NATIONAL ENERGY TECHNOLOGY LABORATORY

AVAILABLE TECHNOLOGIES

CRITICAL MINERALS & ADVANCED ALLOYS

U.S. DEPARTMENT of ENERGY | NATIONAL ENERGY TECHNOLOGY LABORATORY

FY 2027

TABLE OF CONTENTS

Extraction and Recovery 2

Improved Rare Earth Element Extraction Method from Coal Ash (20N-12) 2

Downhole Laser System with Improved Laser Output Production and Data Collection (19N-22) 3

Selective Material Recovery from Natural Brines (17N-07) 4

Recovery of Metals from Petroleum Waste Byproducts (17N-02) 5

Thermal Concentration of Rare Earth Elements from Coal Byproducts (17N-01) 6

High Power Q-Switched Downhole Laser-Induced Breakdown Spectroscopy Systems (16N-18) 7

Portable Luminescence-Based Sensor for Rare Earth Element Detection (16N-09) 8

LIBS Probe for Simplified Light Collection and Laser Operation (15N-05) 9

Split Laser Systems for Remote Environmental Monitoring (13N-10) 10

Process Development 11

High-Performance Carbon Electrode Material for Supercapacitors (23N-19 and 23N-13) 11

Fiber-Optic Sensor and Guided Acoustic Wave Monitoring Fusion for Pipelines (23N-01) 12

Fibrous Amine-Functionalized Matrix Flat Sheet Sorbent (22N-08) 13

Distributed Multiparameter Sensors for Corrosion and Humidity Monitoring (22N-05) 14

Stable Immobilized Amine Sorbents for the Decoloration of Wastewaters (21N-17 and 17N-18) 15

Fiber-Optic pH Sensor for High-Temperature and High-Pressure Environments (20N-24) 16

Tunable Fiber Ring Laser for Dual Sensing (20N-23) 17

MARGA Aqueous Solution for Gas Separation (19N-30) 18

Single-Step Synthesis of Chemisorption Fiber Sorbents for Gas Stream Purification (19N-24) 19

Portable, Rapid, Fiber-Optic Luminescent Sensor for Rare Earth Elements Using Metal-Organic Framework Sensitizers (19N-15) 20

Organic Acid–Salt Solutions for Low-Temperature Rare Earth Extraction (19N-11) 21

Multifunctionalized Sorbents for Removal of Metal Contaminants from Wastewater (19N-04) 22

Corrosion Detection Sensors for Use in Natural Gas Pipelines (17N-21) 23

Nanograting Enhanced Distributed Fiber Sensors (17N-13) 24

Regenerable Nonaqueous Sorbent Slurries for Gas Separation (16N-02) 25

Sensors for Corrosion Monitoring in Harsh Environments (15N-22) 26

Metal-Organic Framework and Plasmonic Nanomaterial Fiber-Optic Gas Sensor (15N-04) 27

Fiber-Optic Nanoparticle pH Sensors for Harsh Environments (15N-02 and 14N-19) 28

Palladium and Platinum Nanocomposite Sensors for Selective Hydrogen Detection (15N-01) 29

Computational and Simulation-Based Tools for Drilling Optimization (12N-20) 30

Gas Sensing System Employing Raman Scattering (10N-26) 31

Products and Alloys 32

Self-Healing Cold Spray Coating for Internal Corrosion Protection of Natural Gas Pipelines (23N-12) 32

Low-Cost, High-Performance Alloys for Gas Turbine Blades (21N-18) 33

NiCrCoMoW Age-Hardenable Alloy for Creep-Resistant, High-Temperature Applications (21N-08) 34
Creep-Resistant NiCrMoNb Alloy for High-Temperature Components (20N-15) 35
Creep-Resistant Nickel-Based Superalloy Casting and Manufacturing (20N-13) 36
Microwave Annealing Systems for Alloy Processing (18N-29) 37
High-Performance Corrosion-Resistant High-Entropy Alloys (18N-09) 38
Biodegradable Alloys for Implantable Medical Devices (14N-14) 39
INDEX 40

Improved Rare Earth Element Extraction Method from Coal Ash (20N-12)

Opportunity

The global rare earth element (REE) supply chain is dominated by foreign sources, making domestic recovery methods critical to ensuring long-term availability for U.S. manufacturing and defense applications. Work at NETL has resulted in an improved extraction process that efficiently recovers REEs from coal ash using mild inorganic acids at ambient temperatures. The method operates through a three-step, pH-controlled leaching sequence that isolates REEs, scandium, and other critical minerals without the need for pretreatment or high-temperature processing. This approach provides a cost-effective path to convert coal ash, a byproduct of energy production, into a valuable domestic resource. This technology is available for licensing and /or collaborative research from NETL.



Challenges Addressed

- Reliance on foreign suppliers for REEs needed in electronics, magnets, and energy systems
- Conventional extraction techniques require high temperatures and strong acids or bases, creating safety hazards
- Existing methods coleach large amounts of unwanted metals and radioactive elements, increasing purification costs and waste handling needs
- Coal ash, which contains recoverable REEs, is being discarded as industrial waste rather than utilized as a domestic resource

Potential Commercial Applications

- Scalable recovery of REEs and scandium from coal combustion fly ash, bottom ash, and other industrial residues
- Extraction of critical minerals from biomass ash, waste combustion byproducts, or similar materials in other energy sectors
- Integration into existing coal ash management infrastructure to create valuable byproduct recovery systems

Competitive Advantages

- Extraction occurs at ambient temperature and pressure, reducing operational complexity and cost
- No pretreatment of ash is required, simplifying process flow
- Reduced acid consumption compared to conventional techniques
- Compatible with large-scale deployment
- High extraction efficiency (80%-100%) has been demonstrated for multiple REE species

Intellectual Property Status

A U.S. patent (US12221672) was issued February 27, 2025, and expires December 13, 2043.

Publications

M. Stuckman, et al. Step-Leaching Process of Rare Earth Elements from Ash Materials Using Mild Inorganic Acids at Ambient Conditions. (2022). *United States Patent and Trademark Office.* U.S. Patent No. 12,221,672.

Licensing/Collaboration

Partnerships@netl.doe.gov

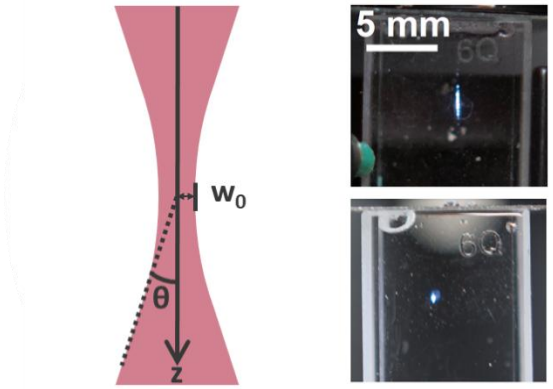
Inventors

Mengling Stuckman, Christina Lopano, and Thomas Tarka

Downhole Laser System with Improved Laser Output Production and Data Collection (19N-22)

Opportunity

Monitoring chemical and physical conditions deep underground remains a major challenge due to extreme temperature and pressure, as well as accessibility limitations. NETL has designed a laser-induced breakdown spectroscopy (LIBS) system that enables real-time, in-situ chemical analysis in harsh downhole environments. The system combines lens, beam, and spectral emission controls to enhance output stability, spark efficiency, and data quality. These optical design improvements allow for accurate trace element detection and continuous monitoring without the need to transport and retrieve samples to the surface. This technology is available for licensing and/or further collaborative research from NETL.



Schematic and example of beam expansion control using the LIBS system

Challenges Addressed

- Traditional downhole monitoring systems can only measure bulk parameters such as pH and conductivity, requiring samples to be extracted for trace analysis
- Current diode-pumped solid-state laser systems suffer from instability under temperature and pressure fluctuations common in downhole environments
- Existing LIBS systems produce elongated, filamentary sparks that result in weak or inconsistent spectral signals
- Conventional optical setups lose significant light during emission collection, limiting data quality and sensitivity

Potential Commercial Applications

- Real-time elemental analysis of fluids in oil, gas, and geothermal wells
- Continuous leak detection and integrity monitoring for injection and production wells
- Environmental and subsurface monitoring in energy and resource extraction industries
- Portable or remote LIBS-based sensor systems for harsh environments

Competitive Advantages

- Beam overlap control provides adjustable and stable laser output characteristics
- Beam expansion control enables efficient spark generation using lower pulse energy
- Spectral emission control improves light collection and reduces signal loss
- Minimizes sensitivity to temperature and pressure variations during operation
- Provides more consistent and accurate trace element measurements than existing systems

Intellectual Property Status

A U.S. nonprovisional and divisional patent were issued and expire November 11, 2040 and October 19, 2040, respectively.

Publications

D. McIntyre and D. Hartzler. Downhole Laser System with an Improved Laser Output Production and Data Collection. (2022). *United States Patent and Trademark Office.* U.S. Patent No. 11,451,004.

Licensing/Collaboration

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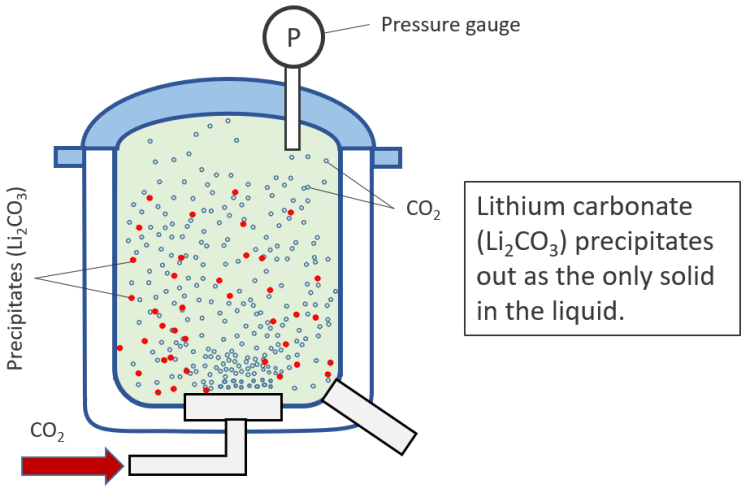
Inventors

Dustin McIntyre and Daniel Hartzler

Selective Material Recovery from Natural Brines (17N-07)

Opportunity

Efficient extraction of high-value materials from natural and industrial brines requires a process that can separate impurities and concentrate target species without extensive evaporation ponds or large chemical inputs. Researchers at NETL designed a carbon dioxide (CO_2)-driven precipitation method that relies on controlled adjustments of temperature and the CO_2-to-pressure ratio (CO_2/P) within a reaction vessel. When CO_2 is introduced into heated brine at a predetermined CO_2/P value, impurities preferentially precipitate and can be removed, leaving a second brine enriched in the desired material. A subsequent heating step followed by a second CO_2 injection at a different CO_2/P value induces selective precipitation of the target compound itself. This staged approach provides a tunable way to separate impurities from valuable species using only CO_2, temperature control, and residence time. The method reduces reliance on large reagent quantities and eliminates time-consuming evaporation steps. This technology is available for licensing and/or further collaborative research from NETL.



Challenges Addressed

- There is an escalating global demand for lithium
- Brines represent a vast and promising resource, but conventional extraction techniques, predominantly solar evaporation ponds, are notoriously slow

Potential Commercial Applications

- Efficiently extracts lithium from various natural brine sources by selectively precipitating impurities and then lithium carbonate
- Directly produces lithium carbonate, a key chemical precursor for battery materials and various industrial applications, from brine solutions

Competitive Advantages

- Traditional lithium extraction from brines via solar evaporation can take 12-24 months, whereas this method achieves lithium precipitation in under an hour
- Conventional methods often yield lithium recovery rates between 30% and 50%, whereas the new approach's controlled CO_2 injection and heating processes achieve higher recovery rates
- Operates effectively regardless of weather, enabling consistent lithium extraction in diverse environments

Intellectual Property Status

A U.S. patent was issued July 25, 2023, and expires September 20, 2041.

Publications

J. Nakano, et al. Selective Material Recovery from Solution. (2023). *United States Patent and Trademark Office.* U.S. Patent No. 11,708,279.

Licensing/Collaboration

Partnerships@netl.doe.gov

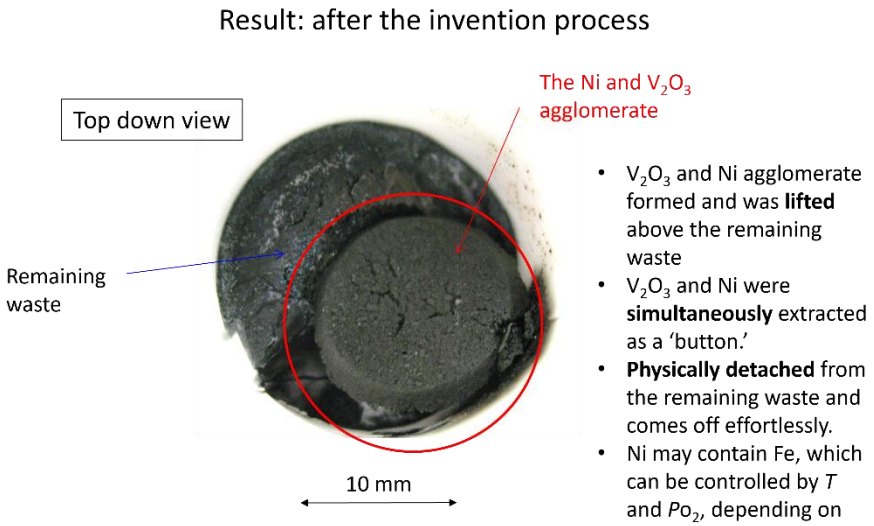
Inventors

Jinichiro Nakano, Anna Nakano, and James Bennett

Recovery of Metals from Petroleum Waste Byproducts (17N-02)

Opportunity

Gasification of petroleum-derived feedstocks produces ash and slag residues that contain valuable metals such as nickel (Ni) and vanadium, but conventional recovery methods rely on multistage acid or base leaching that is slow, costly, and generates additional waste. NETL has developed a single-stage thermal process that recovers these metals directly from petroleum waste byproducts without chemical leaching. The method uses controlled heating in a reducing atmosphere to separate and lift agglomerated metal from the molten waste matrix, enabling simplified downstream beneficiation. This technology is available for licensing and/or further collaborative research from NETL.



Challenges Addressed

- Conventional leaching methods require strong acids, multiple processing stages, and generate secondary waste streams
- Metals such as Ni and V are dispersed in vitrified slag, making extraction difficult with standard separation techniques
- Current recovery approaches are energy- and labor-intensive, increasing operating costs
- Limited domestic processing capacity contributes to reliance on foreign sources of critical materials

Potential Commercial Applications

- Recovery of Ni and V from petroleum coke ash and slag
- Extraction of valuable metals from metallurgical ash, refinery residues, or natural ores
- Integration with gasification and metallurgical facilities to utilize on-site thermal energy
- Production of purified metal concentrates for battery, catalyst, and specialty alloy manufacturing

Competitive Advantages

- Single-stage thermal process simplifies metal extraction and reduces processing time
- Produces high-purity Ni and V with negligible impurities
- Eliminates the need for acid leaching, crushing, or grinding prior to separation
- Generates agglomerated metal that forms above the waste matrix for easy removal
- Can complement existing gasification operations by using available heat and producing carbon monoxide as a usable byproduct

Intellectual Property Status

A U.S. patent was issued June 18, 2019, and expires September 15, 2037.

Publications

J. Nakano, et al. Method for Recovering Target Materials from Source Materials. (2017). *United States Patent and Trademark Office.* U.S. Patent No. 10,323,298.

