

MONTANA UNIVERSITY SYSTEM RESEARCH INITIATIVE

Recovery of Metal Contaminants from Industrial Wastewaters with Magnetic NanoComposites in a Novel Continuous Flow Process System

Jerome Downey, Professor, Montana Tech Department of Metallurgical and Materials Engineering

Edward Rosenberg, Professor, The University of Montana Department of Chemistry & Biochemistry

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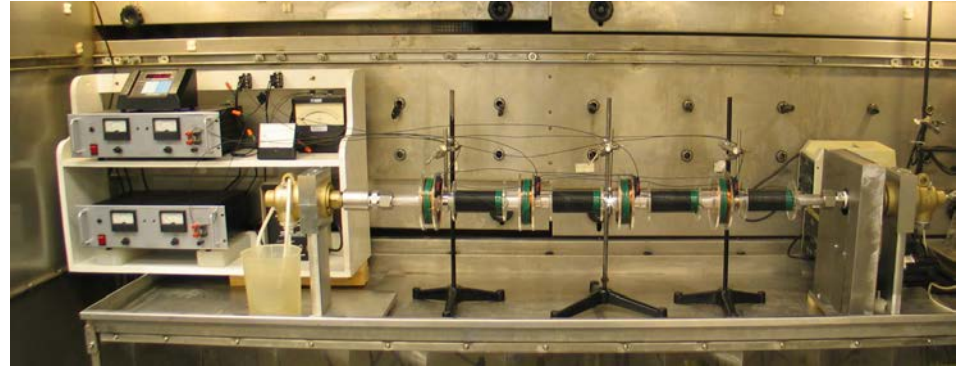
Alysia Cox, Assistant Professor, Montana Tech Department of Chemistry and Geochemistry

Continuous Flow Reactor

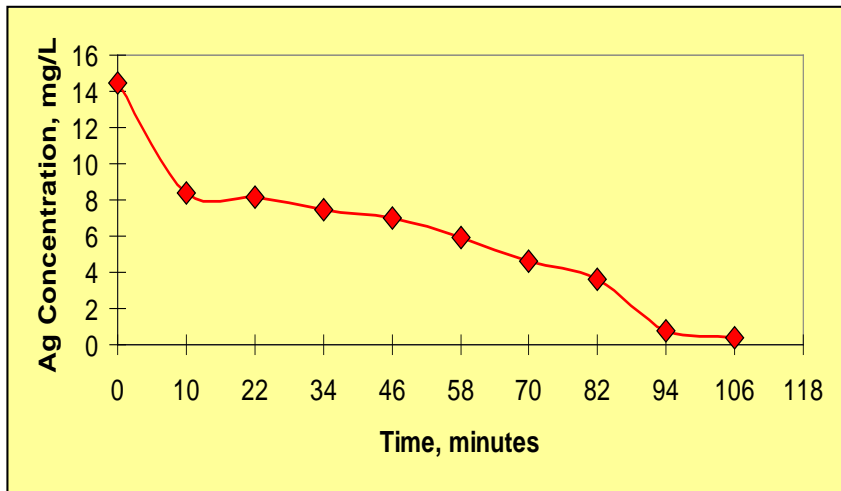
Ion exchange resin is impregnated on fine magnetic particles.

The particles are mixed with the wastewater, which is pumped through the reactor.

Magnets extend the particle residence time as the solution flows through the reactor.



Proof of Concept



More than 93% of the silver was recovered after a 15 ppm (initial) silver solution was continuously circulated through the prototype reactor.

Advantages

Dissolved metals are efficiently captured from dilute solutions; the reactor can also be used to strip metals from the magnetic nanoparticles.

The process is mechanically simple and not labor intensive; energy requirements are low since pumping requirements are not severe.

Silica Polyamine Composites SPC: a proven technology for recovery of valuable metals from mining and industrial waste developed at UM

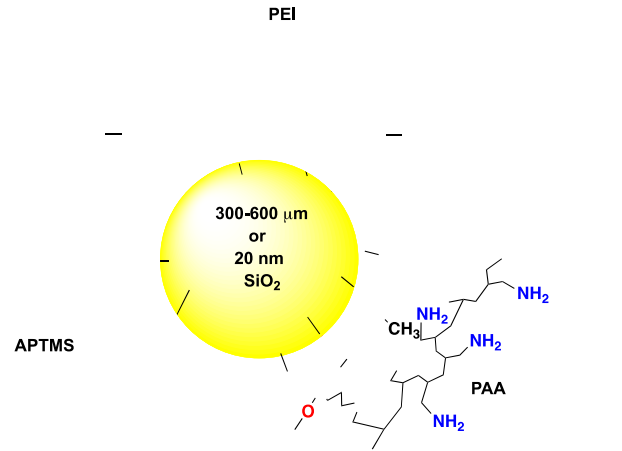
Commercial Projects

Red Banks Mine, Western Australia: flow Open pit mine drainage.

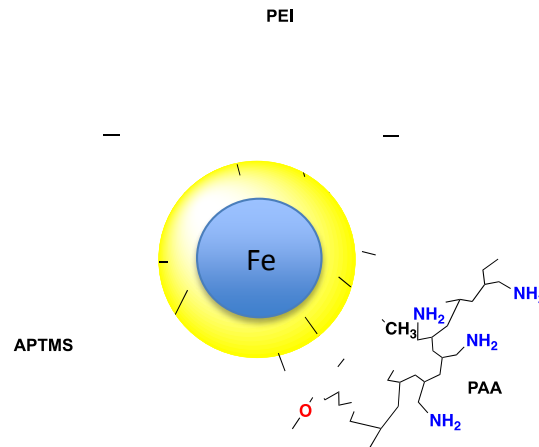
Adelaide Aqua in Western Australia: removal of all transition metals from desalination plant water.

Envirite, St. Louis, MO: Ni recovery and electro-winning from industrial waste.

Yuan Jiang Refinery, China: Ni removal of Ni from mine waste to <5 ppm.



