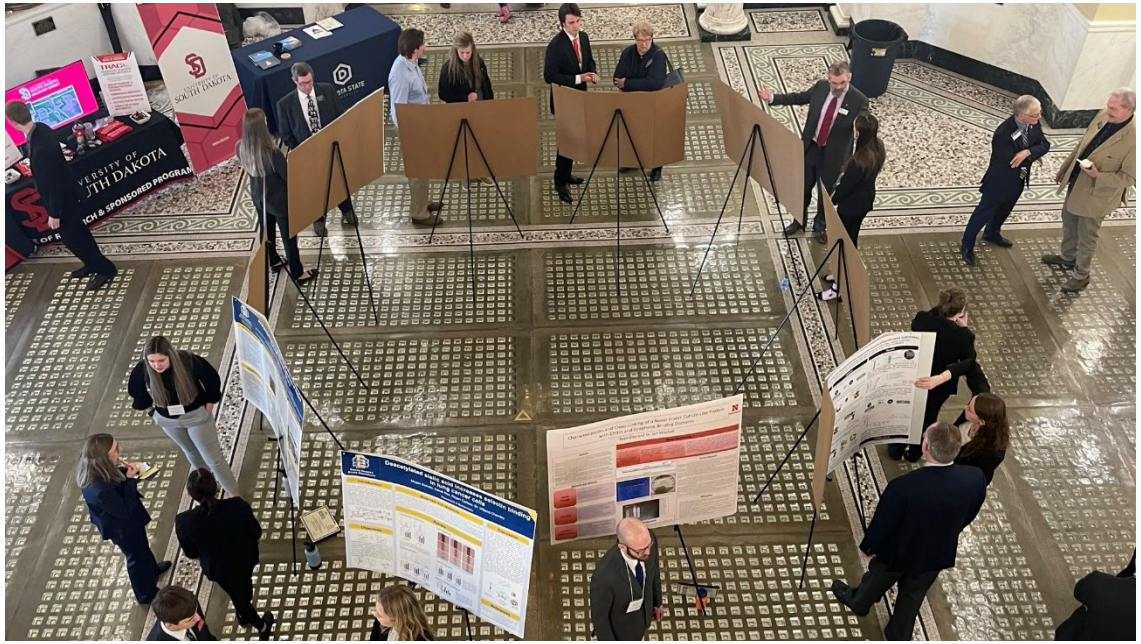
- Development of K-12 teacher leaders in STEM
- Broad-based teacher professional development and support of pre-service teacher preparation
- Education Research
- Summer bridge programs within tribal communities

Undergraduate Research

Undergraduate Researchers

Institution	Undergraduate Participants
Augustana	32
BHSU	27
DSU	37
DWU	19
NSU	13
OLC	16
SGU	9
SWC	0
SDM	17
SDSU	32
USD	26
Total	228

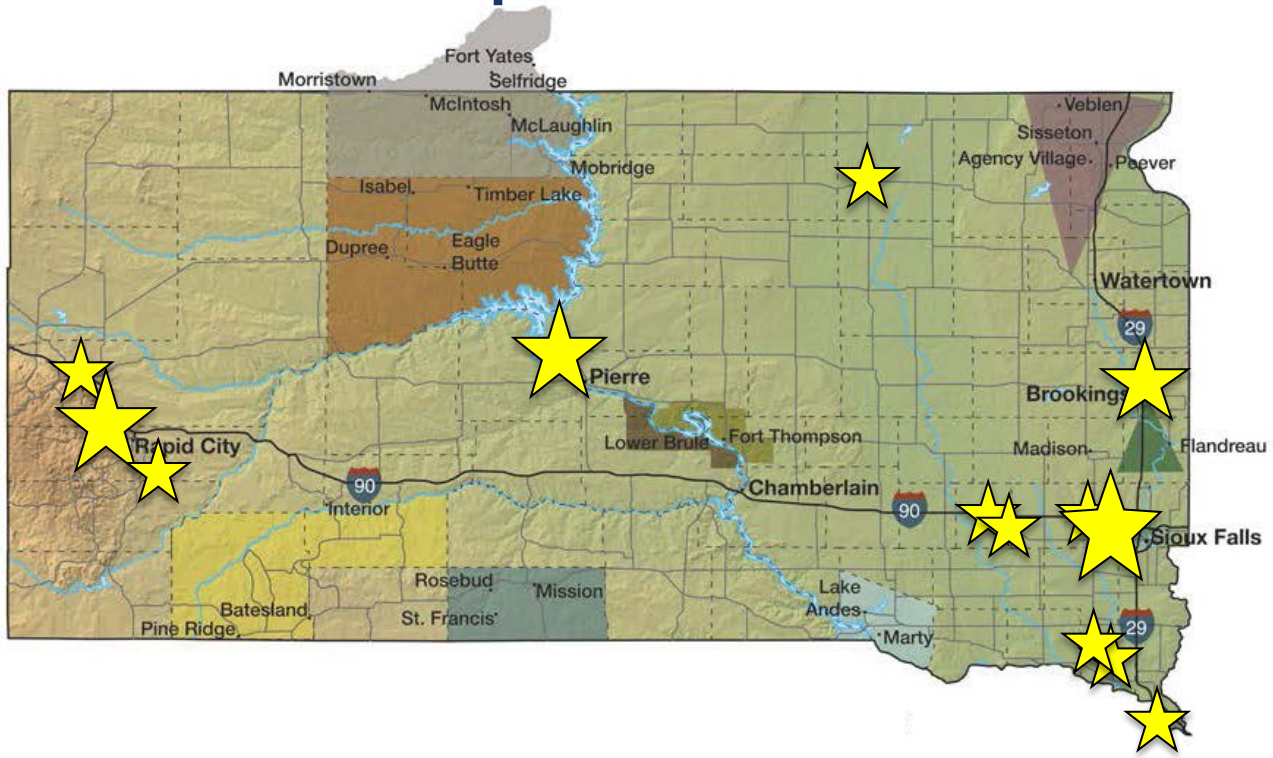
Pierre Poster Session



Student researchers shared their research work with lawmakers and the public at the 2023 Student Research Poster Session on Feb. 7, 2023, in the State Capitol Rotunda in Pierre, South Dakota.

Dakota Seeds Internships

Internship Locations



Dakota Seeds Outcomes

- Cumulative 504 internships approved at 107 companies.
- Thirty percent of interns accept full-time positions with companies they interned with after graduation.

Giant Vision Business Plan Competition

- 2022 AMBER, LLC – Maryam Amouamouha, Track-1 Graduate Student
  - 2021 Student Winner
  - 2022 Business Winner
  - NSF I-Corps Awardee
- 2022 DISAPPEX – Whytneigh Duffie, Track-1 Graduate Student
  - 2022 Student Winner
  - NSF I-Corps Awardee

Whytneigh Duffie *(left)* and Maryam Amouamouha *(right)* receive awards from the Governor's Office of Economic Development Commissioner Steve Westra

Elisha Yellow Thunder Success

- 2020-22 Elisha Yellow Thunder graduated from Oglala Lakota College and assisted with the Summer Institute
- Continuing PhD work at SDSU
- Faculty position at United Tribes Technical College (Bismarck, ND)

Elisha Yellow Thunder Presents Research Poster to Sen. Peri Pourier During Poster Session in March 2022 at the State Capital.

THANK YOU!

Over the past five years, SD EPSCoR has had

- **More than 500 active participants**
- **250 publications and presentations**
- **Over 100 external proposals**