Licensing/Collaboration

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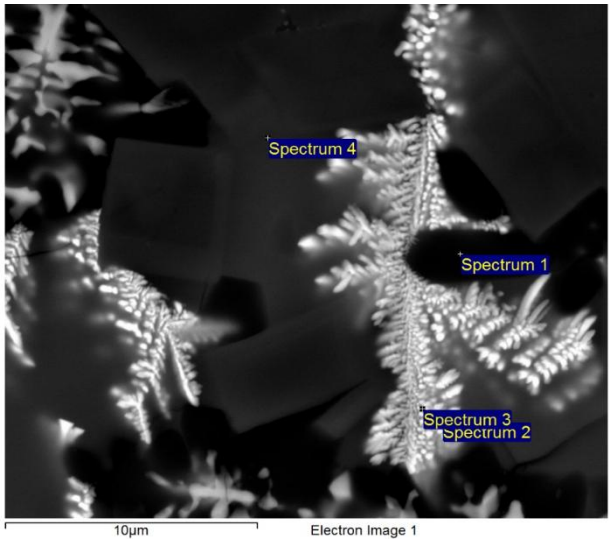
Inventors

Jinichiro Nakano, Anna Nakano, and James Bennett

Thermal Concentration of Rare Earth Elements from Coal Byproducts (17N-01)

Opportunity

Rare earth elements (REEs) are critical to modern electronics, energy systems, and advanced manufacturing, yet their recovery from domestic sources remains limited by inefficient extraction processes. NETL has engineered a patented method that concentrates REEs from coal byproducts such as ash and slag into a single, extractable solid phase through controlled heating and cooling. The process uses temperature and time manipulation at atmospheric pressure, eliminating the need for acid leaching or high-pressure reactors. By converting trace REE content of less than 0.05% into solids enriched up to 59%, the method enables cost-effective recovery from existing industrial waste streams. This technology is available for licensing and/or further collaborative research from NETL.



REE-containing monazite (white) formed from coal byproduct via NETL method

Challenges Addressed

- Current REE recovery relies heavily on imported sources, leaving domestic industries vulnerable to supply disruption
- Conventional leaching and beneficiation methods require hazardous acids and multiple process stages, increasing cost
- REEs in coal byproducts exist in varied mineral forms, making uniform extraction difficult
- There is a need for an economical process that concentrates REEs into a consistent, extractable phase

Potential Commercial Applications

- Extraction and concentration of REEs from coal ash, slag, and gasification byproducts
- Recovery of valuable minerals from metallurgical waste and industrial residues
- Integration with existing coal-fired, ironmaking, or gasification operations to add byproduct value
- Supply chain diversification for domestic manufacturing and high-tech industries

Competitive Advantages

- Achieves REE enrichment up to 59% from initial concentrations below 0.05%
- Uses only temperature and time control under atmospheric conditions
- Can be applied directly to existing coal and metallurgical byproduct streams

Intellectual Property Status

A U.S. patent (US10358694) was issued July 23, 2019, and expires October 23, 2037.

Publications

J. Nakano, et al. System and Method for Concentrating Rare Earth Elements from Coal Byproducts/Slag. (2019). *United States Patent and Trademark Office.* U.S. Patent No. 10,358,694.

Licensing/Collaboration

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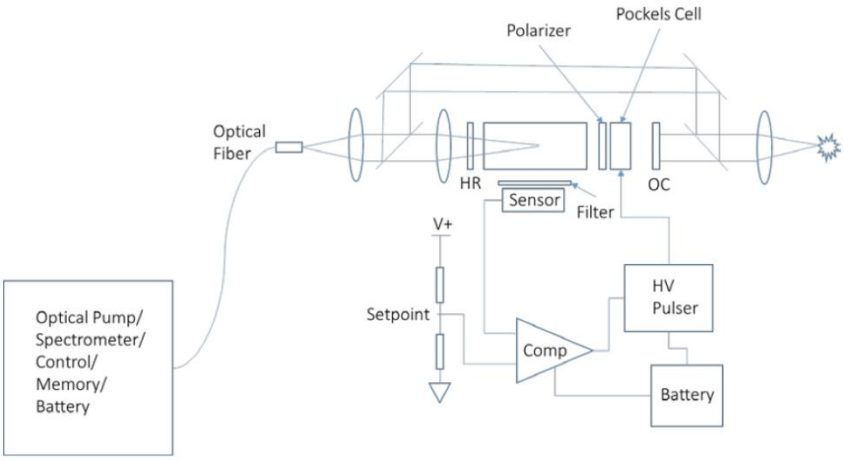
Inventors

Jinichiro Nakano, Anna Nakano, and James Bennett

High Power Q-Switched Downhole Laser-Induced Breakdown Spectroscopy Systems (16N-18)

Opportunity

Accurate subsurface chemical measurements require laser outputs that can generate stable plasmas in water and rock environments, but most downhole laser-induced breakdown spectroscopy (LIBS) probes cannot reach the pulse energies needed for reliable elemental excitation. Engineers at NETL designed an actively Q-switched LIBS architecture that overcomes these limitations while maintaining conventional probe geometry. The system routes a pump beam through an optical fiber to a coupler and collimating lens that feed an internally mounted Q-switched laser equipped with a Pockels cell for controlled high voltage triggering. This configuration enables the laser to store energy and release it in short, high-power bursts that exceed typical downhole thresholds and produce a robust plasma for elemental or molecular analysis. A second lens focuses the outgoing pulse, and the return emission is captured and transmitted back to topside instrumentation. This approach supports high-energy operation without enlarging the probe, which expands LIBS deployment into deeper, higher pressure and more varied monitoring environments. This technology is available for licensing and/or further collaborative research from NETL.



NETL downhole system using an active Q-switch

Challenges Addressed

- Monitoring of gas storage in geological formations is essential to prevent gas leakage
- Energy constraints seen in other systems severely hampers their ability to detect and identify a comprehensive range of elemental species

Potential Commercial Applications

- Robust, in-situ chemical analysis in wells and boreholes, allowing for the detection and tracking of groundwater contaminants and waste leakage
- High-energy, downhole LIBS/Raman capabilities offer real-time, detailed chemical characterization of rock formations, fluids, and minerals

Competitive Advantages

- Actively Q-switched laser system achieves output pulse energies approaching or exceeding 100 mJ, significantly surpassing the 25-30 mJ typical of passively Q-switched systems
- Allows for exact control over pulse timing and repetition rates, facilitating synchronization with external devices

Intellectual Property Status

A U.S. patent (US11953443) was issued April 9, 2024, and expires October 19, 2041.

Publications

D. McIntyre and D. Hartzler. High Power Actively Q-Switched Downhole LIBS Analysis Systems. (2024). *United States Patent and Trademark Office.* U.S. Patent No. 11,953,443.

Licensing/Collaboration

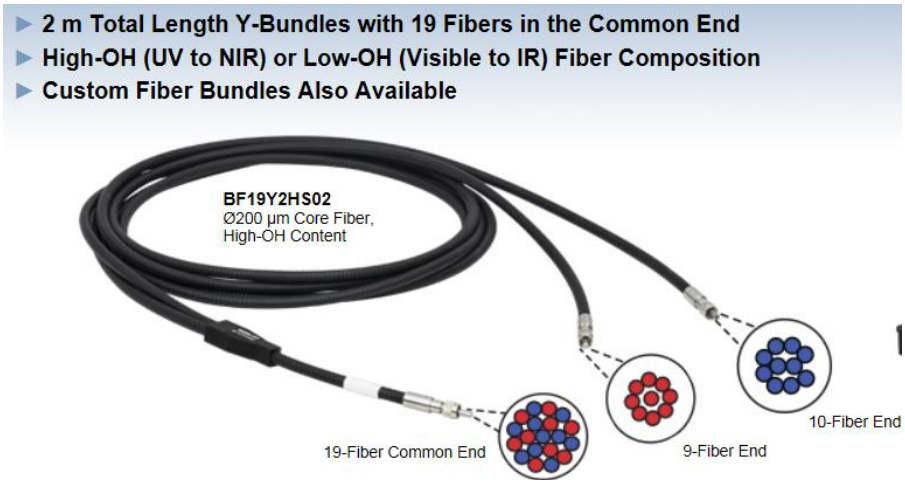
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Inventors

Dustin McIntyre and Daniel Hartzler

Portable Luminescence-Based Sensor for Rare Earth Element Detection (16N-09)

Opportunity



Recovering rare earth elements (REEs) from coal byproduct streams requires rapid, field-ready quantification at very low concentrations, but current laboratory methods are slow, costly, and nonportable, which delays screening and decision making. The U. S. Department of Energy's National Energy Technology Laboratory (NETL) has produced a portable luminescence-based fiber-optic sensor that provides on-site detection and quantification of terbium, europium, dysprosium, and samarium down to parts-per-billion levels. The device uses compact LED excitation, bifurcated fiber-optics, and in-line shortpass and longpass filtering to isolate characteristic emission signatures without quartz cuvettes or hazardous solvents. Optional sensitizers and disposable probe tips can further lower detection limits and streamline field operation. This technology is available for licensing and/or further collaborative research from NETL.

Challenges Addressed

- Conventional detection methods such as inductively coupled plasma mass spectrometry (ICP-MS) require laboratory analysis with long turnaround times
- Tabletop fluorescence and plasma systems are expensive, nonportable, and unsuitable for field screening
- Waste byproduct streams vary significantly, requiring fast on-site assessment to guide recovery operations
- Existing tools do not easily detect REEs at parts-per-billion concentrations without complex sample prep

Potential Commercial Applications

- Detection of low concentrations of REEs in aqueous coal byproduct waste streams
- Field screening of electronic waste, industrial recycling streams, or landfill leachates
- In-line or at-line process monitoring during REE separation and beneficiation
- Portable analytical tools for geological, environmental, and materials science investigations

Competitive Advantages

- Portable and field deployable, reducing the need for laboratory analysis
- Detects REEs down to the parts-per-billion range with rapid response times
- Compatible with luminescence sensitizers to improve detection limits for additional REEs
- Lower cost and simplified optical design compared to conventional spectroscopic tools

Intellectual Property Status

A U.S. patent (US11170986) was issued November 9, 2021, and expires July 21, 2037.

Publications

J. Ahern, et al. Luminescence Based Fiber Optic Probe for the Detection Of Rare Earth Elements. (2021). *United States Patent and Trademark Office.* U.S. Patent No. 11,170,986.

Licensing/Collaboration

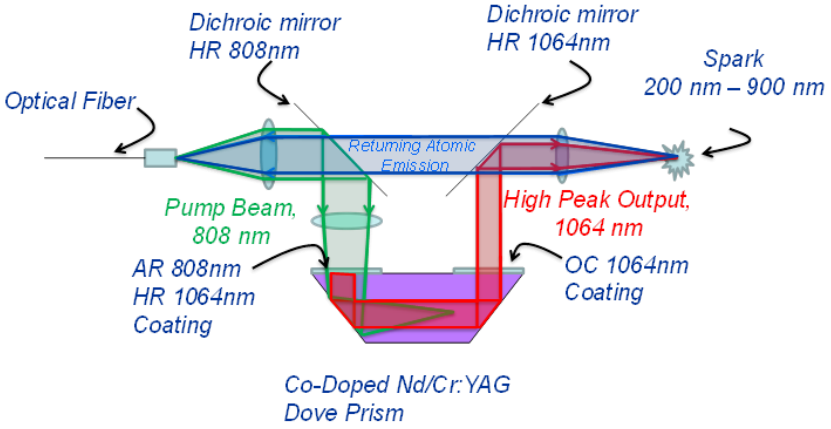
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Inventors

John Ahern, Paul Ohodnicki, Jr., John Baltrus, and Jacob Poole

LIBS Probe for Simplified Light Collection and Laser Operation (15N-05)

Opportunity



NETL has developed an improved laser-induced breakdown spectroscopy (LIBS) probe that simplifies the optical layout and reduces the number of required mirrors. Traditional LIBS systems rely on complex mirror assemblies, including dichroic mirrors that require costly chemical vapor deposition and precision alignment. NETL's design replaces two of these mirrors with a dove prism laser medium that performs both beam reflection and transmission within a compact optical path. This configuration enhances signal strength, minimizes optical losses, and significantly lowers fabrication and alignment complexity. The simplified probe enables high-quality spectral analysis of solids, liquids, and gases while maintaining ruggedness and cost efficiency. This technology is available for licensing and/or further collaborative research from NETL.

Challenges Addressed

- Conventional LIBS probes require multiple mirrors and precise alignments that increase system cost and fragility
- Dichroic mirrors introduce optical losses and can interfere with accurate light collection
- Complex assembly and alignment processes increase calibration time and limit field deployment
- Existing probes are less suitable for confined or harsh environments requiring compact, durable instrumentation

Potential Commercial Applications

- Elemental and molecular analysis in geological, environmental, and industrial monitoring
- Field-deployable spectroscopic analysis for mining, water quality, and pollution detection
- Real-time compositional monitoring of combustion and plasma processes
- Laser ignition systems with integrated diagnostics for engines and turbines

Competitive Advantages

- Simplified optical layout using a dove prism reduces mirror count from four to two
- Enhanced light return improves spectral quality and signal-to-noise ratio
- Lower fabrication and alignment costs enable affordable, scalable deployment
- Compact and robust probe design suitable for challenging environments
- Compatible with existing LIBS spectrometers and fiber-optic collection systems

Intellectual Property Status

A U.S. patent was issued December 4, 2018, and expires October 26, 2037.

Publications

D. McIntyre. Laser Induced Breakdown Spectroscopy (LIBS) Probe for Simplified Light Collection and Laser Operation. (2018). *United States Patent and Trademark Office.* U.S. Patent Publication Application No. 10,145,737.

Licensing/Collaboration

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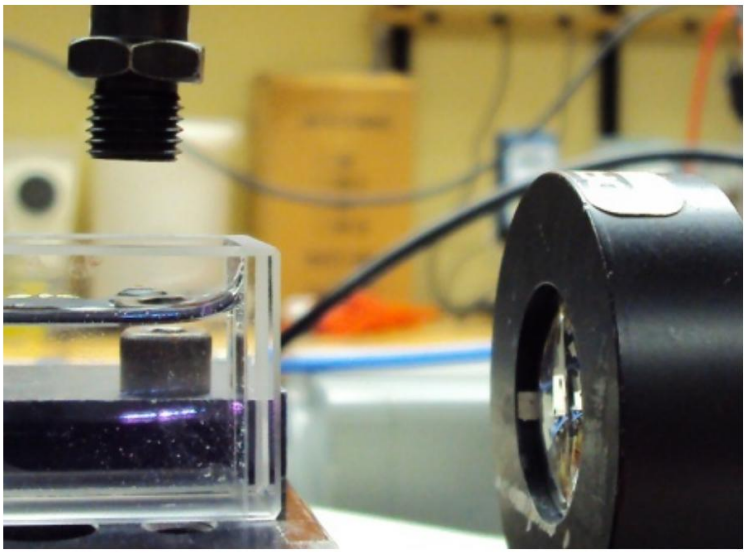
Inventors

Dustin McIntyre

Split Laser Systems for Remote Environmental Monitoring (13N-10)

Opportunity

Accurate environmental monitoring in extreme or remote settings such as subsurface storage, downhole drilling, and offshore exploration requires compact and durable optical systems capable of real-time measurements under high-temperature and -pressure conditions. NETL has developed a family of split laser systems that enable in-situ sensing using low peak power optical pumps and fiber-coupled solid-state lasers. These passively Q-switched systems perform laser-induced breakdown spectroscopy (LIBS) and Raman analysis directly at the monitoring site, allowing sensitive detection of gases, liquids, and solids without high-power transmission through optical fibers. The technology is available for licensing and/or further collaborative research from NETL.