Current SPC: polymer further modified with metal selective ligand



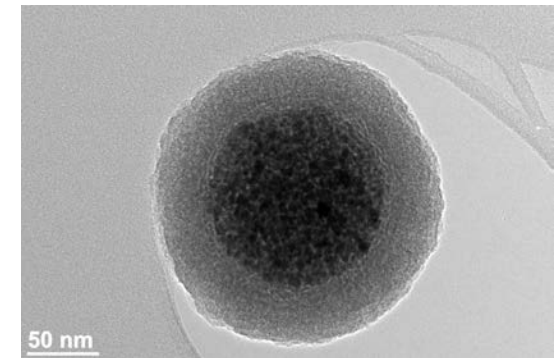
Magnetic core-shell nanoparticle with Fe₂O₃ nanoparticle core

Successful AMD Studies

Berkley Pit: recovery of 97 % pure copper directly from pit; recovery of 100% pure zinc 83% pure manganese.

Colorado/Wickes Mining District, Helena, MT. Removal of As, Pb, Cd and Zn to BDL from AMD creek.

Selective removal of As in AMD from high sulfate stream.



TEM image of a silica coated Fe nanoparticle

Project Objectives and Scope

The goal is to develop the chemistry of the magnetic nanoparticles for metal recovery and optimize their utilization in the continuous flow pipeline reactor.

- Identify candidate wastewater streams in Montana, obtain and characterize representative samples, and develop site-specific neutralization curves.
- Develop resin and magnetic substrates tailored for selected metals extraction
- Synthesize and characterize magnetic nanoparticles; modify with polyamine and metal selective ligands.
- Optimize core-shell configuration (thickness of Fe versus silica layer to optimize capture efficiency)
- Design and construct third generation continuous flow reactor
- Bench testing and deployment to pipeline reactor.
- Optimize operating parameters through computational modeling and bench-scale experimentation
- Evaluate electrowinning and other techniques as means of producing commercially saleable commodities

Economic Impacts of the Proposed Particle Technology

- Address Montana Needs: hundreds of abandoned mine sites throughout Montana require attention, but the technology is not restricted to ARD treatment. The technology represents a cost effective means of remediating these sites and for recovering metals from effluents at existing operations.
- New Entrepreneurial Venture: a Montana-based manufacturing and technical services company will be created to produce magnetic nanoparticles and to manufacture the continuous flow reactors for site-specific applications.
- Job creation: the company will need chemists, materials scientists, design engineers and process engineers. Personnel demands will be satisfied by hiring science and engineering graduates from Montana colleges and universities as well as the collaborative Materials Science Ph.D. program. Each resource recovery/remediation project site will require well-educated technicians for operation and maintenance.
- Spin-off industries: Clean water is a global concern and successful demonstration in Montana is expected to lead to the development of national and global markets thus increasing the ROI to Montana.



MONTANA
STATE UNIVERSITY

Center for Mental Health
Research & Recovery

Synergistic Improvement in the Diagnosis and Treatment of Mental Illness, Dementia, and Chronic Pain

Interdisciplinary Research, Clinical, Commercial Team

- **Principal Investigators:** Matt Byerly, M.D. and Frances Lefcort, Ph.D.
- **Academic Co-Investigators:** Rebecca Brooker, Ph.D., Aurélien Mazurie, Ph.D., David Yeomans, Ph.D.
- **Montana Industry:** Neuralynx Inc., (Casey Stengel); SiteOne Therapeutics Inc., (Stan Abel) Western Montana Mental Health Center-Butte (Natalie McGillen)
- **Additional Partners:** NAMI Montana (Matt Kuntz, J.D.)

Expertise and Experience

Neuroscience, Clinical and Cognitive Psychology, Psychiatry, Electrical and Mechanical Engineering, Computer Science, Bioinformatics

Strong track record of NIH-NSF-Funded research

Bringing innovative neurotechnology to market

Serving Challenging State-Funded Patient Populations

Project 1 & 2: Combining EEG and fNIRS to improve diagnostic and treatment approaches

- EEG detects electrical brain waves
 - Real time
 - Poor at locating site of activity
- fNIRS (functional Near Infrared Spectroscopy)
 - Effective at locating site of brain activity
 - Delay in collecting the information (blood oxygen level)
 - Cost of fNIRS is low compared to fMRI
- Combining EEG and fNIRS can improve identification of disturbed areas of brain function associated with mental disorders



Project 1. Use converging neuroimaging techniques to advance understanding about anxiety and depression

- 1 in 5 adults in Montana have been diagnosed with depression
- 1 in 10 adults in Montana have been diagnosed with anxiety
- Mental illnesses cost US taxpayers more than \$300 million each year



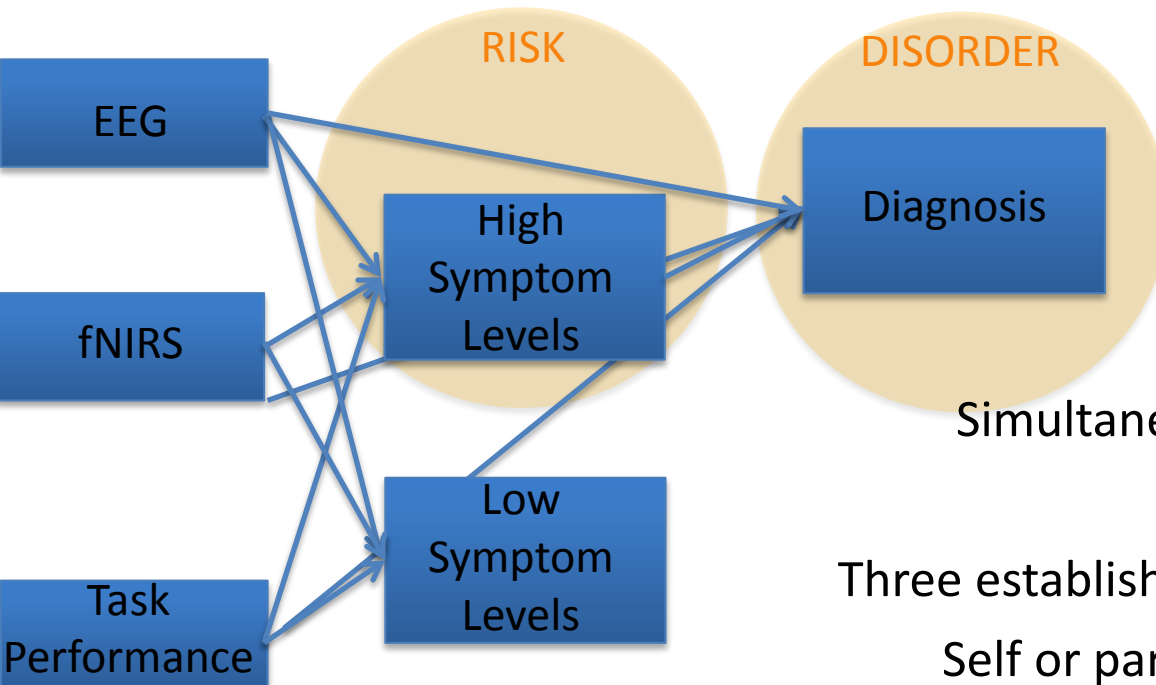
- Anxiety and depression linked to disordered function in the brain
- We are unable to identify who is at risk or how disorders develop over time
- Current neuroscience largely relies on single-methods, which are insufficient for fully understanding what risk for anxiety or depression look like “in the brain”

