Careers in Industrial Microbiology and Biotechnology

CONTENTS

What is Industrial Microbiology and Biotechnology?

What Trends are Driving the Industry?

What Kind of Work Do Industrial Microbiologists Do?

Where Are Industrial Microbiologists Employed?

Examples of Applications of Industrial Microbiology

Training and Education Required to Succeed in Industrial Microbiology?
What is Industrial Microbiology and Biotechnology?

Industrial microbiology is the application of scientific and engineering principles to the processing of materials by microorganisms or plant and animal cells to create products or processes with commercial or industrial significance. The terms industrial microbiology and microbial biotechnology are often interchangeable as they have significant overlap.

The microorganisms that are utilized may be native isolates, laboratory-selected mutants, microbes that have been genetically modified using gene editing methods, or any combination of the above. The industrial microbe may be useful in one of three ways:

**Producing useful products**
e.g., antibiotics, vaccines, proteins/enzymes, food ingredients, organic acids, and natural products

**As tools to make products**
e.g., bioremediation and wastewater treatment, creating foods (beer, bread), and soil enhancers and biocontrol for agricultural applications

**As the products themselves**
e.g., animal feed, single-cell protein, or part of materials (concrete)
What Trends are Driving the Industry?

While much of the basic science is done in university and government laboratories, industrial microbiologists translate ideas to practice and make products at a commercial scale. The translational research industrial microbiologists do is based on current research. Recent applications of biotechnology employment include the following:

**Sustainability**
- Replacing petrochemicals with bio-sourced versions (e.g., biosurfactants)
- Producing biofuels and biomaterials
- Replacing endangered/scarc carbon sources (e.g., cocoa, palm oil)
- Carbon mitigation and waste management
- Waste valorization to prevent pollution (i.e. food and plastic waste as precursors for valuable chemicals)

**New Low-Carbon Foods and Materials**
- Plant-based meats and dairy
- Plant-and fungus based leather
- Microbially enhanced concrete

**Increased Role of Microbial Communities**
- Microbiome/Microbial consortia
- Anaerobic digestion
- Plant growth promotion
- Biologics (environmental)
**Application of Systems Biology Tools**

Systems biology is the application of computational and modeling tools to biological systems to create targeted products, such as an enriched intermediate, or custom metabolite. Applications include:

- Heterologous gene expression
- Expression of genes in other cellular compartments
- Balancing pathways for optimum flow of carbon toward the product

Employment opportunities include applications of bioinformatics, artificial intelligence, gene editing, genome design and protein engineering.
What Kind of Work Do Industrial Microbiologists Do?

Technical Roles and Relevant Processes:

RESEARCH

- **Bioinformaticists** - identify pathways, genes, and mutations to be edited to optimize product formation. This may include the application of artificial intelligence.

- **Metabolic Engineers** - understand how perturbations affect the flux of carbon and metabolites through the cell. This may include -OMICS analysis and the construction of genome-scale metabolic models. Classical approaches are also employed, such as Adaptive Laboratory Evolution and Classical (global) mutagenesis. Replacing endangered/scarc carbon sources (e.g., cocoa, palm oil)

  More information can be found at the International Metabolic Engineering Society (aiche.org/imes) and the American Institute for Chemical Engineers – Society for Biological Engineers (aiche.org/sbe)

- **High-throughput Screening (HTS)** - identifies the best genes/enzymes/strains, large numbers of transformants/variants are screened in microtiter plates, microfluidic droplets, fluorescence activated cell sorters and small-scale reactors. Liquid handling robots may be employed. Waste valorization to prevent pollution (i.e. food and plastic waste as precursors for valuable chemicals)

  More information can be found at the Society for Laboratory Automation and Screening (slas.org)

- **Assay Developers** - Assays are developed to quantify the metric to be screened. Assay Developers identify the best measuring tool for the product and customize the protocol to demonstrate the presence and quantity of the desired product. These assays are incorporated into the screening workflow. An assay can also be the product itself.
• **Analytical Support** - These roles apply the tools developed by the Assay Developers that make the measurements required for the product being assayed, e.g. HPLC, Mass spec, chemical assays, etc. Analytical support starts initially in the screening process for a production strain and during fermentation process development but may remain in place through commercial manufacturing to validate the product. This encompasses the measurement of product molecules, contaminants, and substrates, as well as process parameters such as pH, temperature, and shear.