Challenges Addressed

- Conventional laser monitoring systems are bulky, complex, and unsafe for remote or high-pressure use
- High peak power delivery through optical fibers can damage cables and limit deployment distance
- Real-time fluid chemistry monitoring during drilling or sequestration remains challenging

Potential Commercial Applications

- Long-term sequestration and leakage detection
- Downhole and offshore oil and gas monitoring
- Groundwater and municipal water quality analysis
- Real-time pollution assessment

Competitive Advantages

- Performs LIBS and Raman spectroscopy at remote sites using low-power optical pumping
- Compact, low-cost design with no moving parts or active electrical components
- Operates reliably in harsh environments such as boreholes or subsea wells
- Enables multipoint, fiber-linked sensing networks for distributed environmental monitoring

Intellectual Property Status

A U.S. patent was issued July 22, 2014, and expires June 2, 2032. Related patents include U.S. Patent No. 9,297,696 (Laser Based Analysis Using a Passively Q-Switched Laser, issued March 29, 2016) and U.S. Patent No. 9,548,585 (Multi-Point Laser Ignition Device, issued January 17, 2017). Related NETL Ref. Nos.: 12N-02 and 11N-06

Publications

- S. Woodruff, et al. Multi-Point Laser Ignition Device. (2017). *United States Patent and Trademark Office.* U.S. Patent No. 9,548,585.
- D. McIntyre, et al. Laser Based Analysis Using a Passively Q-Switched Laser. (2016). *United States Patent and Trademark Office.* U.S. Patent No. 9,297,696.

Licensing/Collaboration

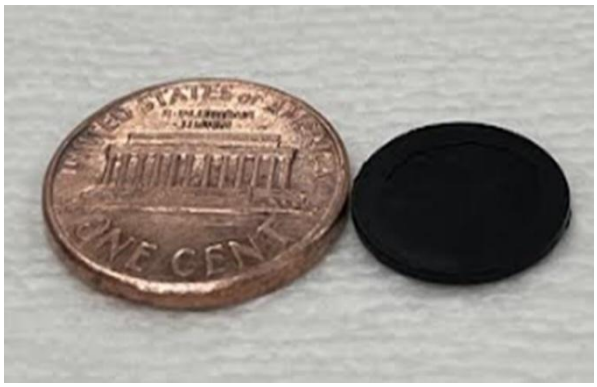
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Inventors

Steven Woodruff, Dustin McIntyre, and Jinesh Jain

High-Performance Carbon Electrode Material for Supercapacitors (23N-19 and 23N-13)

Opportunity



Compressed NETL 3DG electrode in comparison to a penny

Electrode design strongly influences the power density, energy density, and cycling durability of supercapacitors, yet many commercial carbons suffer from limited crystallinity, restricted ion transport, or mechanical instability at practical electrode loadings. NETL has developed a three-dimensional graphitized carbon (3DG) architecture that provides a highly conductive, hierarchically porous network capable of sustaining rapid charge storage in thick, free-standing electrodes. Produced through a simple, scalable process using low-cost carbon precursors, the material maintains structural integrity during compression and preserves its interconnected micro- and mesoporous framework. Electrodes fabricated from 3DG demonstrate increased specific and areal capacitance relative to standard activated carbons and retain approximately 80% of performance after 20,000 cycles. This innovation enables durable, high-loading electrodes suited for advanced grid storage, transportation, and power electronics applications and is available for licensing and/or collaborative research from NETL.

Challenges Addressed

- Conventional activated carbons show low capacitance, limited energy density, and poor conductivity
- Performance drops at commercial electrode loadings and thicknesses
- Lack of hierarchical porosity restricts ion transport and surface accessibility
- Advanced materials often require costly, complex, and unscalable synthesis methods

Potential Commercial Applications

- Grid-scale energy storage and stabilization
- Fast-charging energy systems for electric vehicles
- High-energy, high-power hybrid capacitors

Competitive Advantages

- Stores significantly more energy than standard commercial materials
- Charges and discharges faster while maintaining stability over repeated cycles
- Performs well even in thicker, commercially sized electrodes

Intellectual Property Status

A nonprovisional patent application has been filed in the U.S.

Publications

C. Matranga, et al. Carbon Electrode Material for Improving the Performance of Supercapacitors and Method of Making Carbon Electrode Material. (2024). *United States Patent and Trademark Office*. U.S. Patent Application Publication No. US20250054708A1.

Licensing/Collaboration

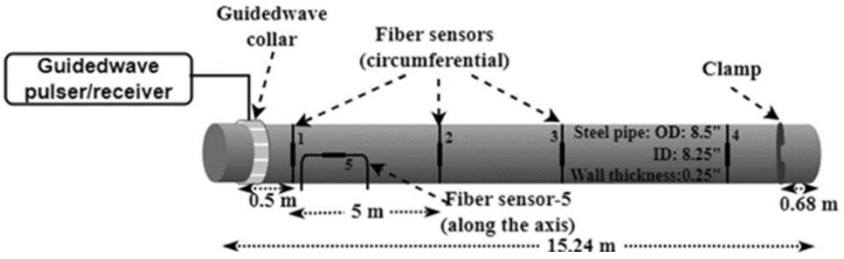
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Inventors

Christopher Matranga, Congjun Wang, Viet Hung Pham, Jennifer Weidman, and Yuan Gao

Fiber-Optic Sensor and Guided Acoustic Wave Monitoring Fusion for Pipelines (23N-01)

Opportunity



Schematic illustration of the guided wave acoustic/fiber-optic fusion system for pipeline health monitoring

Pipeline operators require monitoring systems that capture distributed structural changes rather than isolated inspection points, especially in environments where access is limited and electromagnetic interference may degrade electronic instruments. To address this need, NETL, in partnership with the University of Pittsburgh (Pitt), developed a sensing architecture that merges guided acoustic wave interrogation with multiplexed fiber-optic acoustic sensors. The system uses single-mode–multimode–single-mode (SMS) fiber structures capable of detecting vibration-induced spectral shifts from 10 Hz to 400 kHz, while guided waves generated along the pipe reveal reflections from corrosion, cracking, or third-party intrusion. Combining these modalities enables continuous, real-time localization of defects over long distances with minimal sensor footprint and straightforward fabrication. This technology is available for licensing and/or collaborative research through NETL in partnership with Pitt.

Challenges Addressed

- Point sensing and narrow bandwidth limit defect coverage in conventional guided wave systems
- Electrical sensors are bulky, susceptible to electromagnetic interference, and less practical for long runs
- Existing fiber solutions can be costly, complex to fabricate, and difficult to scale for multipoint monitoring

Potential Commercial Applications

- Continuous structural health monitoring of liquid and gas transmission pipelines
- Detection and localization of corrosion, erosion, fatigue, weld anomalies, and third-party intrusion
- Retrofit monitoring for remote or harsh environments where electromagentic interference immunity is required

Competitive Advantages

- Wide frequency response from 10 Hz to 400 kHz for high-resolution defect detection
- Quasidistributed sensing via multiplexed SMS fiber sensors for scalable coverage along the pipe
- High sensitivity with optical immunity to electromagnetic interference and suitability for harsh conditions
- Cost-effective sensor fabrication and integration with active guided wave excitation and advanced analytics

Intellectual Property Status

A PCT application has been filed in the U.S.

Publications

P. Ohodnicki, et al. Pipeline Monitoring Based on Ultrasonic Guided Acoustic Wave and Fiber Optic Sensor Fusion. (2024). *World Intellectual Property Office.* PCT Patent Application No. WO2024206298A1.

Licensing/Collaboration

Partnerships@netl.doe.gov

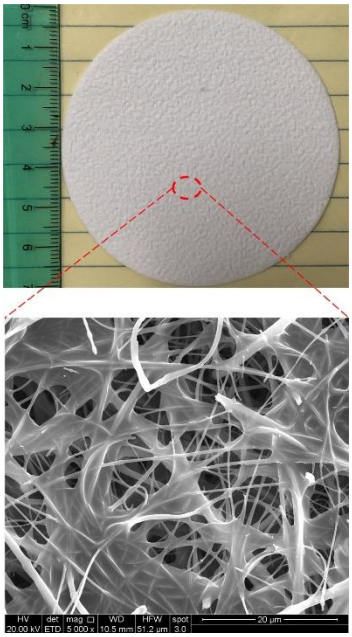
Inventors

Paul Ohodnicki Jr., Nageswara Rao Lalam, Ruishu Wright, and Pengdi Zhang

Fibrous Amine-Functionalized Matrix Flat Sheet Sorbent (22N-08)

Opportunity

Effective removal of dilute gases from air and selective recovery of metals from water require materials that load quickly, regenerate with low energy, and are simple to handle in flow systems. NETL and Battelle Memorial Institute have designed a fibrous amine functionalized matrix (FAM) flat sheet sorbent that applies a crosslinked polyamine coating to a glass microfiber mat, delivering high uptake, fast kinetics, and clean operation without free particles. The sheet format supports rapid microwave regeneration near room temperature for gas service and maintains performance across a wide pH range for metal recovery. This technology is available for licensing and/or further collaborative research from NETL in partnership with Battelle.



Scanning electron microscope image of the FAM

Challenges Addressed

- Particle sorbents are difficult to manage in flow systems and prone to dispersion or clogging
- Existing gas and liquid sorbents often require high regeneration temperatures and slow cycling times
- Many current sorbents have limited capacity or selectivity for low-concentration targets
- Conventional metal and contaminant removal systems can generate secondary waste or require complex chemical handling

Potential Commercial Applications

- Direct removal of trace gases from air and confined environments
- Purification of gas streams from industrial or well operations
- Wastewater treatment and polishing for lead, heavy metals, and rare earth elements
- Recovery of critical minerals from mine drainage or process leachates
- Integration into laminate or modular reactors for gas and liquid purification

Competitive Advantages

- Microwave-assisted regeneration at near-room temperature reduces operational costs and time
- Operates without free particles, minimizing maintenance and enabling direct integration in flow systems
- Maintains strong performance for metal recovery across pH 3-12 with reusable acid or buffer elution
- Adjustable coating chemistry allows performance customization and easy scaling

Intellectual Property Status

A nonprovisional patent application has been filed in the U.S.

Publications

M. Gray, et al. Fibrous Amine-Functionalized Matrix (Fam) For Contaminant Removal from Gaseous and Liquid Sources, Methods of Making and Use. (2024). *United States Patent and Trademark Office.* PCT Application Publication No. WO2024137851A1.

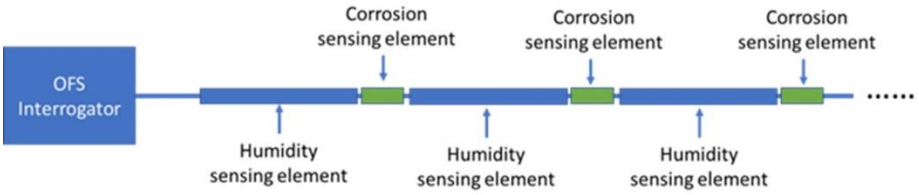
Licensing/Collaboration

Partnerships@netl.doe.gov

Inventors

McMahan Gray, Qiuming Wang, Walter Wilfong, and Fan Shi

Distributed Multiparameter Sensors for Corrosion and Humidity Monitoring (22N-05)



Schematic of distributed multiparameter OFS sensor for simultaneous monitoring of corrosion and humidity

Opportunity

Corrosion and humidity are leading causes of structural degradation in pipelines, bridges, and other critical infrastructure, often going undetected until costly failures occur. NETL has developed distributed multiparameter sensor systems that simultaneously monitor corrosion and humidity in real time. Using either optical fiber sensors (OFS) or surface acoustic wave (SAW) sensors, the system enables early detection of corrosion onset, moisture accumulation, and other precursors to damage across long distances and harsh environments. The optical fiber configuration integrates metal-coated and polymer-jacketed segments interrogated by optical frequency domain reflectometry to provide spatially resolved measurements of corrosion and humidity along a single fiber. Alternatively, the passive wireless SAW sensor array uses humidity- and corrosion-sensitive coatings to detect resonant frequency shifts, enabling wired or wireless monitoring. This technology is available for licensing and/or collaborative research from NETL.

Challenges Addressed

- Conventional corrosion monitoring relies on periodic inspections and localized sensors that cannot deliver continuous or distributed data
- Existing techniques are costly, limited in coverage, and often fail to detect early signs of corrosion or humidity-induced degradation
- Current sensors may lose accuracy or fail in harsh industrial conditions due to temperature, pressure, or electromagnetic interference

Potential Commercial Applications

- Continuous corrosion and humidity monitoring in oil, gas, and water pipeline networks
- Structural integrity management for bridges, tunnels, aircraft, and industrial facilities
- Monitoring of turbines, reactors, and combustion systems exposed to extreme environments

Competitive Advantages

- Simultaneous, real-time measurement of corrosion and humidity along a single optical fiber or multielement SAW array
- Distributed sensing enables spatial mapping of conditions over extended distances
- Operable in both liquid and gaseous environments, with resilience to heat, pressure, and electromagnetic interference
- Wireless and passive operation reduces maintenance and installation costs

Intellectual Property Status

A nonprovisional patent application has been filed in the U.S.

Publications

R. Wright, et al. Distributed Multi-parameter Sensors for Simultaneous Monitoring of Corrosion and Humidity: Optical Fiber Sensors and Surface Acoustic Wave Sensors. (2023). *United States Patent and Trademark Office.* U.S. Patent Application Publication No. US20230333024A1.

Licensing/Collaboration

Partnerships@netl.doe.gov

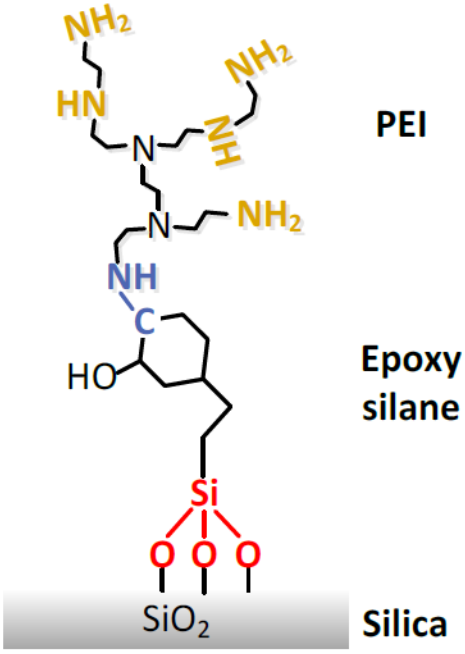
Inventors

Ruishu Wright, Nathan Diemler, Nageswara Lalam, Jagannath Devkota, and Paul R. Ohodnicki, Jr.

Stable Immobilized Amine Sorbents for the Decoloration of Wastewaters (21N-17 and 17N-18)

Opportunity

Industrial and municipal systems frequently struggle to remove organic colorants and similar pollutants from wastewater streams without incurring high costs or media loss. NETL has developed basic immobilized amine sorbents that covalently attach polyamines to porous silica or alumina supports using epoxysilane or polyepoxide linkers. This creates a durable, water-stable network capable of capturing a broad range of organic contaminants, including dyes and structurally related compounds, while maintaining performance in variable pH and high-salinity conditions. Laboratory studies show these sorbents can retain more than 90% of their active content after extended water exposure and remove up to 99% of target dyes under continuous flow. This technology is available for licensing and/or further collaborative research from NETL.