We will use converging neuroimaging techniques to advance current understanding about who is most at risk for depression and anxiety

Project 1. Use converging neuroimaging techniques to advance understanding about anxiety and depression

Study Participants:

150 Montanans
Ages 6 through 25



Study Procedures:

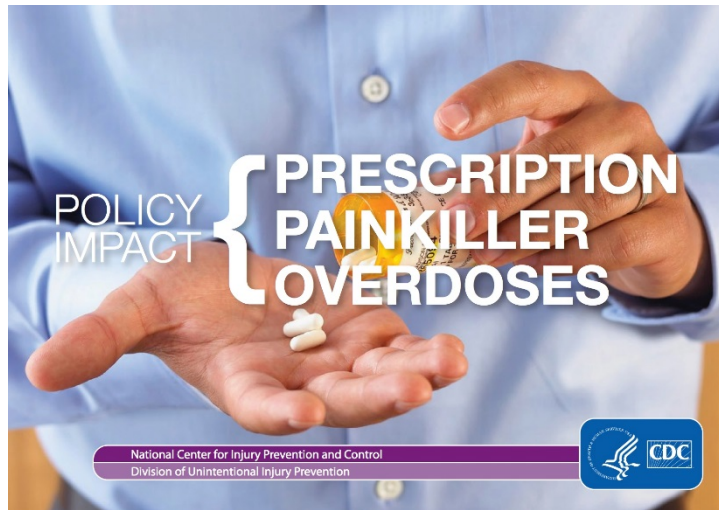
Simultaneous EEG and fNIRS data collection
Baseline (resting) recording
Three established measures of cognitive function
Self or parent reported symptoms of anxiety
Self or parent reported symptoms of depression

Project 2: Develop novel neurotechnologies to address cognitive function in adults with Alzheimer's disease

- 16/18 studies in AD showed improvements with TMS, but individual response is highly variable
- Being able to predict which patients will respond, considering the cost and intensity of care, would make TMS more cost-effective
- We will use combined EEG-fNIRS technology to attempt to identify a pattern of brain activity (or “biomarker”) that predicts who will benefit from dTMS treatment
- 20 patients with mild AD will receive a course of TMS treatment and EEG-fNIRS assessments before and after treatment



Project 3: SiteOne/Montana State University Collaboration



- Overdose from opioid pain medications results in over 15,000 deaths annually in the US
- There is a significant link between chronic pain, opioid abuse, depression and suicide
- The opioid abuse crisis has emerged in both active duty military and veterans as they struggle to deal with PTSD and long-term chronic pain
- Site one is developing drugs that selectively block a nerve cell channel that is the source of pain signals without the addictive qualities of opioid medications

Vitalsigns™
CDC

“The United States is in the midst of a prescription painkiller overdose epidemic”

SiteOne Therapeutics’ technology has the potential to fundamentally transform the treatment of pain

Project 3: SiteOne/Montana State University Collaboration

- **Research Objectives:**

- Utilize proprietary pre-clinical models to select one or more clinical candidates to initiate investigational new drug package for the FDA
- Potential for multi-billion \$ revenue once FDA approved
- Clinical candidate selection will trigger a significant venture capital financing and / or strategic collaboration with big pharma/biotech



- **Benefits to Montana:**

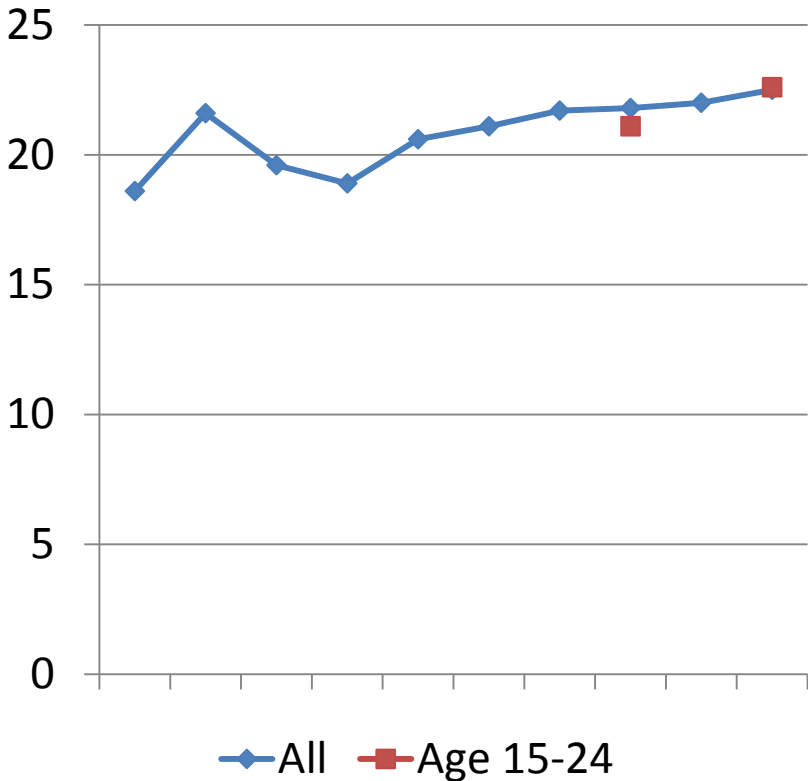
- SiteOne's management team will be building out the company in Bozeman, MT, resulting in high paying jobs and an expanded biotech research presence in the state
- A demonstrated successful research collaboration with MSU in a an area of critical unmet medical need which will serve to attract additional research activities / companies to the state
- A direct benefit from the potential approval of a non-opioid pain medication with no abuse potential, improved pain treatment and reduced side effects for Montana residents

