AECOM Imagine it. Delivered.

PROCESS DEVELOPMENT

Life-Cycle R&D Services from Concept Through Commercial Operation

CONTENTS

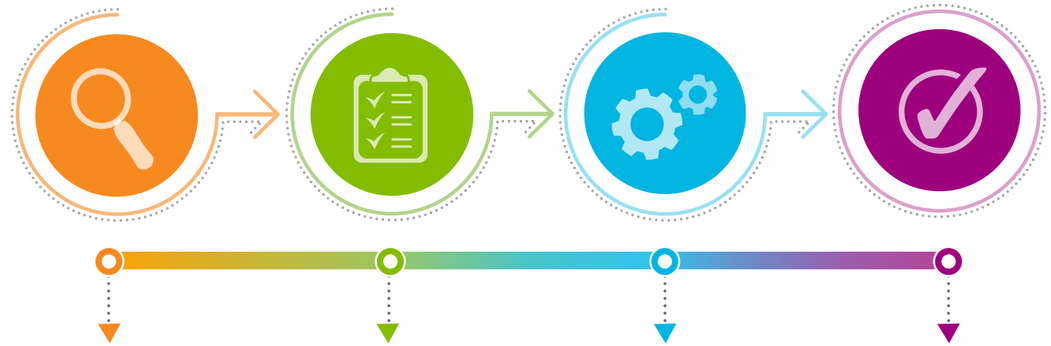
PROCESS DEVELOPMENT

AECOM has the resources and experience to guide concepts or technologies through the entire development cycle: from proof-of-concept research experiments through commercial deployment.

AECOM has a recognized history of advancing state-of-the-art processes from conception to commercialization. For almost fifty years, our engineers and scientists have played a vital role in advancing technologies across numerous industries. For the past two decades, we have excelled at seamlessly expanding our capabilities from R&D to detailed design.

We have built our reputation on our repeated ability to develop thorough understandings of processes and how they can be optimized to achieve our client and market needs. We know that it is through the establishment of such a foundation, along with meticulous planning and execution, that we can most effectively navigate the obstacles associated with process commercialization. Whether we are developing our own intellectual property positions or working with third parties, the process largely remains the same.

AECOM has vast experience evaluating and optimizing third-party technologies, and have partnered or worked with several prominent technology providers and research organizations. Our ability to seamlessly integrate R&D with detailed design and ultimately procurement and construction allows us to advance processes at a fast pace without sacrificing quality. Our experience and perspective keep us focused on commercialization and ultimately market objectives; we understand the need to develop a process that can be economically implemented and safely and reliably operated.



RESEARCH
Literature reviews
Paper studies
Market assessments
Laboratory-scale studies
Analytical method development
Simulations & modeling

DEVELOPMENT
Feasibility studies
Bench-scale evaluations
Integrated unit operations

DEMONSTRATION
Pilot-scale test
Full-scale demonstration
Budgetary pricing

COMMERCIAL DEPLOYMENT
Detailed design
Implementation
Operational and control procedure development
Troubleshooting
Optimization

RESEARCH

Laboratory-Scale Studies

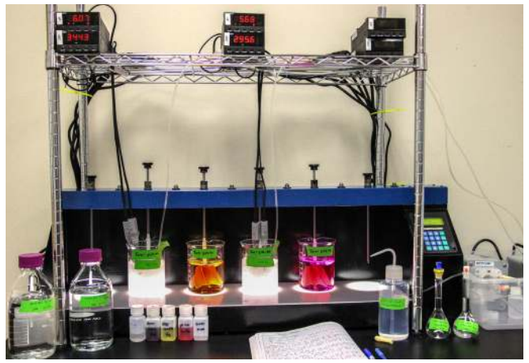
To support the development process, AECOM maintains a suite of process and analytical laboratories in a 10,000+ sq. ft. state-of-the-art research complex located in Austin, TX. The facility is staffed by scientists and engineers, and is capable of 24/7 operation. The laboratories are easily modified with equipment and instrumentation to meet our clients' changing needs. Our on-site analytical laboratory ensures that test results are obtained quickly so that a large test array can be accomplished efficiently.

The research phase focuses on understanding the science and verifying concepts.

AECOM manages research projects for industrial clients, technology vendors, and public- and private-sector research organizations like the Electric Power Research Institute (EPRI), and Department of Energy/National Energy Technology Lab (DOE/NETL), and electric power utilities. Typical research projects include any combination of the following::

- Literature reviews
- Paper studies
- Market assessments
- Experimental design
- Fundamental laboratory investigations
- Beaker tests
- Bench-scale tests
- Analytical method development
- Simulations & modeling

Photo left:
Evaluation of an alternate solvent mixture for the CrystaSulf® H_2S removal technology.



Jar testing apparatus equipped with pH controllers and ORP measurement capabilities to evaluate wastewater samples.