Schematic of 181D chemical structure

Challenges Addressed

- Organic dyes and similar contaminants persist through conventional treatment and foul membranes
- Many adsorbents leach active species or lose capacity across variable pH and salinity
- Existing solutions can be costly to regenerate and sensitive to co-ions such as sodium and calcium
- Media often lack mechanical stability under continuous flow

Potential Commercial Applications

- Textile, food processing, and coffee wastewater treatment
- Point-of-use and point-of-entry polishing for drinking water systems
- Polishing of ponds, lakes, rivers, seawater, and groundwater
- Adsorption of structurally similar organic pollutants, including selected phenols, pesticides, and perfluoro compounds

Competitive Advantages

- Covalently immobilized polyamines resist leaching in flow
- High capture across diverse dye classes and selected organics in the presence of salts
- Recyclable over multiple adsorption–desorption cycles with retained capacity
- Simple, scalable synthesis from low-cost raw materials
- Demonstrated structural stability and high organic content retention after accelerated water exposure

Intellectual Property Status

A U.S. patent was issued November 17, 2020, and expires January 19, 2039.

Publications

M. Gray, et al. Stable Immobilized Amine Sorbents for Removal of an Organic Contaminate From Wastewater. (2020). *United States Patent and Trademark Office.* U.S. Patent No. 10,836,654.

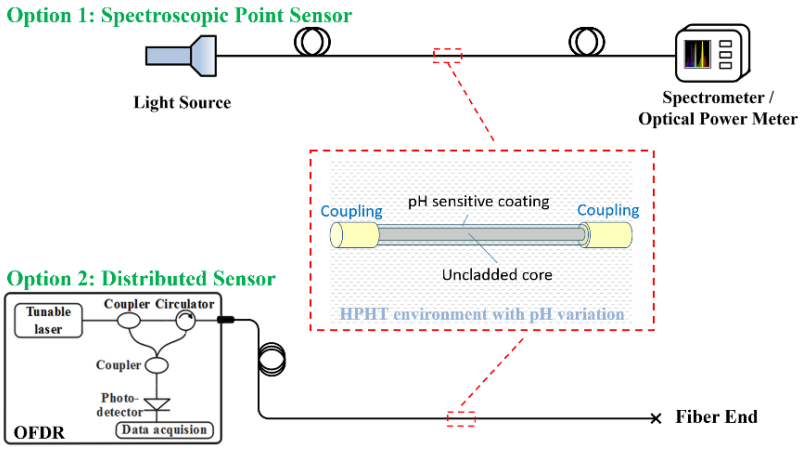
Licensing/Collaboration

Partnerships@netl.doe.gov

Inventors

McMahan Gray, Brian Kail, Qiuming Wang, and Walter C. Wilfong

Fiber-Optic pH Sensor for High-Temperature and High-Pressure Environments (20N-24)



Opportunity

Measuring pH in deep subsurface and industrial systems is essential for detecting corrosion, predicting cement degradation, and ensuring long-term operational safety. However, most conventional sensors fail under the high temperatures, pressures, and salinity typical of these environments. NETL has developed a fiber-optic pH sensor that uses a metal oxide-based coating to provide reversible and repeatable optical response over a broad pH range. The sensor operates without electrical components at the measurement site, enabling continuous, real-time pH monitoring in environments that exceed the limits of traditional electronic systems. This technology is available for licensing and/or collaborative research from NETL.

Challenges Addressed

- Inability of conventional electrode-based sensors to function reliably in deep or high-temperature environments
- Electrical component failure in corrosive and high-salinity wellbore conditions
- pH instability and measurement drift caused by degradation of polymer or dye-based coatings
- Difficulty monitoring cement chemistry and corrosion in real time during well operation or abandonment

Potential Commercial Applications

- Continuous pH monitoring in wellbores for early detection of corrosion and cement failure
- Subsurface sensing in oil, gas, geothermal, and underground storage systems
- Real-time monitoring of fluid chemistry in nuclear and chemical process facilities
- Corrosion detection in pipelines, wellbore plugs, and water-handling infrastructure
- Embedded or distributed sensing systems for industrial and research applications

Competitive Advantages

- Provides stable optical response to pH while resisting leaching and degradation at high temperature and pressure
- Operates without electrical wiring, preventing electromagnetic interference and hardware failure
- Lightweight design enables deployment in confined or distributed sensing networks
- Maintains accuracy and response stability over repeated cycles
- Compatible with additional optical coatings for temperature, pressure, or chemical monitoring

Intellectual Property Status

A nonprovisional patent application has been filed in the U.S.

Publications

F. Lu, et al. Metal Oxides Enabled Fiber Optic pH Sensor for High Temperature High pH Subsurface Environments. (2022). *United States Patent and Trademark Office*. U.S. Patent Application Publication No. US20220341902A1.

Licensing/Collaboration

Partnerships@netl.doe.gov

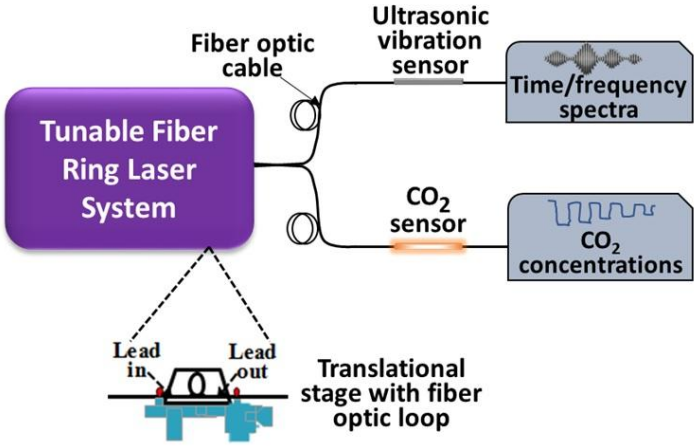
Inventors

Fei Lu, Ruishu Wright, Paul Ohodnicki Jr., and Ping Lu

Tunable Fiber Ring Laser for Dual Sensing (20N-23)

Opportunity

Real-time detection of gas composition and vibration signatures is critical for maintaining the safety and performance of pipelines, reactors, and industrial systems. NETL has developed a compact, low-cost fiber-optic sensor system that simultaneously measures both gas concentration and vibration using a single tunable fiber ring laser. This dual-function configuration simplifies traditional setups that require separate instruments, reducing system cost and complexity while improving accuracy and sensitivity. The invention integrates a vibration sensor based on a single-mode-multimode-single-mode (SMS) fiber structure with a gas detection module using a coreless optical fiber coated with a gas-sensitive film. The unified system enables continuous, high-resolution monitoring in harsh or confined environments. This technology is available for licensing and/or collaborative research from NETL.



System design for simultaneous vibration and gas sensing based on a tunable fiber ring laser

Challenges Addressed

- Conventional vibration sensors are prone to electromagnetic interference and limited frequency bandwidth
- Fiber-optic sensors using Bragg gratings or interferometers require complex fabrication and exhibit low sensitivity
- Gas and vibration parameters typically require separate systems, increasing cost and integration difficulty
- Existing sensor configurations lack compactness and real-time dual-parameter functionality

Potential Commercial Applications

- Condition monitoring of gas transmission and storage systems
- Integrity assessment of wellbores, reactors, and industrial process equipment
- Structural and vibration monitoring in turbines, transformers, and power systems
- Environmental or process gas analysis in transportation, aerospace, and manufacturing sectors

Competitive Advantages

- Dual sensing capability for gas and vibration using a single laser source
- Wide vibration frequency detection range (10 Hz to 400 kHz)
- Resistant to electromagnetic interference and extreme conditions
- Enables remote, real-time monitoring with improved sensitivity and signal quality

Intellectual Property Status

A U.S. patent was issued May 27, 2025, and expires August 26, 2043.

Publications

N. Lalam, et al. Simultaneous Ultrasonic Vibration and Gas Sensing Based on a Tunable Fiber Ring Laser. (2022). *United States Patent and Trademark Office.* U.S. Patent No. 12,313,540.

Licensing/Collaboration

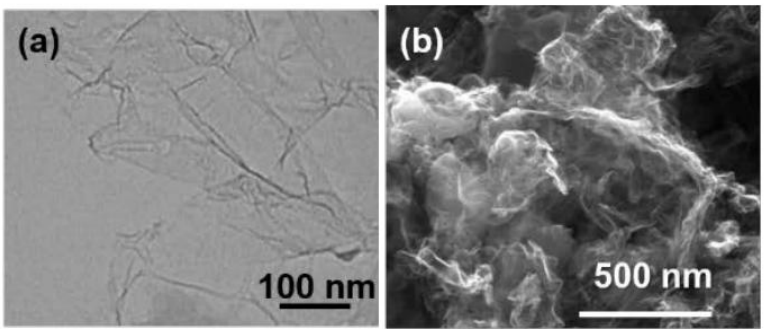
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Inventors

Nageswara Lalam, Michael Buric, Ping Lu, Fei Lu,Tao Hong, and Ruishu Wright

MARGA Aqueous Solution for Gas Separation (19N-30)

Opportunity



(a) Scanning electron microscopy and (b) transmission electron microscopy of coal-based graphene

Gas separation technologies, particularly those employing amine-based absorption, face substantial challenges, including being energy-intensive and having slow regeneration of the amine solution. As an alternative approach, NETL has employed a microwave-accelerated regeneration of a graphene-amine (MARGA) aqueous solution for gas separation. It utilizes microwave heating to rapidly and volumetrically heat a carbon dioxide (CO_2)-rich amine solution, typically 30% aqueous monoethanolamine. The addition of coal-based graphene to the solution significantly enhances microwave absorption, creating localized hot spots that accelerate CO_2 desorption. This method achieves CO_2 desorption rates over two orders of magnitude faster than conventional thermal heating and lowers the activation energy for desorption to 25.6 kJ/mol, enabling regeneration at lower temperatures. This technology is available for licensing and/or further collaborative research from NETL.

Challenges Addressed

- Conventional thermal regeneration processes demand significant energy input, typically in the form of steam, to heat the solution to high temperatures, resulting in high operating costs and substantial capital investment for the necessary equipment
- Slow kinetics of CO_2 desorption under these conditions further contributes to large equipment footprints and considerable water usage, ultimately hindering economic viability

Potential Commercial Applications

- Significantly reduces energy consumption and equipment size for CO_2 separation from large industrial and power plant emissions, making the process more cost-effective and efficient
- Offers a highly efficient and lower-cost method for removing CO_2, hydrogen sulfide, and sulfur dioxide from natural gas, biogas, refinery streams, and flue gases, improving product quality

Competitive Advantages

- The MARGA process utilizes microwave heating combined with graphene-enhanced amine solutions, significantly lowering the energy required for CO_2 desorption
- The MARGA method achieves effective CO_2 desorption at reduced temperatures, decreasing water evaporation and solvent degradation

Intellectual Property Status

A U.S. patent (U.S. App. No: 18/420,481) was filed January 23, 2024.

Publications

F. Shi, et al. Microwave-Accelerated Aqueous Solvent Regeneration Using Microwave Absorbers for Carbon Capture. (2025) *United States Patent and Trademark Office.* U.S. Patent Application Publication No. US20250235851A1.

Licensing/Collaboration

Partnerships@netl.doe.gov

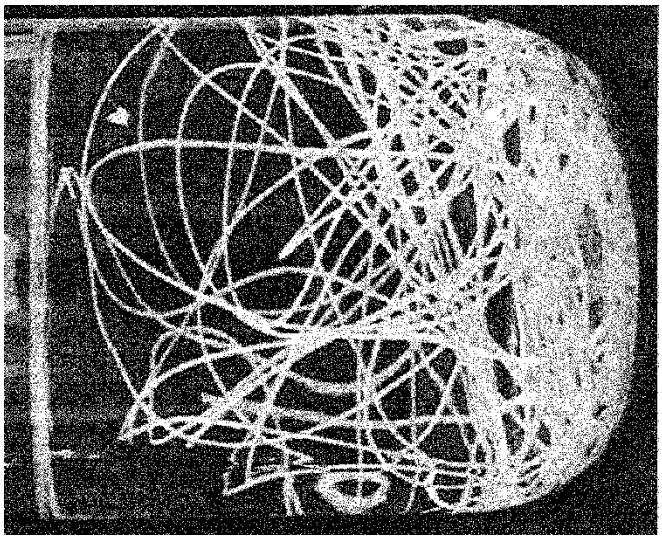
Inventors

Fan Shi, McMahan Gray, Yee Soong, Yuhua Duan, and Tuo Ji

Single-Step Synthesis of Chemisorption Fiber Sorbents for Gas Stream Purification (19N-24)

Opportunity

Many industrial gas purification systems rely on multistage sorbent processes that are costly, energy-intensive, and slow to regenerate. NETL has developed a method for fabricating chemisorption fiber sorbents through a single-step spinning process. The invention incorporates crosslinked, amine-based basic immobilized amine sorbents (BIAS) within a porous polymer fiber network to enable rapid and efficient separation of target gases from high-volume process streams. The resulting fibers combine the high sorption capacity of amine sorbents with the fast kinetics and heat management of a fiber structure, reducing cost, complexity, and energy use compared to traditional pellet or membrane systems. This technology is available for licensing and/or collaborative research from NETL.



Photograph of NETL chemisorption fiber sorbents

Challenges Addressed

- Multi-step fabrication of conventional fiber sorbents increases cost and limits scalability
- Sorbent degradation from high-temperature regeneration cycles
- Slow adsorption and desorption rates in packed-bed systems
- High energy penalties from inefficient heat transfer during adsorption

Potential Commercial Applications

- Gas purification and selective removal of acidic or reactive species from industrial exhaust streams
- Conditioning and upgrading biogas and process gas streams
- Integration with temperature- or pressure-swing adsorption systems for gas recovery or separation
- Chemical and petrochemical plant gas processing and emissions control

Competitive Advantages

- Direct spinning process reduces cost and enables large-scale production
- Up to 85% BIAS content uniformly distributed within fibers
- Porous fiber architecture allows rapid gas diffusion and efficient sorption
- Reduced thermal degradation and longer operational life
- Fiber structure promotes uniform temperature control and stable cycling

Intellectual Property Status

A U.S. patent was issued August 29, 2023, and expires September 16, 2041.

Publications

M. Gray, et al. Single-Step Synthesis of CHEmisorption Fiber Sorbents (CHEFS) for the Capture of CO2 and Removal of Water Contaminants. (2022). *United States Patent and Trademark Office.* U.S. Patent Application Publication No. US20220347654A1.

Licensing/Collaboration

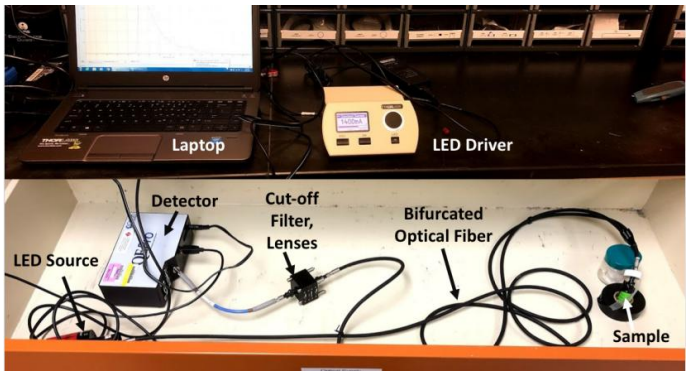
Partnerships@netl.doe.gov

Inventors

McMahan Gray, Fan Shi, Shouliang Yi, Walter Wilfong, and Qiuming Wang

Portable, Rapid, Fiber-Optic Luminescent Sensor for Rare Earth Elements Using Metal-Organic Framework Sensitizers (19N-15)

Opportunity



Photograph of the portable, optical, fiber-based luminescence spectrometer designed for REE detection

Rare earth elements (REEs) are indispensable components in a wide array of modern technologies, necessitating efficient and accurate detection methods throughout their life cycle, such as prospecting, resource characterization, processing and environmental monitoring. To address this need, researchers at NETL have designed a portable, optical, fiber-based luminescence spectrometer that utilizes a 275 nm LED excitation source and a spectrometer, which connects to a metal-organic framework (MOF)-functionalized sensing layer via a bifurcated fiber. MOF sensitizers, such as zinc adeninate MOFs with benzene-1,3,5-tricarboxylate linkers, are immobilized on the optical fiber tip using tetraethyl orthosilicate. These MOFs transfer energy to REEs like terbium, dysprosium, samarium, and europium, causing them to luminesce for detection and differentiation. The MOF immobilization process enables reversibility through dilute hydrochloric acid regeneration and enhances signal, achieving low detection limits (e.g., ~10 ppb for terbium) and improved selectivity and robustness against interferants. This technology is available for licensing and/or further collaborative research from NETL.