Project 4: Preventing Youth Suicide with YAM

Suicide Rates (per 100,000)

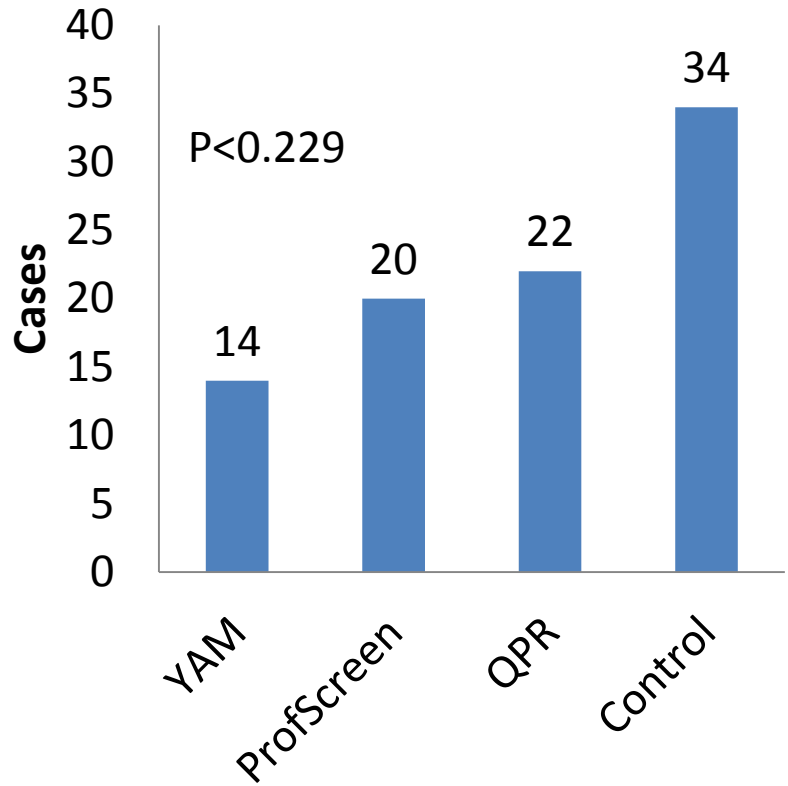
Montana Residents, 2004-2013

Office of Epidemiology and Scientific Support



Montana Strategic Suicide Prevention Plan, 2015

YAM and Suicide Attempts at 12 Months



Wasserman et al, Lancet 2015

Immediate Return on Investment: Montana Jobs

- Immediate hiring of scientists, engineers, technicians, students and contractors
- **EEG-fNIRS** research will open new sector for Neuralynx's existing products that retails at over \$60,000 - expected sales over \$5 million.
- Alzheimer's trial at Western Montana Mental Health Center in Butte will create expertise in **dTMS** treatment for AD - potentially attracting patients from across the region.
- **dTMS** treatment for 500 patients per year would generate \$7.5 million of gross revenue.



Brainsway, dTMS System

Long-Term Return on Investment: Montana Economy

- Novel treatment strategies and therapeutics will mitigate the cost to the State for mental health services
- Enable testing of non-opioid compounds for chronic pain at MSU by SiteOne Therapeutics, bringing additional biotechnology jobs to MT
- New applications for Federal research grants
- Establish CMHRR as a center of excellence for development and implementation of innovative neurotechnology and prevention measures
- Tighter coupling of local tech companies with researchers and students at MSU

**University-Based
Research**



**Clinical
Applications**



**Commercialization
of Technology**

Address Montana issues/needs – solve Montana Problems with Montana solutions

- Focus on a critically important challenge for Montana – addressing mental health needs
- Use an interdisciplinary research, clinical, commercial team of Montanans to design, test, and implement solutions
- Support the development of the CMHRR, studying mental illness causes, prevention, and treatment from the brain to the community

Enhancing Montana's Energy Resources: Research in Support of the State of Montana Energy Policy Goals

Project Director: Lee H Spangler, Director, The Energy Research Institute, MSU

Project Investigators:

Martha Apple, Department of Biological Sciences, Montana Tech

Al Cunningham, Civil Engineering and Center for Biofilm Engineering , MSU

Matthew Fields, Microbiology & Immunology and Center for Biofilm Engineering, MSU

Robin Gerlach, Chemical & Biological Engineering and Center for Biofilm Engineering , MSU

Ellen Lauchnor, Civil Engineering and Center for Biofilm Engineering, MSU

Brent Peyton, Chemical & Biological Engineering and Thermal Biology Institute , MSU

Adrienne Phillips, Civil Engineering and Center for Biofilm Engineering, MSU

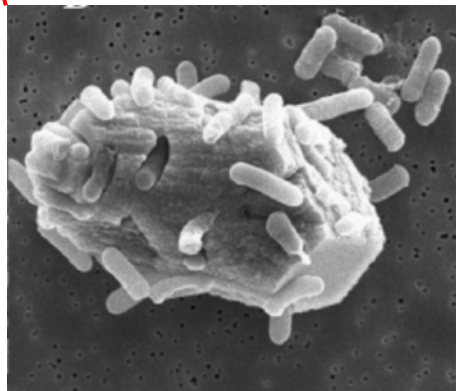
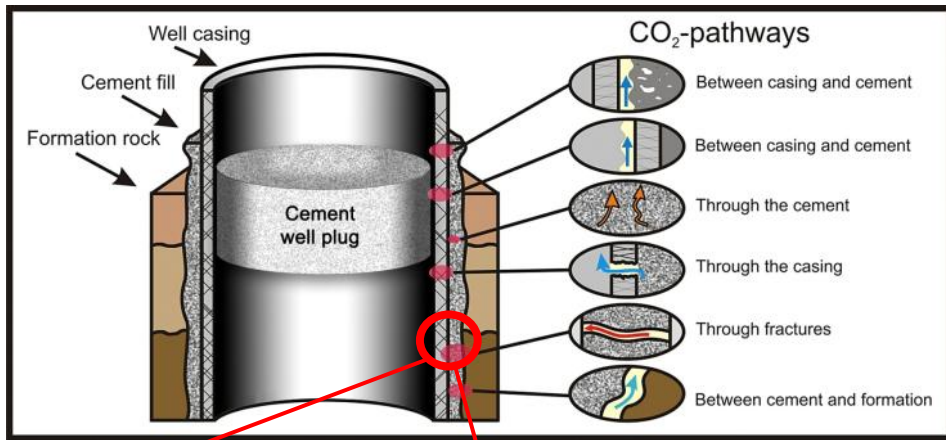
Xiaobing Zhou, Geophysical Engineering, Montana Tech