• **Data Handlers and Biostatisticians** - to organize and analyze the screening data to identify producers which are statistically confirmed to be better producers.

**PROCESS DEVELOPMENT**

• **Upstream Process Development** – Once a strain or cell line is created, that strain has the genetic potential to make the product. Fully realizing that phenotype entails finding the best conditions for the strain to maximize its production capacity. This work is done at the fermenter level for better control over the parameters which can scale up to commercial volumes. Qualities that can be optimized include temperature, agitation, oxygenation, media composition, and feeding strategies.

• **Downstream Processing (DSP)** - describes the series of operations required to recover and purify biological materials from the reactor vessel.

• **Technology Transfer** - is a formalized process for the transfer of protocols in moving the manufacture of a product from one facility to another, often for commercial-scale manufacturing. Technology transfer of research developed at universities to companies occurs with similar protocols, often in conjunction with agreements over Intellectual Property (patents and licensing).
MANUFACTURING

- **Scale-up Engineering** – identifies and develops processes and solutions to optimize production at the commercial scale. Upstream and downstream processes optimized at a smaller scale may not transfer efficiently to a larger scale due to differences in equipment and cost. For example, oxygen transfer may be less efficient in larger fermenters due to difficulties in mixing larger volumes of media. Remedies include increasing agitation and/or genetic modification to better utilize oxygen. Downstream, a reagent that may be used at a small scale may be too expensive to use at a large scale, or too toxic to store in large quantities, so substitutions must be preemptively considered.

- **Cell Bank Curators** - create Master and Working cell banks and keep track of inventory, and stability studies to know when to expand the cell bank and how long it can be stored to maintain viability.

- **Good manufacturing practice (GMP)** - is a system of guidelines to ensure consistent production according to quality standards. GMP guidelines govern the manufacturing, testing, and quality assurance to ensure that a manufactured product conforms to the specification established by the manufacturer as well as any regulatory agencies. Work entails establishing standards and Standard Operating Procedures for controlled conditions and manufacturing processes. Batch records are made for the reagents and tasks for each run, and procedures are put in place to deal with deviations.

- **Quality Assurance (QA)** – QA is set of specifications that are established for the product to ensure consistent character. QA practitioners identify the qualities that connote that a product meets specifications and determines how those qualities are tested and how the results are interpreted. QA is intended to prevent mistakes and defects in the product and manufacturing process.

- **Quality Control (QC)** - is the process by which an organization reviews all factors of production to ensure product quality is maintained.
• **Product Stability** - how long the product can be stored under all anticipated storage conditions, with the goal of defining the range of acceptable conditions for storage to maximize quality.

• **Techno-Economic Analysis (TEA)** - allows customers to judge the feasibility of a project on an economic and technical basis. This begins with a process flow diagram identifying major pieces of equipment and the product flow. A mass balance identifies major input, waste, product, and co-product flows. The capital and operating costs are calculated and annualized to be compared to the potential revenue from the product line.

• **Life Cycle Assessment (LCA)** - is a tool used to assess the full environmental impact of a product’s life. This includes the impact due to raw materials production, materials processing, manufacturing, customer end use, and the final disposal of a given product. A LCA is required for approved pathways of the California Low Carbon Fuel Standard (LCFS) as well as the US EPA Renewable Fuel Standard (RFS). In addition, the energy and mass balances performed during an LCA are the starting point for process flow analysis, which provides vital information for process improvements for the energy and cost efficiency.

• **Lab Support Roles** - include glassware washers, media preparation technicians, and fermentation maintenance workers.

Logistic/Administrative Supporting Roles

Non-technical roles directly support the technical work by providing funding, organization, and expansion of markets.