Challenges Addressed

- High-precision laboratory methods, such as inductively coupled plasma mass spectrometry (ICP-MS), are typically costly and time-intensive
- Field-portable techniques like X-ray fluorescence and laser-induced breakdown spectroscopy often lack the sensitivity required for trace-level detection

Potential Commercial Applications

- This portable, rapid, and cost-effective sensor enables on-site detection of REEs in environmental samples
- This technology enables real-time, selective, and robust monitoring of REE concentrations in liquid process streams

Competitive Advantages

- Portable, field-deployable sensors allow on-site detection of REEs, unlike ICP-MS
- Fiber-optic luminescent sensor MOF sensitizers reduce equipment and operating expenses
- Quick detection of multiple high-value emissive REEs using photoluminescence enables higher efficiency compared to traditional methods

Intellectual Property Status

A U.S. patent (U.S. App. No: 18/229,329) was filed August 2, 2023.

Publications

P. Ohodnicki, et al. Fiber Optic Luminescence-Based Sensor Using Metal-Organic Frameworks for Detection of Rare Earth Elements. (2025). *United States Patent and Trademark Office.* U.S. Patent Application Publication No. US20250044227A1.

Licensing/Collaboration

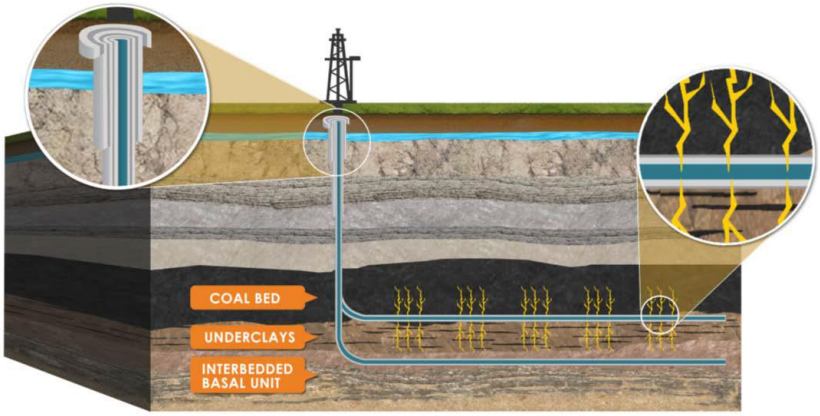
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Inventors

Paul Ohodnicki, Jr., John Baltrus, and Scott Crawford

Organic Acid–Salt Solutions for Low-Temperature Rare Earth Extraction (19N-11)

Opportunity



In-situ recovery concept drawing of one possible extraction method applied in advance of underground mining

Recovering rare earth elements (REEs) or critical minerals from domestic sedimentary materials remains difficult using conventional high-temperature, strong-acid leaching processes that dissolve large amounts of unwanted minerals and introduce safety, waste-handling, and cost barriers. NETL has established a low-temperature extraction method that uses tailored organic acid solutions containing both an organic acid and an ionic salt to selectively mobilize REEs from underclays, claystones, shales, coal-mining waste, and waste coal. These organic acid solutions operate at near-ambient temperatures and moderate pH, allowing selective leaching of rare earths and yttrium while substantially limiting dissolution of iron, aluminum, thorium, and other problematic gangue elements. By leveraging mild chemistries inspired by natural weathering processes, the approach can reduce processing hazards, shorten extraction steps, and enable the productive use of clay-rich materials that are currently discarded. This technology is available for licensing and/or further collaborative research from NETL.

Challenges Addressed

- REEs are vital for advanced technological and energy applications, yet the global supply is largely dominated by international competitors, creating strategic vulnerabilities for the U.S.
- There are significant hurdles in efficiently recovering these critical elements from underutilized domestic resources, such as coal-related waste materials and underclay deposits

Potential Commercial Applications

- Cost-effective method to extract valuable REEs and critical metals from abundant coal mining wastes and byproducts, transforming liabilities into assets
- Selective recovery of REEs and critical metals from natural clay-rich geological formations, including through innovative in-situ methods

Competitive Advantages

- Organic acid leaching operates effectively at lower temperatures, decreasing energy consumption and associated costs compared to high-temperature inorganic acid leaching
- Organic acids like citric acid preferentially leach heavy REEs, enhancing selectivity over traditional inorganic acids

Intellectual Property Status

A U.S. patent (US11814700) was issued November 14, 2023, and expires September 4, 2040.

Publications

J. Yang, et al. Assessing the Extractability of Rare Earth Elements from Coal Preparation Fines Refuse Using an Organic Acid Lixiviant. (2021). *Mining, Metallurgy and Exploration* 38. DOI: https://doi.org/10.1007/s42461-021-00439-2.

Licensing/Collaboration

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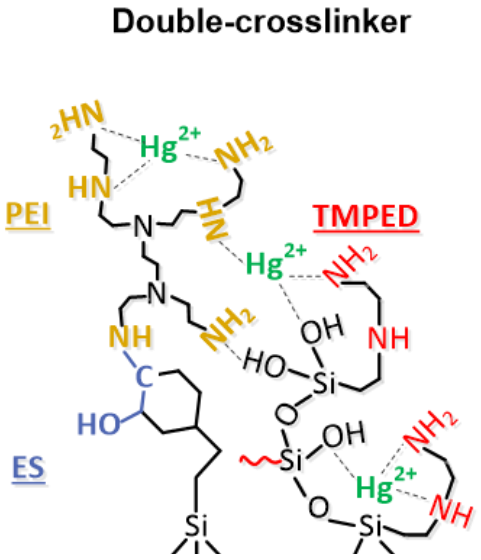
Inventors

Circe Verba, Mark McKoy, Thomas Tarka, Scott Montross, and Jonathan Yang

Multifunctionalized Sorbents for Removal of Metal Contaminants from Wastewater (19N-04)

Opportunity

Heavy metal contamination in industrial and municipal wastewater presents persistent challenges due to the stability and mobility of metal ions and oxyanions such as those of arsenic, selenium, and chromium. NETL has developed a multifunctionalized amine-based sorbent material with significantly enhanced capacity, more than 50% higher than conventional amine sorbents, for removing both cationic and oxyanionic metals from aqueous sources. This technology is available for licensing and/or collaborative research from NETL.



Chemical structure of NETL amine sorbents immobilized on silica oxide

Challenges Addressed

- Ineffective capture of oxyanion-based heavy metals using conventional amine sorbents
- Leaching and degradation of sorbents during use in aqueous and variable pH environments
- Limited selectivity and capacity for mixed-metal or radioactive waste streams
- High operational cost of solvent extraction and ion exchange methods

Potential Commercial Applications

- Treatment of industrial wastewater, including coal combustion, mining, and hydraulic fracturing effluents
- Recovery of valuable or toxic metals from process streams
- Water purification in energy production and nuclear waste management
- Deployment in fixed-bed or flow-through systems for continuous contaminant removal

Competitive Advantages

- More than 50% improvement over conventional amine-based sorbents
- Combines epoxysilane and aminosilane linkers to stabilize polyamines and prevent leaching
- Maintains performance under acidic and caustic conditions
- Strong affinity for both cationic and oxyanionic metals, including radioactive isotopes
- Simple one-step preparation using widely available raw materials

Intellectual Property Status

A U.S. patent was issued December 26, 2023, and expires August 10, 2041.

Publications

M. Gray, et al. Multi-Functionalized Basic Immobilized Amine Sorbents for Removal of Metal Contaminants from Wastewater. (2023). *United States Patent and Trademark Office*. U.S. Patent No. 11,850,571.

Licensing/Collaboration

Partnerships@netl.doe.gov

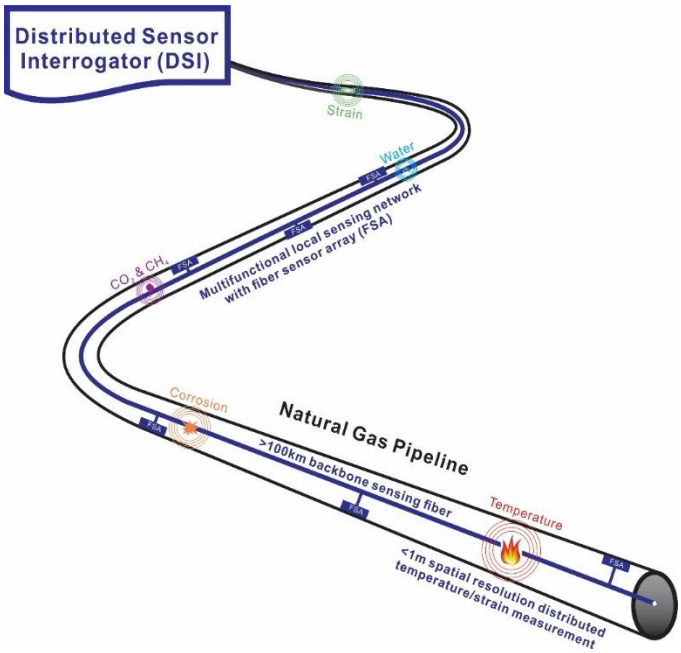
Inventors

McMahan Gray, Brian Kail, Walter Wilfong, Qiuming Wang, and Fan Shi

Corrosion Detection Sensors for Use in Natural Gas Pipelines (17N-21)

Opportunity

Pipeline corrosion poses a major safety and economic challenge for the natural gas industry, accounting for billions of dollars in maintenance and failure-related costs each year. NETL has developed a new sensing technology that enables early detection of corrosion inside natural gas pipelines using either optical or wireless platforms. The system employs a distributed fiber-optic network or wireless sensor array capable of monitoring localized condensation and corrosion indicators along extensive pipeline systems, allowing operators to predict corrosion rates and implement preventive measures before damage occurs. This technology is available for licensing and/or further collaborative research from NETL.



Challenges Addressed

- Corrosion is responsible for a significant portion of natural gas pipeline failures and associated maintenance costs
- Existing inspection and monitoring systems are limited in their ability to detect early corrosion or localized pitting
- Pipeline operators need real-time, distributed sensing systems that can detect internal corrosion onset without disrupting operations

Potential Commercial Applications

- Real-time corrosion monitoring for natural gas transmission and gathering lines
- Structural health assessment for oil, gas, and chemical pipeline infrastructure
- Integration into digital pipeline management and predictive maintenance systems
- Monitoring of other metal structures exposed to moisture or corrosive environments
- Deployment in subsea, industrial, or refinery applications where internal corrosion risk is high

Competitive Advantages

- Identifies corrosion indicators such as water droplet condensation and pH changes
- Available in both optical fiber and wireless sensor configurations
- Enables precise, spatially resolved corrosion detection along pipeline segments
- Detects subtle chemical and environmental variations before visible corrosion occurs
- Provides continuous data without requiring invasive inspection procedures

Intellectual Property Status

A U.S. patent was issued August 15, 2023, and expires October 2, 2038.

Publications

P. Ohodnicki, et al. Distributed Fiber-Optic Sensor Network for Sensing the Corrosion Onset and Quantification. (2023). *United States Patent and Trademark Office.* U.S. Patent No. 11,726,047.

Licensing/Collaboration

Partnerships@netl.doe.gov

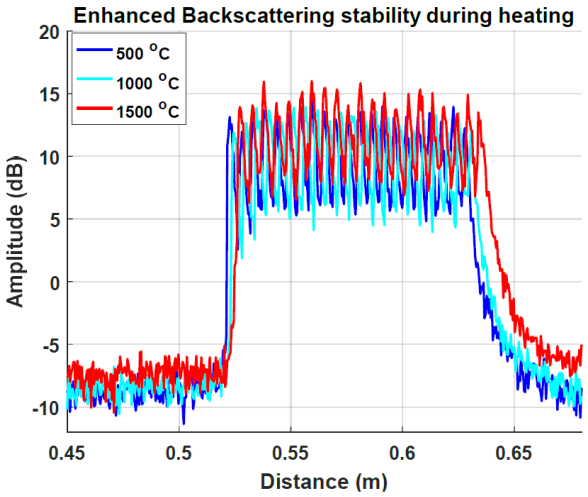
Inventors

Paul Ohodnicki, Jagannath Devkota, Ping Lu, and Ruishu Wright

Nanograting Enhanced Distributed Fiber Sensors (17N-13)

Opportunity

Reliable temperature mapping in high-temperature reactors requires optical fibers that maintain stable Rayleigh scattering profiles even after prolonged exposure to harsh thermal and chemical conditions. Rayleigh scattering arises from nanoscale refractive index variations within the fiber core, and its wavelength dependent pattern acts as a unique optical fingerprint used for distributed sensing. Researchers at NETL and the University of Pittsburgh (Pitt) established a method that uses tightly focused ultrafast laser pulses to inscribe nanograting elements directly within the fiber core. These periodic structures amplify the intrinsic Rayleigh response, improving spectral correlation for optical frequency domain reflectometry and enabling high-resolution distributed measurements. The modified fibers sustain their scattering characteristics at temperatures where standard telecommunications fibers experience structural drift, supporting long duration monitoring in systems such as solid oxide fuel cell assemblies. The fabrication process preserves the external geometry of single-mode fibers, enabling straightforward integration into existing sensing architectures. This technology is available for licensing and/or further collaborative research from NETL in partnership with Pitt.



Enhanced backscattering profile along with the central tube-furnace reading as the furnace ramped up to 1,500°C

Challenges Addressed

- Reliable distributed temperature measurements are crucial for monitoring critical infrastructure and processes, particularly in harsh environments such as solid oxide fuel cells
- Approaches involving liquids in hollow core fibers or specialized polymer fibers can be prohibitively expensive or incompatible with standard optical equipment

Potential Commercial Applications

- Enables precise, distributed temperature measurements in high-temperature and harsh industrial and energy production environments
- Provides reliable, distributed temperature sensing for critical assets and infrastructure, enhancing safety and operational integrity

Competitive Advantages

- Increases Rayleigh backscattering intensity by over 50 dB
- Remains stable up to 800°C, unlike ultraviolet-induced enhancements in hydrogen-loaded fibers, which may degrade at elevated temperatures
- Utilizes commercially available silica fibers, avoiding the need for specialized fibers like hollow-core or polymer fibers

Intellectual Property Status

A U.S. patent (US10670802) was issued June 2, 2020, and expires August 30, 2038.

Publications

P. Chen, et al. Method of Making a Distributed Optical Fiber Sensor Having Enhanced Rayleigh Scattering and Enhanced Temperature Stability, and Monitoring Systems Employing Same. (2020). *United States Patent and Trademark Office.* U.S. Patent No. 10,670,802.