**The Energy Research Institute
Montana State University**

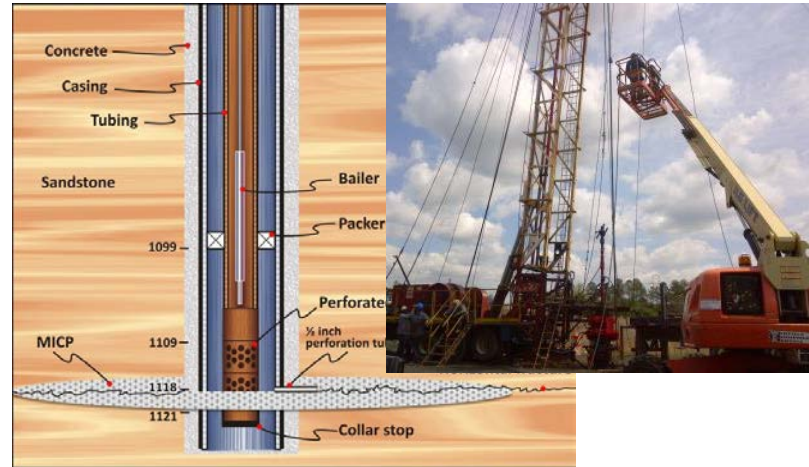
Montana Tech

Well Sealing Technology

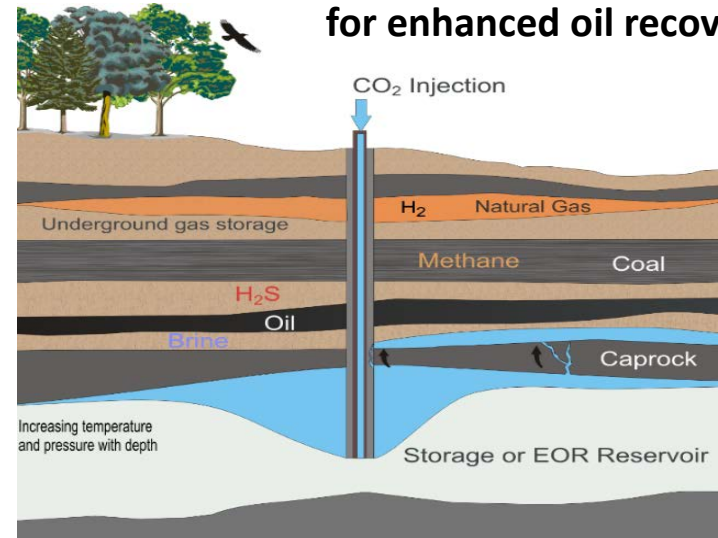
1. ERI studied bacteria that precipitate minerals and grow new rock. Performed lab work to show this can be used to seal small cracks in leaky oil and gas wells. Licensed to a MT company.



2. Performed a successful well demonstration



3. Now target deeper depths and thief zones for enhanced oil recovery



Clean Coal Technologies – Fly Ash

- EPA rule [40 CFR Parts 257 and 261] requires *mitigation of unlined fly ash ponds.*
- Southern Co. (US largest utility) contacted us to apply technology. We are also in contact with Montana companies.
- Use mineral precipitation to:
 - Co-precipitate heavy metals out of the water
 - Solidify fly ash & make impermeable
 - Develop spray technology for dust control
- Initial bench scale work shows solidification, cap formations



Clean Coal Technologies – Enhanced Oil Recovery

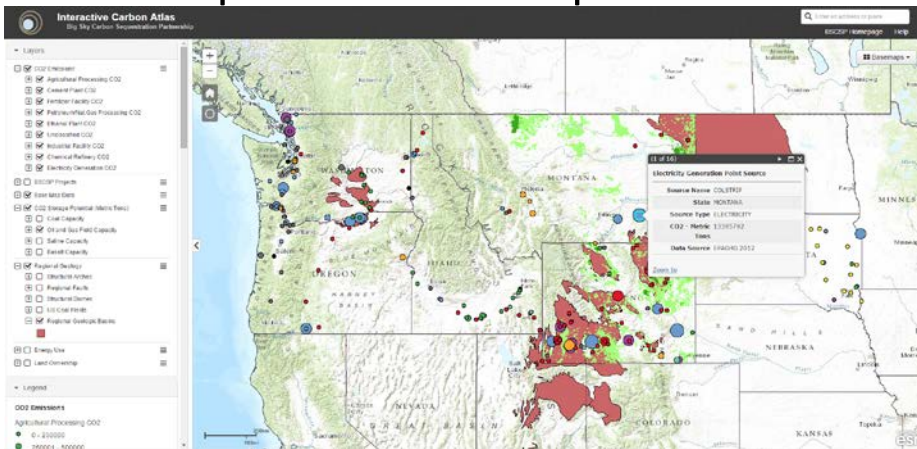
1. Assimilate Data

- Gather data from literature
- Convert data to digital formats
- Develop a geospatial database