• **Project Management** - is the process of leading the work of a team to achieve all project goals within the given constraints. This brings together all the teams involved (e.g. strain development, fermentation, DSP, analytical, business development) usually described in project documentation, created at the beginning of the development process. The primary constraints are scope, time, and budget. Project plans map who does what and when,
and make sure that reagents, materials, and equipment are available when needed. Project Managers monitor the progress of projects, ensure the timely transition of materials and tasks between steps, and troubleshoot deviations to get back on track.

More information can be found at the Project Management Institute (pmi.org) and the Project Management Society (projectmanagementssociety.com). PMI issues the Project Management Professional (PMP) certification.

- **Intellectual Property (IP)** - The IP department is responsible for the protection of an institution’s intellectual assets. They identify what is patentable (vs. trade secret or institutional knowledge), and work with the scientists to craft the patent applications. In developing an IP strategy for a project, they perform competitive IP landscape analysis, looking for precedence (older patents and applications) and potentially blocking IP. Additional training as a Patent Agent or as a Lawyer is useful and usually required.

- **Regulatory Approval Groups** - research and advise the science and production teams on adherence to rules for product registrations for new and modified products. They interact with governmental regulatory agencies, other third-party accrediting bodies, and trade associations on the company’s behalf.

  More information can be found at the Regulatory Affairs Professionals Society (raps.org)

- **Business Development (BD)** - identifies and seeks out applications of the company’s products and technologies for business partnerships. The BD team engages in meetings with potential partners, making presentations and negotiating terms. They execute due diligence on markets for their product, identifying gaps and competitors. Internally, they partner with scientific and development teams to develop proposals for partners.

- **Sales and Marketing Personnel** - provide the front line to the customer. Marketers use their knowledge of the product to identify the market for the product and designs targeted advertising campaigns. The Sales team interfaces with customers and conveys customer feedback to the team.
• **Technical Field Representatives** - are the liaisons between the science application teams and the customer. Not only do they help the customer utilize the product optimally and safely, but they also collect feedback from the users to help improve the quality and sales of the product.

• **Policy Analysts** - observe and influence the direction of local, state, and national science policy by working directly with lawmakers or establishing and advising government programs. They serve as the communication bridge between researchers, the public, and policy makers. Policy analysts identify current or impending problems, create solutions, and evaluate other proposed solutions. Once a problem is recognized, researchers might attempt to determine its causes. They may then analyze how various policy ideas and proposals could affect the problem and suggest solutions.

More information on policy careers and how to get into them can be found at https://career.ucsf.edu/phds/career-paths/science-policy#Get-experience
Venues where Industrial Microbiologists are Found

**Biotechnology Companies**
- Agricultural
- Pharmaceutical (e.g., vaccines, antibiotics)
- Chemicals
- Foods+
- Cosmetics
- Microbiome

**Manufacturing of Products Developed by Biotechnology Companies**

**Universities (Research, Tech Transfer, Legal Department)**

**National Laboratories**

**Food Companies**
- Traditional
- New foods (proteins)

**Environmental Applications (e.g., bioremediation)**

**Law Offices**

**Bioinformatics, Artificial Intelligence/Machine Learning**

**Data Management**

**Government or Lobbying Groups for Policy**

**Investment Firms**
Areas of High Employment Demand as of 2023

DEFINED BY LABOR SHORTAGES

- Fermentation (all levels = technicians, scientists, management) and downstream processing
- Computational biologists (bioinformaticists)
- Data processing and management
- High throughput screening/analytics

DEFINED BY EMERGING AREAS OF SCIENCE

- Food science biotechnology
- Valorization of low-carbon feedstocks to make valuable products
- Microbial consortia (microbiomes)
- Gene editing
- Fermentation engineering science
- Artificial Intelligence and Machine Learning applications
Examples of Applications of Industrial Microbiology

• **Pharmaceuticals and Diagnostics**
  Microorganisms are also used to produce human or animal biologicals such as insulin, growth hormone, antibodies, and components for cosmetics. New microbial sources (e.g., marine or cave-dwelling microorganisms) may be screened for their ability to produce new pharmaceuticals or develop new diagnostic assays. The development and production of diagnostic assays that utilize monoclonal antibody or DNA probe technology are essential in the manufacture of healthcare products such as rapid tests for strep throat, pregnancy, and AIDS.