Analytical Method Development

AECOM research chemists are able to develop preparation and analytical methodologies for new species of interest or for analytes in new or unusual matrices. The target compound/element/ion, as well as any potential interferences, impurities, side reaction or degradation products, are investigated in available literature. Rigorous experiments are then conducted to ensure that the resulting data are representative, precise, and accurate.

One example of an analytical method AECOM developed is the preparation and detection of low-levels of mercury (to 0.5 ppt) in flue gas desulfurization (FGD) wastewaters high in total dissolved (10,000 - 100,000 ppm) and suspended solids (10 - 100 ppm), each of which cause difficulties in the sampling, preparation, and analytical process. Other examples include the development of a separation methodology to isolate large, organic acids from the FGD matrix, and the development of an analytical method to detect low levels of nitrite and nitrate in the presence of high background interferences for meeting the proposed effluent limitation guideline (ELG) regulations.

Analytes

WATER QUALITY

- pH
- ORP
- Hardness
- Total dissolved solids
- Total suspended solids
- Alkalinity

METALS

- Aluminum
- Boron
- Calcium
- Iron
- Magnesium
- Manganese
- Mercury (ultra low levels)
- Potassium
- Sodium
- Strontium

HALIDES

- Bromide
- Chloride
- Fluoride
- Iodide

ORGANIC COMPOUNDS

- Hydrocarbon analysis by GC/FID
- Total organic content in aqueous samples
- Unknown sample characterization by UV/Vis/NIR Spectroscopy and Fluorimetry
- Light gas analysis by GC/TCD

POLYATOMIC IONS

- Ammonium
- Carbonate
- Nitrate
- Nitrite
- Sulfite
- Sulfate
- Persulfate
- Thiosulfate
- Dithionate
- Tetrathionate
- Hydroxylamine-N,N-disulfonate (HADS)
- Hydroxylamine-trisulfonate (HATS)
- Formate
- Succinate
- Glutarate
- Adipate

OTHER TECHNIQUES/ANALYSES

- Particle Size Distribution
- Loss on Ignition
- Foam Index
- Wet Sieving
- Various types of leaching

DEVELOPMENT

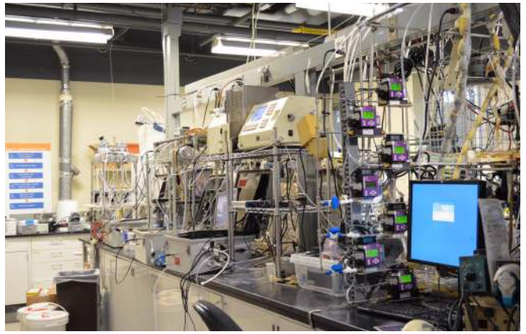
In the development phase, AECOM is focused on determining a process or technology's technical and economic feasibility. This often involves designing bench-scale systems to mimic the key features of the process being investigated, including replicating specific process conditions. Systems are built to simulate gas-liquid contactors, gas-solid contactors, catalytic reactors, and membranes, to name a few. Systems typically consist of a process stream generation and distribution system, an experimental reaction chamber, and sample collection ports. With support from our analytical laboratories, bench-scale tests help researchers identify the best reagents, reactor designs, and operating conditions for the process being studied.

The development phase bridges scientific research to engineering.

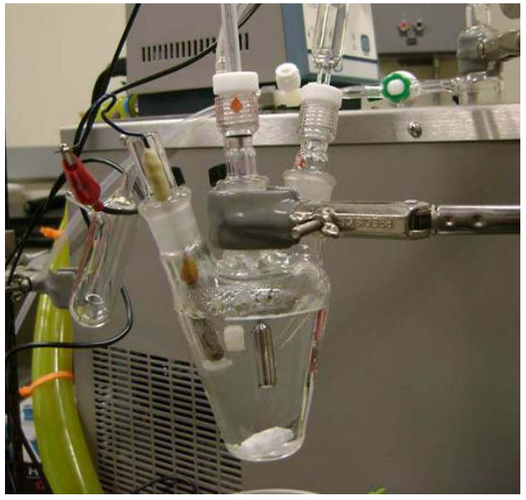
To facilitate efficient process development, AECOM often employs chemical process modeling and computational fluid dynamics (CFD) simulations.

Example bench-scale systems:

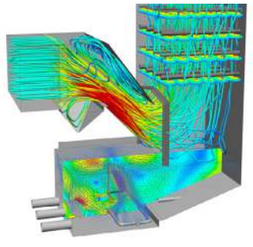
- Flue gas desulfurization (FGD) scrubber for SO_2 removal and trace metal studies (e.g., Hg, Se)
- Selective catalyst reduction (SCR) catalyst for NO_x removal and Hg oxidation
- Mercury adsorption and oxidation reactors
- Selenium adsorption reactors
- CO_2 adsorption reactors
- Corrosion simulation devices
- Stopped flow kinetic measurement system



Trace metals and SO_2 chemistry is studied in a bench-scale FGD system.