Criteria for Screening Reservoirs for CO₂ EOR Suitability

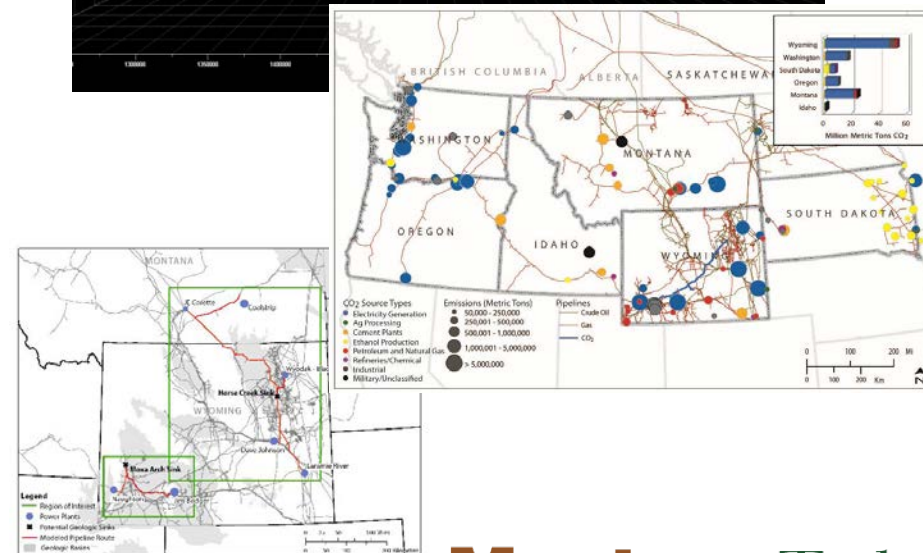
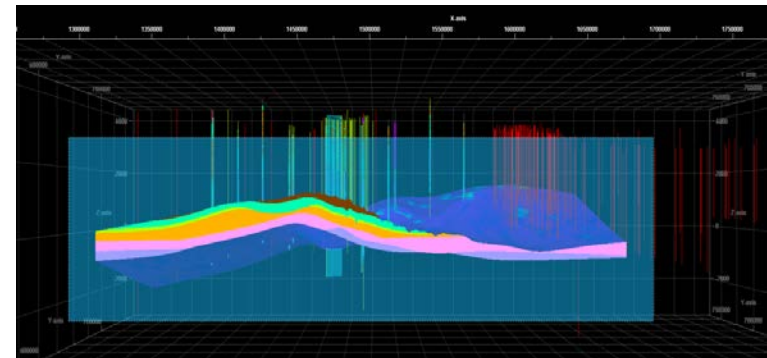
Depth, ft	< 9,800 and > 2,000
Temperature, °F	< 250, but not critical
Pressure, psia	> 1,200 to 1,500
Permeability, md	> 1 to 5
Oil gravity, °API	> 27 to 30
Viscosity, cp	≤ 10 to 12
Residual oil saturation after waterflood, fraction of pore space	> 0.25 to 0.30

3. Develop Interactive Map

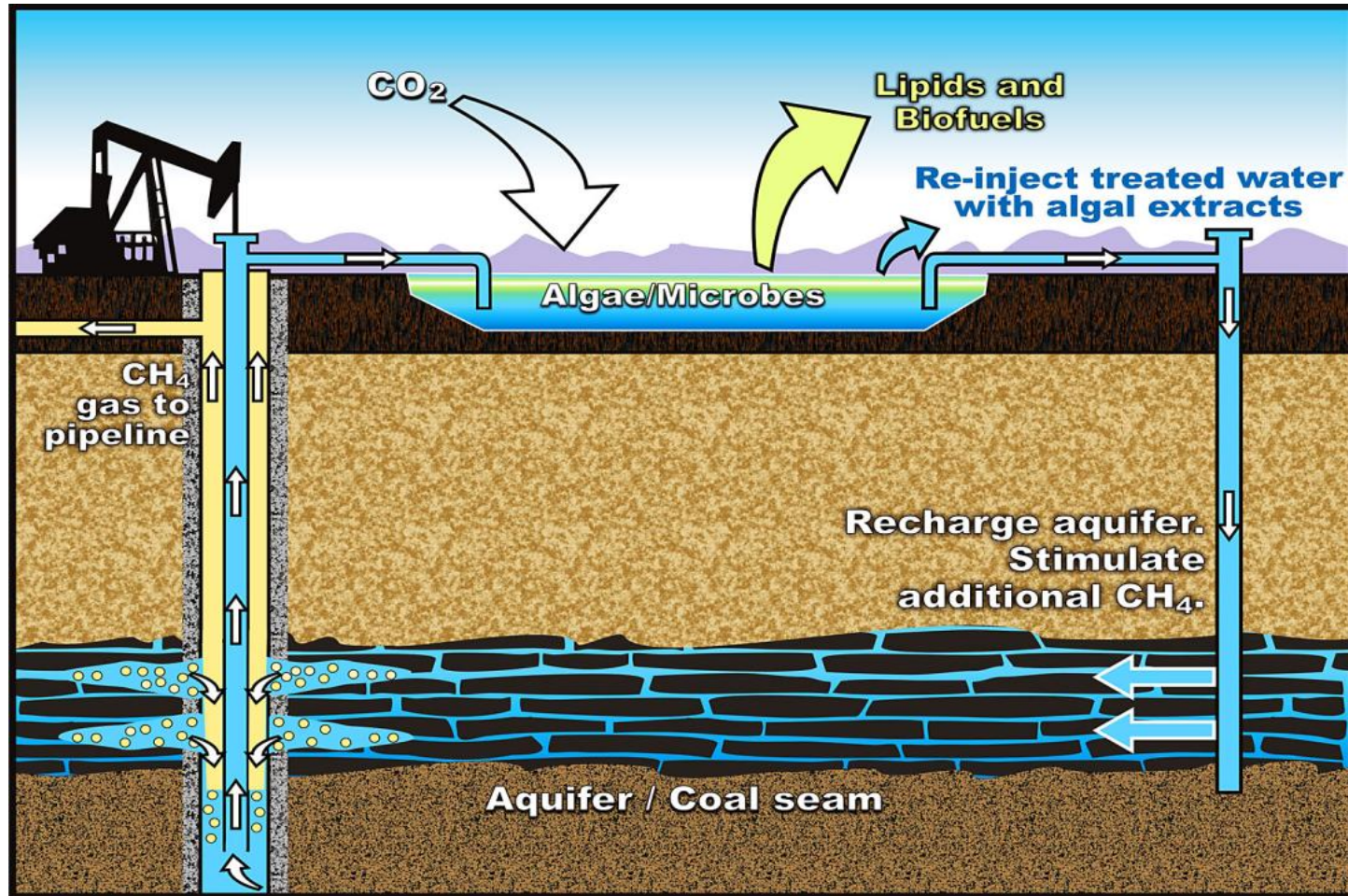


2. Assess Carbon Storage and EOR Potential

- Generate 3D models
- Grid with formation properties
- Network analysis to link sources to EOR / Storage