• **Microbiome**
  An exciting emerging area is the study of Microbiomes. A Microbiome is a community of microorganisms that can usually be found living together in any given habitat with distinct bio-physio-chemical properties. The habitats of biomes are wide in their variety: in bodies, on plants, in soil, on surfaces of foods, etc. Areas where microbiologists are active is in identifying the members of microbiomes, how they interact and depend on each other, and ways to control the composition of the consortia. Tool development for studying the microbiome is a very active area, in identification methods for the component microbes, large-scale sequencing, and artificial intelligence (AI)-related machine learning to analyze large sets of data.

• **Food**
  Many foods are the product of microbial bioconversions, including e.g., yogurt, cheese, chocolate, butter, pickles, sauerkraut, soy sauce, food supplements (such as vitamins and amino acids), food thickeners (produced from microbial polysaccharides), alcohol (beer, whiskeys, and wines), sausages, coffee, tea, cocoa, chocolate, vanilla, cheese, olives, and tobacco. Industrial microbiologists may be involved in producing concentrated microbial inocula for fermentations or the maintenance of fermentation systems utilized in production facilities. They may also take part in identifying the organ-
isms involved, improving these microbial catalysts by genetic means, and maintaining proprietary culture collections. Microbial products may also be used as Food Flavoring Agents and Preservatives: Organic acids, such as citric, malic, and ascorbic acids, and monosodium glutamate are microbial products commonly used in foods. The microbes themselves may be the food. Mushrooms, truffles, and some red and green algae are consumed directly. Yeasts are used in food supplements for humans and animals.

More information can be found at the Institute for Food Technology (ift.org)

• **Agriculture**
  Classic mutagenesis techniques and gene editing are employed to improve microbial inoculants (soil additives) which can serve as fertilizer supplements by fixing atmospheric nitrogen or solubilizing nutrients to improve crop yields. As with pharmaceuticals, microbials produce natural products that are effective biocontrol agents of plant pathogens (e.g. insecticides, fungicides, or herbicides).

• **Enzymes**
  Industrial applications of enzymes include the production of cheese, the clarification of apple juice, the development of more efficient laundry detergents, pulp and paper production, and the treatment of sewage. These processes have been dramatically enhanced by the application of protein engineering to design enzymes and increase activity, stability, and specificity. Increasingly, Artificial Intelligence and Machine Learning are being applied to protein design.

• **Carbohydrates**
  Some molecular sieves for purification/separation processes (e.g., dextran) and thickening agents (e.g., xanthan used in salad dressings), which are stable at high temperatures, are examples of microbial carbohydrates. The latter are also used for secondary oil recovery in oil fields and as lubricants in drilling oil wells, gelling agents in foods, and thickeners in both paints and foods.

• **Oils**
  Microbial oils can be customized for foods (e.g., to add flavor and texture
to plant-based meats), parenteral feeding and baby formula, as well as for cosmetics and industrial applications (e.g. lubricants).

More information can be found at the American Oil Chemists Association (aocs.org)

- **Organic Chemicals**
  Compounds such as acetone, methanol, butanol, and ethanol have multiple applications in industrial settings, often as raw materials for industrial processes. Microbiologists can be involved in research on improvements in the production and detection of new metabolic pathways. Microbes will increasingly be used to supplant or replace those processes which rely on petroleum/natural gas to produce these compounds.

- **Contamination Control**
  Industrial microbiologists can develop assays to detect microbial contaminants in food and develops preservatives; evaluates natural or synthetic agents for the prevention of disease, deterioration, or spoilage; and determines minute quantities of vitamins or amino acids in food samples. Microbiologists are also involved in the development of procedures for the control of deterioration in cosmetics, steel, rubber, textiles, paint, and petroleum products.

- **Waste and Wastewater Management**
  The production of clean water and the destruction of waste material are important for preserving the environment and providing drinkable water. The industrial microbiologist is directly involved in developing microbial strains to detoxify wastes of industrial, agricultural, or human origin.