Electrochemical apparatus used to explore aqueous phase redox chemistry and corrosion processes.



Computational Fluid Dynamics (CFD) is used in the design, evaluation and optimization of fluid flow processes.

DEMONSTRATION

AECOM has successfully planned, designed, implemented and operated numerous pilot- and full-scale demonstration programs intended to demonstrate the performance and reliability of a process or technology using actual process streams and operating conditions. Our focus is on not only demonstrating, but also optimizing processes to provide the greatest likelihood of commerical success.

During the demonstration phase, commercial system design requirements are determined.

As part of this phase of the process development life cycle, prior laboratory- and bench-scale experimental results are assessed and the engineering design is refined and optimized for the scale of the demonstration. The installation, start-up, and operation of the final pilot- or full-scale demonstration system are orchestrated by AECOM engineers and scientists. Real-time performance is assessed and documented. Samples are collected and submitted to our in-house laboratory or to an external laboratory for the appropriate analytical regime. Troubleshooting is inherent in any experiment; therefore, it is planned for and undertaken as needed.

AECOM designed, fabricated and operated a pilot-scale system to evaluate the effectiveness of a limestone forced oxidized wet FGD process at removing catalytically oxidized mercury from flue gas.

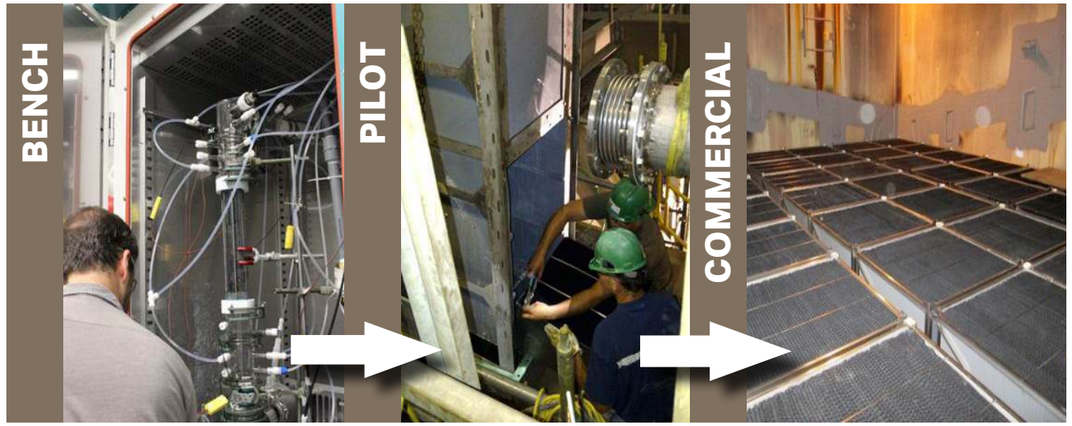
COMMERCIAL DEPLOYMENT

During commercial deployment, designs are finalized and process operation is optimized.

When the time is right, AECOM can be counted upon to advance a process or technology from bench-, pilot- or a full-scale demonstration to commercial operation. With an ability to marry traditional R&D and process consulting with engineering, procurement and construction (EPC) services, we have supported or partnered with numerous companies and organizations to transition processes into successful commercial offerings. As a trusted partner, we are dedicated to delivering innovative solutions for clients. Our role is to apply creative vision, technical expertise, interdisciplinary insight, and local experience to address complex challenges in new and better ways.

Select Processes AECOM Helped Commercialized

Area of Concern	Technology Solutions
Water Treatment	Selenium Removal
SO_2 Control	SYNGYP Co-Flo Lime-to-limestone Conversions
Hg Control	Gore Mercury Control System Halogen Injection
SO_3 Control	SBS Injection™
H_2S Removal	CrystaSulf®



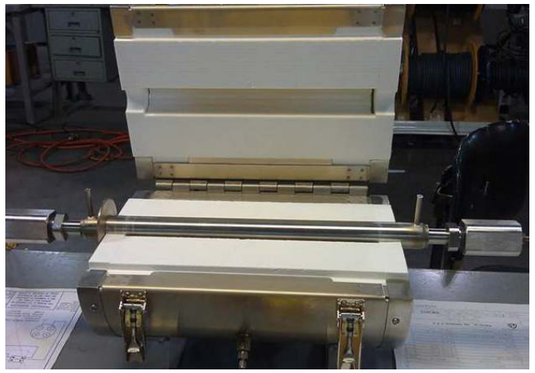
AECOM advanced the Gore Mercury Control System through the process development lifecycle culminating in a commercial system within five years.