Clean Coal: CO₂ Capture & Increasing Coal Bed Methane Production



1. Test Algal Extract for stimulation of methane production (MSU)
2. Test Algal Byproduct for fertilizer properties (MT Tech)
3. Determine pond growth potential by remote sensing (MT Tech)

MREDI Program Goals

1. Address Montana issues/needs - solve Montana problems with MT solutions.

This project addresses Montana issues as defined by the legislature in the state energy policy goals provided in the Montana Code Annotated 90-4-1001 and subparts. The solutions are being developed in the Montana University System and, in multiple projects, involve Montana companies.

2. Create Montana jobs - create good Montana private-sector jobs

Solutions being pursued as part of this project provide general assistance to the state energy industry, a major source of jobs in the state. Specific aspects of the project involve Montana companies in the research and as potential licensees of the technology.

3. Help support the Montana economy - grow emerging and important research sectors that contribute to the diversity of Montana's economy.

Montana has 25% of the nation's coal reserves and 6% of the world reserves that can be a tremendous economic asset but could be stranded due to policy changes. This project investigates CO₂ air capture by algae, biomass co-firing of fossil fueled plants, fly ash mitigation, sequestration via EOR (could add 100 million barrels to the state economy)

4. Provide a strong ROI to Montana – leverage the MUS research enterprise.

Equipment, capabilities and expertise initially developed at MSU with federal funds to address federal issues will be leveraged by this project to address Montana needs. Advances made with state funds will position ERI and affiliated MT businesses to be more competitive for grants and other federal funds including SBIRs and STTRs.

“Translational Science at the Neural Injury Center.”

Alex Philp, PhD
Alex Santos, PhD
Charles Leonard, PT PhD
Cindi Laukes, MA
Erik Guzik, PhD
Sambit Mohapatra, PT PhD
Sarjubhai Patel, PhD
Thomas Rau, PhD



Neural Injury Center (NIC) Mission



Clinical Services

*Assessment & rehabilitation services
for TBI sufferers at UM*

Translational Research

*Develop diagnostics and
treatments to improve TBI outcomes*

Synergy

- *Interdisciplinary collaborations*
- *Generate intellectual property (IP)*
- *Validation of IP via clinical research*
- *Support TBI clinical trials*
- *Clinical services model for MUS*

Our focus: Traumatic brain injury (TBI) in Montana



- 2nd in the nation for TBI per capita (~130,000 diagnosed residents)
- Cost: Estimated at \$50m per year for moderate to severe TBI*
- Lack of diagnosis and treatment options for spectrum of TBI
- Funding the gap to rapidly **implement and commercialize intellectual property (IP)**

Our objectives



Address a Montana issue.

- TBI affects 13% of Montana's adult population (~130,000 residents) resulting in loss of productivity.
- Expansion of Montana Biotech industry (small businesses <20 employees account for 70% of all companies in the US).
- Creating hi-tech high paying jobs for Montana graduates. The biotech industry grows 10x faster than other industries. Salaries are 65% higher.

Create Montana jobs. Using *IMPLAN* economic modeling we project over a 5-year period,

- The direct creation of 135 private jobs.
- Additional 300 jobs through indirect and induced spending.
- Development of IP by the TBI consortium will lead to job creation in the areas of clinical and research sciences, information technology and engineering.

Our Strategy

Area of Focus - *Health and Biomedical Sciences*

#1 Expand current **clinical capabilities of the Neural Injury Center (NIC)** and support translational research

Improve veteran student graduation rates through access to essential clinical and rehabilitative services on UM campus + MUS

#2 Develop a comprehensive panel of objective **tests to diagnose mild TBI** (mTBI)

- *Clinical validation of novel Optokinetic, Oculomotor, Cognitive Fatigue and blood-based medical test*

#3 Develop **novel therapeutic intervention** (miRNA inhibitors) to reduce brain damage after TBI

- *Development of new IP*

TBI
Diagnosis &
Treatment

#4 VAST Next Generation Learning

Complete the development of a **computer-based cognitive training** (CCT) system for TBI subjects with cognitive impairment

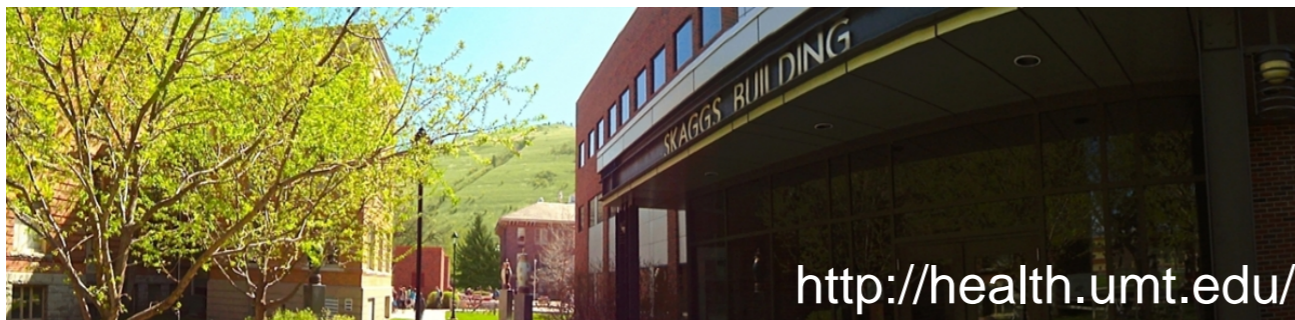
- *Development of mobile assessment algorithm*
- *Released for iOS and Android platforms*

#5 N-SITE LLC

Complete the development and testing of a **novel post-traumatic epilepsy diagnostic analysis program**