Licensing/Collaboration

Partnerships@netl.doe.gov

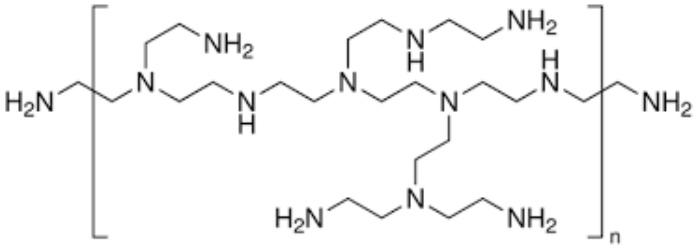
Inventors

Peng Kevin Chen, Aidong Yan, Michael Buric, Paul Ohodnicki, and Sheng Huang

Regenerable Nonaqueous Sorbent Slurries for Gas Separation (16N-02)

Opportunity

Efficiently separating target gases from process streams remains a persistent challenge for industries seeking durable, low-energy separation technologies. NETL has developed a regenerable sorbent slurry that uses basic immobilized amine sorbent (BIAS) particles suspended in a nonaqueous silicone oil carrier. This system combines the benefits of solid sorbents with the flow properties of a liquid medium, offering high gas absorption capacity, reduced corrosion, and simpler regeneration compared to conventional aqueous amine systems. The composition can be readily integrated into existing industrial gas treatment systems using standard scrubber or reactor designs. This technology is available for licensing and/or further collaborative research from NETL.



Chemical structure of polyethyleneimine, a component of BIAS particles

Challenges Addressed

- Conventional aqueous amine systems are energy-intensive and prone to corrosion and degradation
- Solid sorbents used in dry systems can be difficult to handle and lose effectiveness through particle attrition or aerosolization
- Many gas separation technologies require large infrastructure modifications or complex regeneration processes
- Industries need cost-effective, regenerable materials that maintain stability under continuous operation

Potential Commercial Applications

- Gas purification and separation in power generation and industrial processing
- Treatment of natural gas and synthesis gas streams to remove target contaminants
- Adaptable for use in chemical manufacturing, gas sweetening, and refining operations
- Retrofitting existing scrubber systems with nonaqueous sorbent slurries
- Regenerable solvent systems for continuous gas absorption and release

Competitive Advantages

- Nonaqueous silicone oil carrier reduces heating requirements during gas release
- Immobilized amines minimize chemical breakdown and equipment wear
- Provides strong gas absorption without the limitations of liquid-only systems
- Compatible with existing reactor types such as scrubbers, packed beds, and bubble columns
- Maintains sorbent integrity through multiple absorption-regeneration cycles

Intellectual Property Status

A U.S. patent was issued September 8, 2020, and expires August 23, 2038.

Publications

F. Shi, et al. Regenerable Non-Aqueous Basic Immobilized Amine Slurries for Removal of CO2 from a Gaseous Mixture and a Method of Use Thereof. (2020). *United States Patent and Trademark Office.* U.S. Patent No. 10,765,997.

Licensing/Collaboration

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Inventors

Fan Shi, McMahan Gray, Jeffrey Culp, Brian Kail, and Christopher Marin

Sensors for Corrosion Monitoring in Harsh Environments (15N-22)



Opportunity

Critical infrastructure in the subsurface and other harsh environments is routinely exposed to high temperatures, high pressures, salinity, and chemically aggressive species that accelerate corrosion. Conventional electrochemical probes require electrical contacts at the measurement point, limiting their usefulness for wide-area or distributed monitoring and increasing the likelihood of sensor failure. NETL has developed corrosion proxy material integrated sensor devices that provide early detection of corrosion onset using optical or passive wireless sensor platforms. By incorporating a thin film that corrodes faster than the underlying structural material, the system detects characteristic changes in optical, electrical, or mass-related properties before significant degradation occurs in the host component. This approach enables remote, embedded, and distributed corrosion monitoring in extreme environments without the need for electrical wiring at the sensing location. This technology is available for licensing and/or further collaborative research from NETL.

Challenges Addressed

- Conventional electrochemical sensors require electrical connections that are unreliable in harsh environments
- Existing corrosion sensors are not well suited for wide-area or distributed monitoring
- Early-stage corrosion is difficult to detect before significant structural damage occurs

Potential Commercial Applications

- Corrosion monitoring in natural gas pipelines, wellbores, and subsurface infrastructure
- Integrity assessment for offshore systems, geological formations, and high-salinity environments
- Monitoring of turbines, combustion chambers, boilers, and other high-temperature systems
- Condition-based maintenance for bridges, water pipelines, industrial assets, and critical facilities

Competitive Advantages

- Enables remote, wireless detection of early corrosion onset
- Operates under extreme temperature and pressure conditions
- Compatible with optical fiber and surface acoustic wave sensor platforms
- Facilitates wide-area, distributed monitoring without electrical connections
- Utilizes corrosion proxy films that provide measurable signals before bulk material degradation

Intellectual Property Status

A U.S. patent was issued March 1, 2022, and expires December 30, 2036.

Publications

P. Ohodnicki, et al. Corrosion Proxy Material Integrated Sensor Devices for Distributed Sensing of Early Corrosion Onset and Corrosion Quantification. (2022). *United States Patent and Trademark Office.* U.S. Patent No. 11,262,289.

Licensing/Collaboration

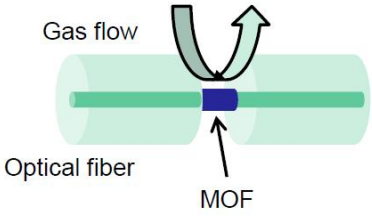
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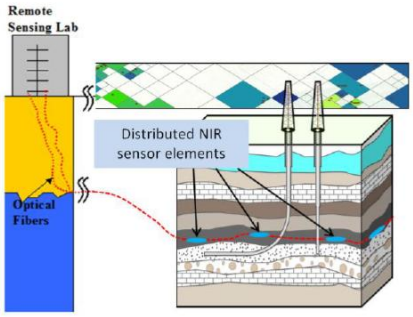
Inventors

Paul Ohodnicki and Malgorzata Ziomek-Moroz

Metal-Organic Framework and Plasmonic Nanomaterial Fiber-Optic Gas Sensor (15N-04)

Opportunity





Gas sensing platforms used in industrial environments must be compact and stable while still offering strong analyte selectivity and high signal strength at low concentrations. Engineered in collaboration between NETL and Oregon State University (OSU), this fiber-optic sensor combines a metal-organic framework (MOF) coating with a plasmonic nanostructure to strengthen analyte–light interactions and amplify near-infrared absorption signals. The MOF layer functions as a selective preconcentrator that draws target molecules into the optical field, while the plasmonic material provides localized electromagnetic enhancement that produces measurable transmission shifts at low gas concentrations. The architecture supports rapid response times, compatibility with standard fiber components, and tuning for specific analytes through MOF chemistry selection. This technology is available for licensing and/or further collaborative research from NETL in partnership with OSU.

Challenges Addressed

- Mid-infrared absorption spectroscopy offers high sensitivity and reliability for identifying various gases; however, these systems are typically bulky, expensive, and require specialized equipment
- Near-infrared (NIR) systems have inherently low sensitivity for most gases, as molecular absorption bands in the NIR region are generally weak

Potential Commercial Applications

- Rapid response, high sensitivity for trace gases, and robustness make it suitable for real-time monitoring of industrial processes
- The sensor can precisely monitor critical gas levels in greenhouses for optimal crop growth or in food storage facilities to detect spoilage and extend shelf life

Competitive Advantages

- Use of MOF coatings significantly increases local gas concentration at the fiber surface, amplifying the weak NIR absorption signals
- By operating in the NIR region and utilizing fiber-optic technology, the invention offers a compact and robust sensor suitable for distributed and remote sensing applications
- Ultrathin MOF films provide high surface area and rapid adsorption/desorption kinetics, resulting in faster response times for real-time monitoring

Intellectual Property Status

A U.S. patent (US9983124) was issued May 29, 2018, and expires February 9, 2036.

Publications

A. Wang, et al. Sensor Device Comprising a Substrate Coupled to a Sensing Component Comprising a Metal-Organic Framework and a Plasmonic Nanomaterial. (2018). *United States Patent and Trademark Office*. U.S. Patent No. 9,983,124.

Licensing/Collaboration

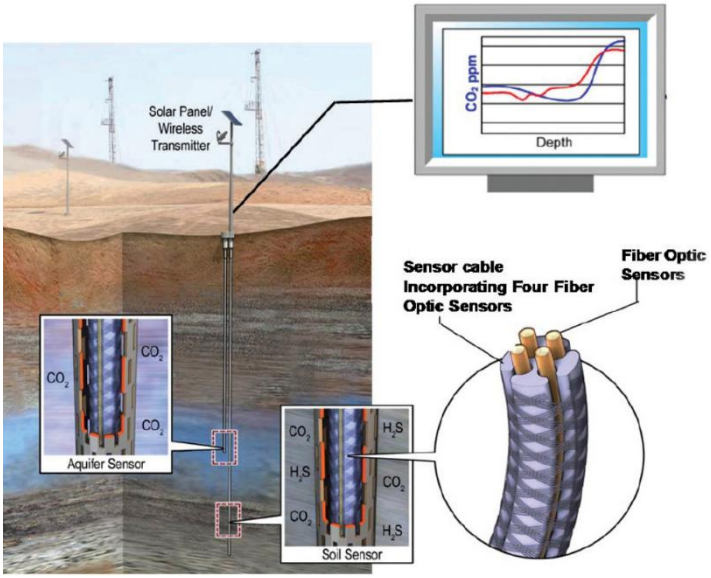
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Inventors

Alan X. Wang, Chih-Hung Chang, Ki-Joong Kim, Xinyuan Chong, and Paul R. Ohodnicki

Fiber-Optic Nanoparticle pH Sensors for Harsh Environments (15N-02 and 14N-19)

Opportunity



Accurate, real-time pH measurement in downhole, subsea, and other harsh environments is difficult because conventional electrode and dye-based sensors drift, leach, or fail under high temperature, high pressure, high salinity, and corrosive conditions. NETL has developed complementary optical pH sensing approaches that transduce pH-dependent changes in optical properties using nanoparticles integrated with fiber-optic platforms. One method embeds electronically conductive or plasmonic metal nanoparticles in a stable matrix that modulates optical response with surface charge changes over pH 2 to 12. A second method fixes inorganic-oxide nanoparticles directly on a substrate or optical fiber to achieve localized refractive index modulation without requiring a responsive host matrix. Together, these approaches enable robust, reversible, and fast pH sensing suitable for distributed or embedded monitoring. This technology is available for licensing and/or further collaborative research from NETL.

Challenges Addressed

- Conventional pH probes lack stability at elevated temperature and pressure
- Electrical sensors require local wiring and packaging that fail in aggressive media
- Prior sol-gel coatings often need bent fibers and offer limited long-term stability
- Lack of real-time, distributed pH data limits process control and materials selection

Potential Commercial Applications

- Downhole and subsea pH monitoring for resource extraction and well integrity
- pH mapping in geological formations and test wells
- Industrial process monitoring in hot, corrosive, or saline aqueous systems

Competitive Advantages

- High-stability sensing layers for harsh environments with reversible response
- Compatibility with silica fiber platforms for remote and distributed measurements
- Tunable response via nanoparticle composition, size, and morphology

Intellectual Property Status

U.S. Patent No. 11,408,827 issued August 9, 2022, with anticipated expiration on April 24, 2035.
U.S. Patent No. 10,274,431 issued April 30, 2019, with adjusted expiration on February 10, 2037.

Publications

- P. Ohodnicki, et al. Method of Evaluating pH Using a Metallic Nanoparticle Incorporated Nanocomposite-Based Optical pH Sensor. (2022). *United States Patent and Trademark Office.* U.S. Patent No. 11,408,827.
- D. Kauffman, et al. Method of Evaluating pH Using an Inorganic-Oxide Nanoparticle-Based Optical pH Sensor. (2019). *United States Patent and Trademark Office.* U.S. Patent No. 10,274,431.

Licensing/Collaboration

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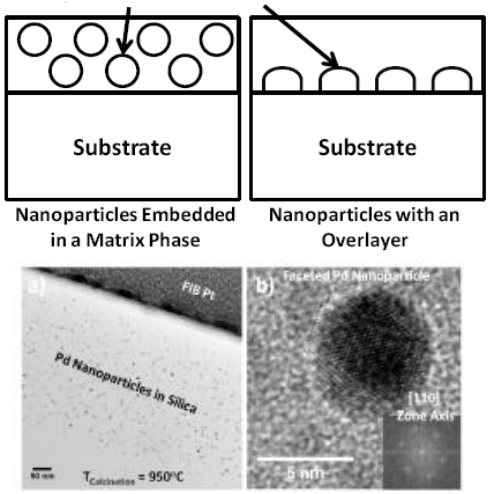
Inventors

Paul Ohodnicki, Jr., Congjun Wang, Thomas Brown, Barbara Kutchko, Douglas Kauffman, Christopher Matranga, and Xin Su

Palladium and Platinum Nanocomposite Sensors for Selective Hydrogen Detection (15N-01)

Opportunity

Accurate detection of hydrogen in complex gas environments is critical for safety and performance in energy, aerospace, and industrial systems. NETL has developed an optical hydrogen sensor that uses palladium- and platinum-based nanoparticles dispersed in an inert matrix to detect hydrogen through shifts in optical signals. The sensor structure can include engineered filter layers that enhance selectivity by allowing hydrogen to diffuse through while blocking other gases such as carbon monoxide or methane. This optical approach eliminates the need for electrical wiring at the sensing point, improving safety and reliability in high-temperature or explosive environments. This technology is available for licensing and/or further collaborative research from NETL.



Schematic and images of Pd nanoparticles embedded (left) or coating silica substrate (right)

Challenges Addressed

- Conventional hydrogen sensors often suffer from poor selectivity in mixed gas environments
- Electrical contact-based sensors present ignition and corrosion risks in explosive or high-temperature conditions
- Existing systems require frequent calibration and are limited in their response range and sensitivity
- Many sensing materials degrade under repeated hydrogen cycling or long-term operation

Potential Commercial Applications

- Hydrogen leak detection and safety monitoring for industrial and energy systems
- Real-time hydrogen sensing in gas turbines, fuel cells, and reformers
- Condition-based monitoring of dissolved hydrogen in transformer oil
- Aerospace and defense applications where lightweight, wireless sensors are preferred
- Metallurgical and process monitoring at elevated temperatures

Competitive Advantages

- Engineered filter layers improve discrimination against interfering gases
- Nanoparticle-based films maintain structural integrity and responsiveness at high temperatures
- Eliminates electrical wiring and contacts at the sensing point, reducing explosion risk
- Applicable as single-layer nanocomposites, multilayer thin films, or integrated optical coatings

Intellectual Property Status

A U.S. patent was issued December 26, 2023, and expires August 10, 2041.

Publications

P. Ohodnicki, et al. Palladium and Platinum-Based Nanoparticle Functional Sensor Layers and Integration with Engineered Filter Layers for Selective H2 Sensing. (2019). *United States Patent and Trademark Office.* U.S. Patent No. 10,345,279.