CASE STUDIES

AECOM has successfully taken technologies from invention in the laboratory to commercial operation, as demonstrated in the following examples.

Photo right:
Demonstration-scale CrystaSulf® unit in Australia removing H2S from a shale retort process gas stream.

Pre-combustion CO_2 Capture



High-temperature, high-pressure reactor system.

AECOM led a U.S. Department of Energy sponsored R&D effort to investigate pre-combustion CO_2 capture from a gasified coal stream. The technology, termed Sorbent Enhanced Water Gas Shift (SEWGS), combined CO_2 capture, via a solid sorbent, with the water-gas shift reactor in a gasification unit of an Integrated Gasification Combined Cycle (IGCC) facility.

Together with the University of Illinois at Urbana-Champaign, the program employed computational simulations and laboratory- and bench-scale experimentation for research and development in the following areas:

- Novel sorbent synthesis
- Sorbent regeneration
- Production of a CO_2 waste stream for recompression and potential beneficial use

Results were used to complete a techno-economic analysis of the technology; the processis currently ready to advance to pilot-scale testing.

Mercury Oxidation Catalyst

Mercury oxidation catalyst modules being installed for a full-scale demonstration.

AECOM led the development of a low-temperature mercury oxidation catalyst from lab- to full-scale operation. Beginning in the lab, AECOM evaluated numerous candidate materials for their effectiveness at oxidizing elemental mercury present in simulated flue gas streams. The objective was to minimize the amount of insoluble elemental mercury present at the inlet to the wet flue gas desulfurization (FGD) process, maximizing the amount of mercury captured in the FGD.

Pilot testing was performed at the EPRI Environmental Control Technology Center, proving that catalysts could be fixed on a support in the gas stream and that catalytically oxidized Hg could be scrubbed at high efficiency in the downstream wet FGD process. After evaluating several catalysts at bench and pilot-scale, a catalyst was identified that provided the best performance for the price. In addition, the ideal structure and location of the catalyst were identified.

Under a DOE-funded demonstration project, AECOM designed and installed a full-scale catalyst reactor, at a coal-fired power plant, including detailed engineering for the modifications to the existing ductwork. In a follow-on project , AECOM executed a 17-month commercial test of the catalyst, during which 80% of the elemental mercury was converted to oxidized mercury, with the majority of that mercury subsequently removed from the gas stream by the wet FGD process.

Thermal Energy Storage

Molten salt thermal energy storage pilot-scale system.

As our nations electricity supply transitions from fossil fuels to renewable energy sources, AECOM is investigating non-traditional ways to store energy. Part of this transition involves adapting our laboratory space for new programs and different technologies. AECOM helped design and test a pilot-scale molten salt thermal energy storage reactor. The reactor extracts heat from hot, compressed gas, stores the resulting thermal energy, and then reinjects that heat back into the gas stream as part of an adiabatic compressed air energy storage process (CAES).

AECOM worked with the technology provider to execute a test program to prove this proof-of-concept pilot scale system at our Austin, TX laboratories. This involved:

- Assisting with reactor design,
- First developing and then rigidly adhering to all safety considerations,
- Designing balance of plant piping,
- Balancing pressures throughout the system,
- Executing a parametric test matrix, and
- Decommissioning the system.

SBS Injection™ Technology

The distribution manifold and injection lances for a commercial SBS Injection™ System.

AECOM led the successful commercialization of the SBS Injection™ Technology, (licensed from Codan Development, LLC) for the removal of sulfuric acid from the flue gas generated from the combustion of fossil fuels. To date, the process has been installed on 30 generating units having a combined generating capacity of over 17,000 MW.

AECOM engaged in a two-pronged strategy to quickly commercialize and then refine the process:

1. AECOM developed a process design, including proprietary equipment and control algorithms, that achieved reliable operation. This includes the development of injection lance technology that provides reliable service in harsh flue gas environments.

2. AECOM extended the capabilities of the process to reduce customer O&M costs and derive greater value from other emission control investments. For example, AECOM managed a program supported by a consortium of six electric utilities to demonstrate the feasibility of sulfuric acid removal upstream of the SCR system. The program was successful, and has permitted plants with SBS to reduce NO_X emissions compliance costs. while also permitting reliable operation at low load.

About AECOM

AECOM is built to deliver a better world. We design, build, finance and operate infrastructure assets for governments, businesses and organizations in more than 150 countries. As a fully integrated firm, we connect knowledge and experience across our global network of experts to help clients solve their most complex challenges. From high-performance buildings and infrastructure, to resilient communities and environments, to stable and secure nations, our work is transformative, differentiated and vital. A Fortune 500 firm, AECOM had revenue of approximately $18.2 billion during fiscal year 2017. See how we deliver what others can only imagine at aecom.com and @AECOM.

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