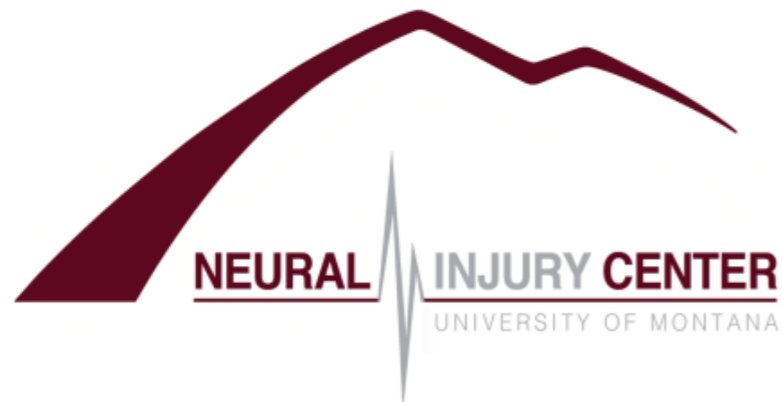
- *Use proprietary Eidos™ software to identify epileptic signatures in TBI subjects*
- *IBM InfoSphere & Big Data Partnership*

Thank you



Alex Philp, PhD
Alex Santos, PhD
Charles Leonard, PT PhD
Cindi Laukes, MA
Erik Guzik, PhD
Sambit Mohapatra, PT PhD
Sarjubhai Patel, PhD
Thomas Rau, PhD

Special Thanks
Reed Humphrey, PhD



<http://health.umt.edu/nic/>



<http://health.umt.edu/mclab/>

Strong ROI to Montana

- Upon implementation ~\$ 615,500 will be invested in the State through private sector funding

- Generate direct or indirect revenues for the MUS through new grants

- Increase quality employment

- Reduce TBI associated treatment costs

- Enhance the value of IP owned by the MUS that can be collected as in-licensing agreements with the private business sector

- Five-year projections for this proposal are as follows:

- ◆ Cost savings on improved workforce productivity, reduced health care costs, improved graduation rates, and decreased criminal behavior*.

- ◆ \$12-15 million in in-licensing and royalty agreements on developed IP owned by the MUS

- ◆ \$2-6 million in the development of novel IP for the MUS

- ◆ \$5-7 million in grant submissions to DOD, NIH, NSF, VA, and Private Foundations

* *The costs of traumatic brain injury: a literature review.* Humphreys et al., ClinicoEconomics and Outcomes Research, 2013

* *Outcomes and Costs of Acute Treatment of Traumatic Brain Injury.* McGarry et al, J. Trauma, 2002.

MUS Research Initiative

Montana's Research & Economic Development Initiative

What is the MUS Research Initiative?

- ❖ State funded seed money to leverage university-based research into strategic advancements for Montana's economy
- ❖ Specific goals:
 - Solve Montana problems with Montana solutions
 - Create good Montana private-sector jobs
 - Grow emerging research sectors to strengthen and diversify Montana's economy
- ❖ **\$15 million** appropriation to the MUS to carry out this initiative

➤ **Areas of Focus**

- ❖ Agriculture
- ❖ Natural Resources and Energy
- ❖ Materials and Manufacturing
- ❖ Health and Biomedical Sciences
- ❖ Information Technology and Computer Science

➤ Administered by OCHE:

“The Commissioner of Higher Education will administer competitive grants to researchers on the basis of each new project’s potential for private-sector job creation, commercialization, and economic return on investment for the State of Montana”

➤ Campuses vetted proposals for academic and scientific merit

➤ Research Advisory Panel provided recommendations to the Commissioner of Higher Education

Legislator - Senate

Senator Llew Jones

Legislator – House

Representative Ryan Lynch

Agriculture/Agribusiness

Lola Raska, MT Grain Growers Assoc.

Natural Resources Industry

Larry Simkins, Washington Companies

Health/Biomedical Industry

Ron Zook, Swan Valley Medical

Montana State University

President Waded Cruzado

University of Montana

President Royce Engstrom

INCREASING PROFITABILITY BY IMPROVING EFFICIENCY OF MONTANA'S FARM AND RANCH LANDS

AWARD AMOUNT: \$2,276,734

PRINCIPAL INVESTIGATOR: Dr. Barry Jacobsen - MSU College of Agriculture – Montana Agricultural Experiment Station

Proposal focuses on improving the economic and environmental sustainability of crop and livestock agriculture through:

- Intensifying pulse and cover crop production on 4.6 million acres of Montana land left fallow between crops
- Developing new or improved products, crops or practices
- Increasing adoption of precision agricultural technologies by helping farmers access and use data via an automated on-farm precision experimentation (OFPE) system that will maximize profits

DEVELOPMENT AND COMMERCIALIZATION OF AUTONOMOUS CHEMICAL AND BIOLOGICAL INSTRUMENTATION FOR WATER QUALITY MONITORING

AWARD AMOUNT: \$1,292,398

PRINCIPAL INVESTIGATOR: Dr. Chris Palmer - Department of Chemistry and Biochemistry
- The University of Montana

Proposal develops a suite of measurement and sampling systems to monitor Montana's waterways:

- Detection of contaminant ions such as arsenate
- A method for separation and detection of organic and ionic pollutants
- A sampler for environmental DNA (eDNA) for detection of aquatic invasive species, pathogens, and endangered native species
- A titration and pH sensor for continuous water quality monitoring

OPTICS AND PHOTONICS RESEARCH FOR MONTANA ECONOMIC DEVELOPMENT

AWARD AMOUNT: \$2,496,512

PRINCIPAL INVESTIGATOR: Dr. Joseph Shaw - Optical Technology Center - Montana State University

- **Ultra-compact spectral imagers** for precision agriculture, wild fire mapping, and natural resources
- **Hyperspectral imaging** for monitoring cell growth and high-performance, real-time image processing
- **Microcavity sensors for hyperspectral imaging** – skin cancer detection, counterfeit drug detection, precision agriculture, & natural resources
- **Micro-mirror technology** – microscopy, medical imaging, astronomy
- **Active waveguides and integrated optical circuits** – telecommunications and defense markets
- **Optical Parametric Oscillator for Tunable Lasers** – chemical gas detection
- **Nonlinear Optical Detection of Surface Contaminants** – assessment of drinking water contamination and pesticide usage