Licensing/Collaboration

Partnerships@netl.doe.gov

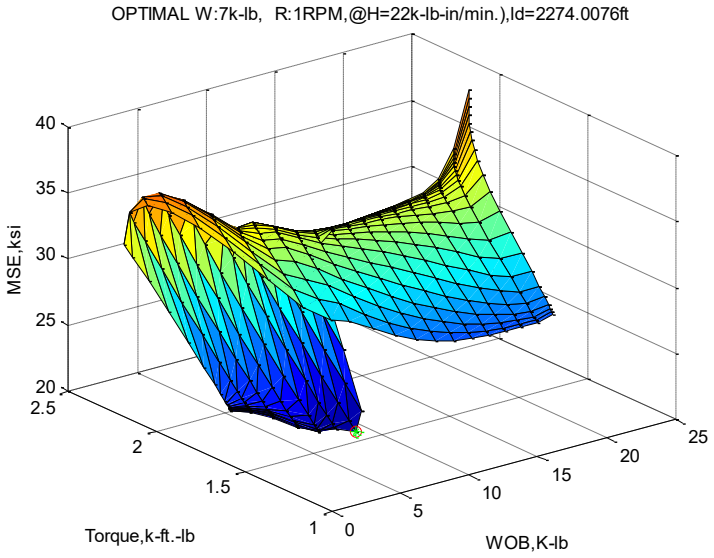
Inventors

Paul Ohodnicki, Jr., Chenhu Sun, John Baltrus, and Thomas Brown

Computational and Simulation-Based Tools for Drilling Optimization (12N-20)

Opportunity

Efficient drilling becomes increasingly difficult as wells deepen and rock strength, temperature, and pressure increase. Conventional drilling practices rely on operator judgment, drill-off tests, and rule-of-thumb parameter ranges that do not capture the complex, nonlinear relationship between weight-on-bit (WOB), rotational speed (RPM), hydraulic power (H), rate of penetration (ROP), and specific energy (SE). NETL has designed a computational method that uses real-time measurement-while-drilling (MWD) data and artificial neural networks to directly relate controllable drilling parameters to performance indicators such as mechanical specific energy and ROP. The system predicts drilling behavior at probable operating points and recommends parameter combinations that achieve the lowest SE or highest ROP/SE ratio. This technology is available for licensing and/or further collaborative research from NETL.



Mechanical specific energy, the mechanical energy consumed in removing unit volume of rock, as a function of controlled drilling parameters

Challenges Addressed

- Drilling parameters (WOB, RPM, H) are adjusted through trial-and-error rather than optimized relationships
- Current practices do not directly link controllable parameters to SE or ROP
- Empirical models fail under changing subsurface conditions
- Inefficient drilling leads to slower penetration and reduced operational effectiveness

Potential Commercial Applications

- Onshore and offshore oil and gas drilling
- Geothermal drilling operations
- Real-time drilling automation systems
- Digital drilling platforms requiring predictive control models

Competitive Advantages

- Direct prediction of torque, SE, and ROP from controllable inputs
- Continuously updated models that adapt to changing drilling conditions
- Supports safer, more consistent drilling performance
- Requires no specialized hardware and leverages existing MWD data streams

Intellectual Property Status

A U.S. patent was issued March 5, 2019, and expires July 22, 2037.

Publications

W. Zhang, et al. MSE-Based Drilling Optimization Using Neural Network Simulation. (2019). *United States Patent and Trademark Office.* U.S. Patent No. 10,221,671.

Licensing/Collaboration

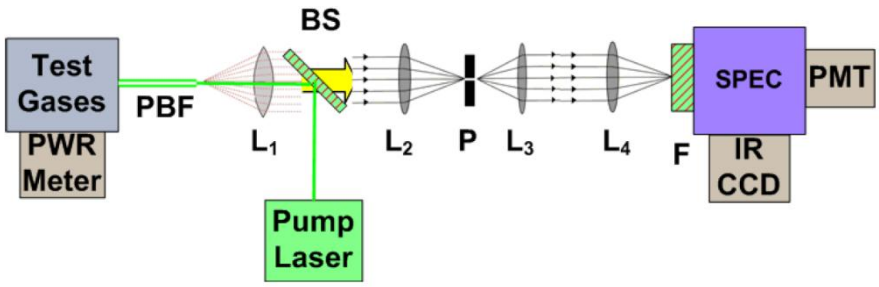
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Inventors

Wu Zhang

Gas Sensing System Employing Raman Scattering (10N-26)

Opportunity



Accurate, real-time measurement of gas composition is essential for industrial systems that rely on natural gas, synthesis gas, biogas, or mixed fuel streams, yet existing analytical methods such as mass spectrometry and gas chromatography are too slow or complex for continuous control. NETL , in collaboration with the University of Pittsburgh (Pitt), has developed a Raman-based gas sensing system that rapidly identifies and quantifies all major components in a gas mixture. Raman scattering generates only a small number of useful photons during each laser–gas interaction, limiting sensitivity and demanding high-end optics. By guiding the laser through a hollow waveguide and optimizing the coupling of the Stokes-shifted photons to the detector, this design increases Raman signal strength and allows continuous measurement of gas composition in one second or less. The system enables real-time fuel characterization that can dramatically improve combustion efficiency and process control. This technology is available for licensing and/or further collaborative research from NETL and Pitt.

Challenges Addressed

- Conventional gas analyzers lack the speed needed for real-time process control
- High-accuracy measurements require large instruments and laboratory workflows
- Natural gas composition varies by source, reducing combustion efficiency without active adjustment
- Existing sensors cannot simultaneously quantify all major fuel-gas components at high speed

Potential Commercial Applications

- Real-time characterization of natural gas composition for turbine and pipeline operations
- Process monitoring for gasifiers, reformers, and industrial reactors
- Analysis of biogas, landfill gas, and other variable-quality fuel streams
- Inline fuel-air ratio control for combustion optimization

Competitive Advantages

- Measures major gas components with better than 0.1% accuracy in one second or less
- Uses low laser power and low-resolution spectrometers to reduce system cost
- Operates at pressures from 10 to 800 psi and gas temperatures up to 200°C
- Hollow waveguide design increases Raman signal strength and sensitivity
- Enables continuous, high-speed monitoring for improved process efficiency

Intellectual Property Status

A U.S. patent was issued March 18, 2014, and expires February 4, 2032.

Publications

J. Falk, et al. Gas Sensing System Employing Raman Scattering. (2014). *United States Patent and Trademark Office.* U.S. Patent No. 8,674,306.

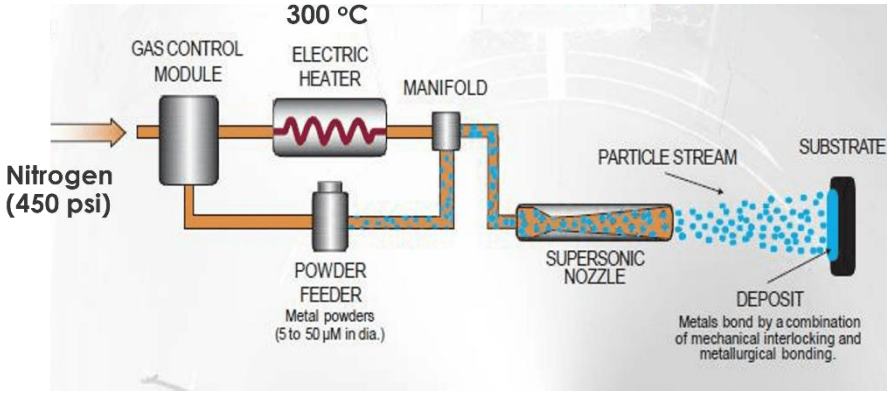
Licensing/Collaboration

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Inventors

Joel Falk, Peng Chen, Michael Buric, and Steven Woodruff

Self-Healing Cold Spray Coating for Internal Corrosion Protection of Natural Gas Pipelines (23N-12)



Opportunity

Internal corrosion poses a significant threat to the integrity of pipelines transporting natural gas, hydrogen blends, and carbon dioxide (CO_2), primarily driven by the presence of water, CO_2, and hydrogen sulfide within the fluid stream. To mitigate challenges caused by corrosion, NETL and Battelle Memorial Institute have designed a cold-sprayed coating composed of zinc (Zn) and 2-12 wt% titanium (Ti). This coating is applied to steel substrates using a high-pressure nitrogen gas process that mechanically mixes and supersonically deposits Zn and Ti powders. It provides cathodic protection through galvanic coupling between Zn and Ti, which accelerates hydrogen evolution and increases local pH, thereby promoting the formation of a stable, passivating zinc carbonate ($ZnCO_3$) layer. This $ZnCO_3$ layer acts as a corrosion barrier, significantly reducing the corrosion rate over time, even in acidic and CO_2-rich environments. A key feature is its self-healing capability, where $ZnCO_3$ and zinc oxide form within defect sites, restoring protective integrity. This technology is available for licensing and/or further collaborative research from NETL and Battelle.

Challenges Addressed

- Organic coatings often suffer from poor abrasion resistance, making them vulnerable to mechanical damage and difficult to maintain effectively
- Sacrificial metallic coatings, while offering protection, are rapidly consumed, particularly in acidic or CO_2-rich environments, leading to a short protective lifespan and requiring frequent replacement or reapplication

Potential Commercial Applications

- Self-healing, durable coating for the interior of new and existing pipelines transporting natural gas, hydrogen, CO_2, oil, and water
- Protects a wide range of industrial equipment and public infrastructure components exposed to harsh, corrosive environments

Competitive Advantages

- ZnTi cold spray coating forms protective $ZnCO_3$ layers at defect sites, restoring corrosion protection without external intervention
- Galvanic coupling accelerates hydrogen evolution, increasing local pH and promoting stable $ZnCO_3$ formation, effectively protecting pipelines in CO_2-rich conditions
- Applied via high-pressure cold spray, the coating achieves strong adhesion and resistance to mechanical cleaning processes like pigging

Intellectual Property Status

A U.S. nonprovisional application has been filed.

Licensing/Collaboration

Partnerships@netl.doe.gov

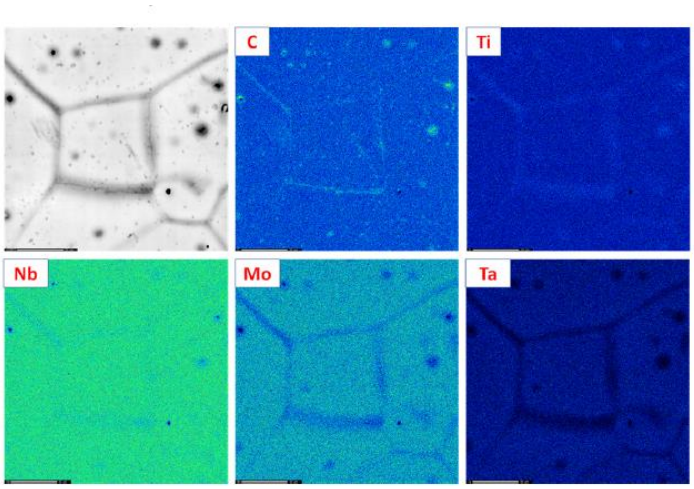
Inventors

Zineb Belarbi, Omer Dogan, Joseph Tylczak, and Margaret Ziomek-Moroz

Low-Cost, High-Performance Alloys for Gas Turbine Blades (21N-18)

Opportunity

Developing materials for ultrahigh-temperature applications, particularly turbine blades operating above 1300°C, presents significant challenges, as existing nickel (Ni)-based superalloys are insufficient for these extreme conditions. NETL has engineered lightweight, cost-effective, precipitation-strengthened refractory high-entropy alloys (RHEAs) designed for turbine blade applications above 1300°C. These alloys, based on niobium, molybdenum, tantalum, zirconium, hafnium, vanadium, carbon and/or other elements, consist of a ductile high-entropy solid solution matrix strengthened by fine precipitates of high-entropy MC carbides (M = Nb, Ta, Ti, Zr, Hf). The MC carbides are expected to enhance high-temperature strength, improve creep performance by hindering dislocation gliding and grain boundary sliding, and reduce thermal expansion. The alloys are additively manufactured, with rapid solidification processing facilitating carbide precipitation, and their design utilizes high-throughput multiscale computer modeling and machine learning for property optimization. This technology is available for licensing and/or further collaborative research from NETL.



Backscatter electron micrograph of NETL superalloy in the as-cast state

Challenges Addressed

- Existing Ni-based superalloys are inadequate for extreme, high-temperature conditions
- Other refractory alloys struggle to achieve a harmonious balance of essential properties, such as room-temperature ductility, fracture toughness, high-temperature creep and fatigue resistance

Potential Commercial Applications

- These alloys are superior to Ni-based superalloys, specifically designed for turbine blades in power generation, commercial, and military aircraft engines operating above 1300°C
- Lightweight, high-temperature strength, ductility, and oxidation resistance make it ideal for components in rocket engines, hypersonic vehicles, and spacecraft re-entry shields

Competitive Advantages

- The precipitation-strengthened RHEAs exhibit superior strength at temperatures exceeding 1300°C, surpassing traditional Ni-based superalloys like Inconel 718, which typically operate effectively up to around 700°C
- The fine MC carbide precipitates in the RHEAs hinder dislocation movement and grain boundary sliding, enhancing creep resistance at elevated temperatures

Intellectual Property Status

A U.S. nonprovisional application was filed January 30, 2024.

Publications

M. Gao, et al. Low-Cost High-Performance Refractory High Entropy Alloys for Gas Turbine Blade Applications Above 1300 Celsius. (2024). *United States Patent and Trademark Office.* U.S. Patent Application Publication No. US20250243568A1.

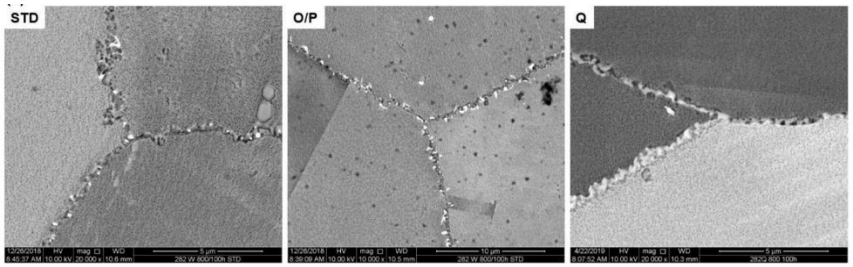
Licensing/Collaboration

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Inventors

Michael Gao, David Alman, Michael Kirka, Michael Widom, and Saket Thapliyal

NiCrCoMoW Age-Hardenable Alloy for Creep-Resistant, High-Temperature Applications (21N-08)



Microstructure of NETL alloys following 100 h exposure at 800°C

Opportunity

Advanced energy conversion systems, such as those in ultra-supercritical and supercritical carbon dioxide power (CO_2) plants, demand materials that maintain high yield strength and exceptional creep resistance well above 800°C. NETL and Battelle have designed an alloy for high-temperature applications. The alloy is a nickel-based superalloy with a modified composition, including adjusted levels of chromium, cobalt, molybdenum, tungsten, titanium (Ti), and aluminum (Al), that maintains high yield strength and creep resistance above 800°C. It is produced via a controlled process involving vacuum induction melting with minimal carbon pickup, followed by a series of homogenization, hot working, and dual-stage heat treatments. This process optimizes the formation of ordered γ' ($Ni_3(Al,Ti)$) precipitates in a matrix, along with the formation of $M_{23}C_6$ carbides along grain boundaries while suppressing topologically close-packed phases. This technology is available for licensing and/or further collaborative research from NETL in partnership with Battelle.

Challenges Addressed

- Existing high-temperature alloys, while effective up to certain thermal thresholds, suffer from rapid degradation, reduced creep life, and formation of destabilizing phases when pushed beyond their design limits
- Conventional materials often lack the necessary balance between mechanical performance and manufacturability, particularly regarding phase stability and long-term microstructural integrity under prolonged high-temperature exposure

Potential Commercial Applications

- Exceptional creep resistance and phase stability make it ideal for critical structural parts such as turbine blades, discs, and boiler tubes in advanced ultra-supercritical and supercritical CO_2 power plants, as well as in traditional steam and gas turbine systems
- Suited for manufacturing high-performance aero engine components, where durability and reliability are paramount

Competitive Advantages

- Demonstrates up to a 130% increase in creep life at 760°C and maintains performance at 780°C, significantly outperforming Haynes 282 in high-temperature applications
- Offers improvements of 7%-14% in ultimate tensile strength and yield stress at both room temperature and 800°C compared to traditional nickel-based superalloys
- The modified composition and specialized heat treatment markedly reduce the formation of detrimental topologically close-packed phases over prolonged exposure at 800°C and 900°C

Intellectual Property Status

A U.S. nonprovisional application (US18/194,447) was filed March 31, 2023.