- **Oil Recovery and Mining**
  Oil recovery may be facilitated by the development of unique bacteria which produce a surfactant that forces trapped oil out of the rocks. In mining, the extraction of minerals from low-grade ores is enhanced by some bacteria (microbial leaching). In addition, the selective binding of metals by biohydrometallurgical processes is important in the recycling of metals such as silver and uranium. Research and developments in these areas also offer career paths for industrial microbiologists.
• **Environmental Microbiology**
  Examination of microbes living in unusual environments (e.g., high temperatures, salt, low pH or temperature, high radiation) may lead to discovery of or engineering of microbes with abilities to degrade or transform pollutants and improve the environment. Industrial microbiologists are involved in engineering microbes to solve contamination and recycling problems.
Training and Education Required to Succeed in Industrial Microbiology

There are roles in industrial microbiology at all levels of education.

- **High school diploma**
  High school students interested in a career in industrial microbiology and biotechnology should take college preparatory courses in biology, mathematics, physics, and chemistry. Employment opportunities in industrial microbiology and biotechnology are very limited for high school graduates. You may become a skilled technician through on-the-job training, but many organizations require that a technician should take career-related college-level courses to advance to higher-paying technical positions. Exposure to industrial microbiology and biotechnology may be obtained by working during the summer in an industrial, university, or hospital microbiology laboratory; some of these positions may be in the form of internships.

- **Associate’s degree**
  Associate degree programs train the lab support workforce, who become the media makers and fermentation, downstream processing, and manufacturing technicians.

The InnovateBio National Biotechnology Education Center https://innovatebio.org/ is an excellent resource for training programs and job placement at this level.

The two most common degrees for employment in industrial microbiology are Bachelor of Science (BS), or Master of Science (MS).

- **Bachelor’s degree**
  BS degrees cover skills needed in industrial microbiology/biotechnology including (but not limited to) microbiology, molecular and cell biology, biochemistry, biotechnology, genetics, chemical engineering, food science, environmental science, immunology, biostatistics and computer science.
Students that can work on research projects during undergraduate studies may have advantages when applying for employment (or graduate school). Such opportunities can often be found within the university’s advisor or career center. Internships in industrial microbiology and biotechnology can also be found at various government and industrial labs’ online career sites.

**Master’s degree**

While a BS degree has several career options, one may begin a career in an industrial entry-level position. Once inside a company, you will gain exposure to many jobs that you did not know existed when in school. This is an opportunity to examine those roles up close and see what is required to transition into them. In many organizations, employees are encouraged to continue their educations. It may be possible in such an environment to obtain a higher degree while working full time. MS degrees are a way to acquire a set of focused, specialized skills.

Many organizations employing industrial microbiologists/biotechnologists will have dual career paths for advancement. This means that the scientists will have the opportunity to advance to higher levels of responsibility either by staying in their chosen technical track or by assuming administrative responsibilities in technical management.

**PhD degree**

Individuals with one or more advanced degrees (MS and/or PhD) can typically begin with higher project/program responsibilities when entering industrial-related positions. These positions may be in the industry, government, or academic situations. With the advanced degrees comes greater expectations for not only knowledge but increasing experiences with project design, conduct, and management. Multidisciplinary experiences are essential. In addition, attendance at national or international meetings is crucial for presenting research results and networking.

The UC Davis Biotechnology Program provides a good overview of “non-traditional (i.e., non-academic)” career options for PhD-level scientists. https://biotech.ucdavis.edu/blog/business-development-bd-non-traditional-career-path-phds
• **Specialty degrees**
There are specialty degrees that are important for certain specializations, and most of these are obtained after the BS degree. These include patent agent certification or law school for IP practitioners, MBA programs for business development, and PMP (Project Management Professional) certification for project managers.

---

**About SIMB**
The Society for Industrial Microbiology and Biotechnology (SIMB) is a nonprofit, international association dedicated to the advancement of microbiological sciences, especially as they apply to industrial products, biotechnology, materials, and processes. Founded in 1949, SIMB promotes the exchange of scientific information through its meetings and publications, and serves as liaison among the specialized fields of microbiology. Membership in the Society is extended to all scientists and companies in the general field of microbiology.