Publications

P. Jablonski, et al. NiCrCoMoW Age Hardenable Alloy for Creep-Resistant High Temperature Applications, and Methods of Making. (2023). *United States Patent and Trademark Office.* U.S. Patent Application Publication No. US20230383382A1.

Licensing/Collaboration

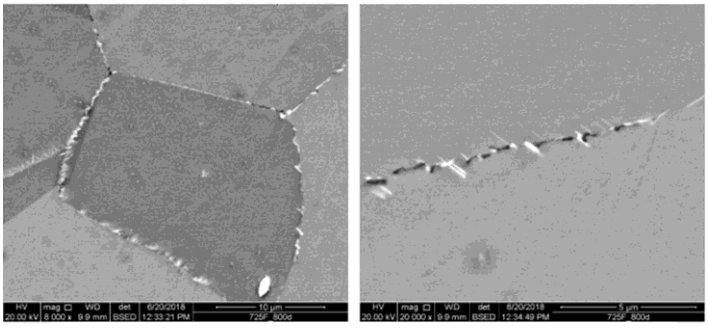
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Inventors

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Creep-Resistant NiCrMoNb Alloy for High-Temperature Components (20N-15)

Opportunity



δ phase precipitates located at the grain boundaries of NETL alloy

Power generation systems are moving toward higher operating temperatures, which places increasing mechanical stress on components such as turbine blades, valves, and heat exchangers. Traditional steels lose strength and creep resistance under these conditions, creating a need for alloys that can maintain performance at temperatures approaching 750°C. NETL and Battelle Memorial Institute have engineered an advanced nickel-chromium-molybdenum-niobium (NiCrMoNb) alloy that provides high yield strength, improved creep life, and stable microstructural behavior at elevated temperatures. The alloy's chemistry is tailored to promote strengthening precipitates within the grains and controlled phase formation at grain boundaries, while heat treatment methods further enhance high-temperature stability. Together, these features enable the alloy to outperform existing commercial Ni-based alloys used in energy, aerospace, and industrial applications. This technology is available for licensing and/or further collaborative research from NETL in partnership with Battelle.

Challenges Addressed

- High-temperature applications in energy and aerospace sectors demand materials that resist creep, oxidation, and corrosion under extreme conditions
- Many conventional alloys struggle to balance strength and long-term durability
- Grain boundary instability and nonuniform precipitate distribution

Potential Commercial Applications

- Superior creep resistance, yield strength, and oxidation/corrosion stability make the alloy ideal for gas turbine disks, blades, and spacers operating at elevated temperatures
- Enhanced high-temperature performance and microstructural stability, suited for next-generation power plants components

Competitive Advantages

- Delivers a 40%-370% increase in creep life and a 53%-550% improvement in creep ductility at 700°C compared to INCONEL 725
- With an average 16% boost in ultimate tensile strength and 21% increase in yield strength at 750°C, this alloy outperforms standard Ni-based alloys
- The use of a computationally optimized homogenization cycle and a dual-step high-temperature aging treatment yields a uniform microstructure

Intellectual Property Status

A U.S. patent (US11827955) was issued November 28, 2023, and expires October 27, 2041.

Publications

M. Detrois, et al. NiCrMoNb Age Hardenable Alloy for Creep-Resistant High Temperature Applications, and Methods of Making. (2023). *United States Patent and Trademark Office.* U.S. Patent No. 11,827,955.

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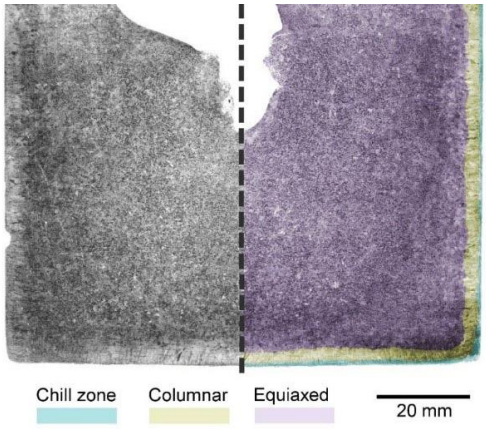
Inventors

Martin Detrois, Paul Jablonski, and Jeffrey Hawk

Creep-Resistant Nickel-Based Superalloy Casting and Manufacturing (20N-13)

Opportunity

Raising the efficiency and durability of high-temperature energy systems depends on materials that can withstand long-term stress without deforming or degrading. The U.S. Department of Energy 's National Energy Technology Laboratory (NETL) has created a refined casting and heat-treatment process for a nickel-based superalloy derived from Inconel 740H that maintains the creep strength of wrought material while offering the versatility of casting. The fine grain homogenized process combines low-temperature pouring with preheated molds and a precisely timed homogenization sequence to create a uniform, fine-grained microstructure with consistent chemical distribution. This advancement enables reliable performance above 760°C in turbine housings, valves, and heat exchangers used in next-generation power systems. The technology is available for licensing and collaborative research from NETL.



Superalloy derived from NETL process

Challenges Addressed

- Conventional cast Inconel 740H exhibits poor creep resistance compared to wrought forms
- Large or complex superalloy components remain expensive to manufacture through traditional methods
- Nonuniform grain structure and elemental segregation reduce long-term material stability
- Existing ferritic and austenitic steels fail to meet strength requirements at high temperature and pressure

Potential Commercial Applications

- Advanced ultra-supercritical and supercritical carbon dioxide power plant components
- Steam turbine, boiler, and heat exchanger fabrication
- Aerospace and industrial gas turbine hardware
- Any high-temperature system requiring long-term creep resistance and oxidation stability

Competitive Advantages

- Produces uniform microstructure with improved creep and tensile strength
- Performs consistently at sustained operating temperatures above 760°C
- Increased resistance to cracking and environmental degradation
- Enables cost-effective casting of large or complex geometries
- Compatible with existing IN740H supply chains and manufacturing infrastructure

Intellectual Property Status

A U.S. patent (US11453051) was issued September 27, 2022, and expires February 24, 2041.

Publications

P. Jablonski, et al. Creep Resistant Ni-Based Superalloy Casting and Method of Manufacture for Advanced High-Temperature Applications. (2022). *United States Patent and Trademark Office.* U.S. Patent No. 11,453,051.

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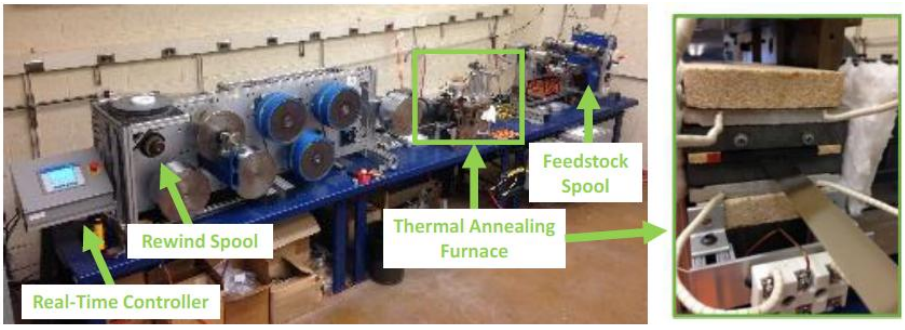
Inventors

Paul Jablonski, Jeffrey Hawk, and Martin Detrois

Microwave Annealing Systems for Alloy Processing (18N-29)

Opportunity

Producing soft magnetic alloys with tightly controlled properties requires heat treatments that can tune microstructure without introducing large thermal gradients or slow furnace cycles. Engineers at NETL and Pennsylvania State University (Penn State), designed a single mode microwave processing system that creates spatially distinct regions of pure magnetic and pure electric fields inside the same chamber. Amorphous alloy segments are automatically positioned in one of these field regions, where microwave energy couples directly into the material to generate internal heating between 400°C and 700°C. Because the chamber geometry separates electric and magnetic field maxima, operators can select annealing conditions that influence permeability, microstructural evolution, or stress relief with high spatial precision. Automated loading and unloading support continuous, in-line treatment of short alloy sections, enabling consistent production of tape-wound cores and other magnetic components. This approach provides a controllable alternative to conventional furnace annealing while allowing real-time adjustment of stress, temperature, and processing speed. This technology is available for licensing and/or further collaborative research from NETL in partnership with Penn State.



In-line processing facility for applied tension annealing using a conventional furnace set-up for high-temperature thermal processing

Challenges Addressed

- Traditional thermal annealing methods involve large heating zones and slow processing, which severely limit spatial control over material properties and reduce production speed
- Existing in-line annealing techniques, such as strain annealing furnaces, lack the fine spatial resolution needed to easily produce localized variations in properties like permeability

Potential Commercial Applications

- High-throughput, in-line production of improved soft magnetic components like inductors, transformers, motors, and sensors
- Efficient, in-line production of electromagnetic interference and general electromagnetic shielding materials

Competitive Advantages

- Microwave and radio frequency (RF) annealing provide fine spatial control over heating, enabling localized treatment of amorphous and nanocrystalline alloy ribbons
- The rapid heating and cooling cycles of microwave and RF annealing significantly reduce processing time compared to traditional thermal annealing methods

Intellectual Property Status

A U.S. patent (US12349262) was issued July 1, 2025, and expires January 16, 2042.

Publications

P. Ohodnicki, et al. In-line Microwave Processing of Alloys. (2025). *United States Patent and Trademark Office.* U.S. Patent No. 12,349,262.

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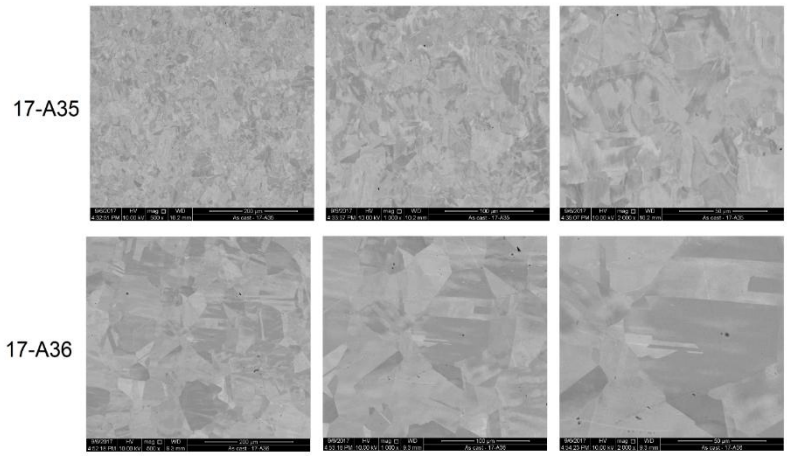
Inventors

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High-Performance Corrosion-Resistant High-Entropy Alloys (18N-09)

Opportunity

Corrosion is a persistent challenge for metals exposed to seawater, acidic environments, and other harsh industrial conditions. NETL has established a new class of high-performance, corrosion-resistant high-entropy alloys that combines exceptional durability with reduced material costs. These alloys, designed using advanced thermodynamic modeling, provide superior resistance to pitting and crevice corrosion compared to conventional nickel-based superalloys such as Hastelloy® C276. They can be manufactured as protective coatings or bulk components for long-lasting service in aggressive environments. This technology is available for licensing and/or further collaborative research from NETL.



Scanning electron micrograph of the as-processed A35 and A36 high-entropy alloys

Challenges Addressed

- Conventional nickel-based superalloys such as Hastelloy® C276 are highly effective but costly
- Metals operating in seawater or acidic environments are prone to localized corrosion that can lead to cracking and structural failure
- Existing materials often exhibit limited ductility or poor chemical stability over long-term service
- Industry lacks a cost-effective alloy with both high corrosion resistance and mechanical strength for extreme conditions

Potential Commercial Applications

- Protective coatings for marine, offshore, and subsea infrastructure
- Structural components for chemical processing and desalination equipment
- Heat exchangers and pressure vessels operating in corrosive or high-temperature environments
- Industrial systems exposed to brines, acids, or aggressive chemical streams
- Replacement for high-cost nickel superalloys in energy and manufacturing applications

Competitive Advantages

- Demonstrates strong resistance to pitting and crevice corrosion in seawater and acidic conditions
- Iron-rich composition lowers reliance on expensive nickel and cobalt
- Maintains mechanical performance in demanding environments
- Suitable for use as both bulk alloys and protective coatings

Intellectual Property Status

A U.S. patent (US11466344) was issued October 11, 2022, and expires July 10, 2040.

Publications

J. Hawk, et al. High-Performance Corrosion-Resistant High-Entropy Alloys. (2020). *United States Patent and Trademark Office*. U.S. Patent No. 11,466,344.

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Biodegradable Alloys for Implantable Medical Devices (14N-14)

Opportunity

Temporary implants must combine the strength of structural metals with a degradation profile that closely follows tissue healing, yet many iron-based systems corrode too slowly or break down unevenly. Researchers at NETL, in collaboration with BIO DG Inc., engineered a biodegradable alloy in which a halogen-bearing phase is incorporated directly into the iron matrix to promote steady, uniform corrosion. The modified electrochemical environment encourages controlled surface dissolution rather than pitting or particulate formation, while the underlying alloy retains the mechanical performance needed for early-stage load support. By adjusting the concentration and distribution of the reactive phase, degradation rates can be matched to clinical timelines for orthopedic, dental, or soft-tissue devices. This technology is available for licensing and/or further collaborative research from NETL in partnership with BIO DG.

Challenges Addressed

- Stainless steel implants often require removal once healing occurs and are not biodegradable
- Existing biodegradable polymers lack sufficient mechanical strength for load-bearing, deformable, or high-stress implant applications
- Conventional steels degrade unpredictably, forming fissures and particulates that can migrate and cause serious injury
- Many metal alloys contain toxic elements that pose risks when released into the body

Potential Commercial Applications

- Temporary or semipermanent orthopedic fixation devices such as screws, anchors, plates, supports, and rods
- Internal tissue fastening devices including surgical staples and fasteners
- Biodegradable dental implants and vascular stents

Competitive Advantages

- Iron-based alloys incorporating a halogen reactive component provide controlled, predictable biodegradation without particulation
- Enhanced degradation rates compared to similar alloys lacking the iron-reactive component
- High mechanical strength suitable for load-bearing and deformation during implantation
- Degradation behavior tunable by adjusting the concentration or distribution of the iron-reactive component

Intellectual Property Status

A U.S. patent (US10765775) was issued September 8, 2020, and expires March 14, 2034.

Publications

H. Radisch and P. Jablonski. Implantable Medical Devices Comprising Biodegradable Alloys with Enhanced Degradation Rates. (2020). *United States Patent and Trademark Office*. U.S. Patent No. 10,765,775.

Licensing/Collaboration

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Inventors

Herbert Radisch and Paul Jablonski

INDEX

Term ..... **Page(s)**

Acid Leaching and Solvents 21

Biomedical Alloys 39

Byproduct Metals Recovery ..... 4—5

Carbon Electrodes and Supercapacitors 11

Coal Ash and Coal Byproducts 2, 6

Cold Spray Coatings 32

Corrosion and Humidity Sensors ..... 14, 23—24, 26

Creep-Resistant Superalloys ..... 34—36

Downhole Laser Diagnostics ..... 3, 7, 9—10

Drilling Simulation Tools 30

Gas Separation Media ..... 18—19, 25

Gas Sensors and Spectroscopy 17, 27, 29, 31

High-Entropy Alloys 38

Microwave Annealing Systems 37

pH and Acidity Sensors 16, 28

Pipeline Acoustic Monitoring 12

Rare Earth Optical Sensors 8, 20

Turbine Blade Alloys 33

Wastewater Remediation Sorbents 13, 15, 22