Case Study: Industrial Combustion and Gasification Research Facility

University of Utah partners with industry to research gasifiers, combustors, pilot-scale reactors, a fluidized bed reactor, process heaters, and other systems

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THE CHALLENGE

The Industrial Combustion and Gasification Research Facility (ICGRF) at the University of Utah in Salt Lake City was established in 1995 to perform research on coal, shale oil, natural gas, municipal waste, biomass, and other energy resources found in the Rocky Mountain region of the United States. University of Utah students as well as corporate and government research partners use the facility.

ICGRF Director Dr. Andrew Fry says students gain valuable hands-on experience with automation systems and process units used in the oil, gas, coal, and utility industries, while research partners work with the ICGRF to test new processes and control techniques and to improve existing ones. In many cases, the research is funded by U.S. utilities, Praxair, and other energy companies. In other cases, government entities provide funding, and some projects are a partnership among the university, government, and industry.

The original facility housed a 1.5 MW pulverized coal research reactor to investigate the formation and control of oxides of nitrogen in utility boilers. Since that time, the ICGRF has grown to 30,000 square feet with eight

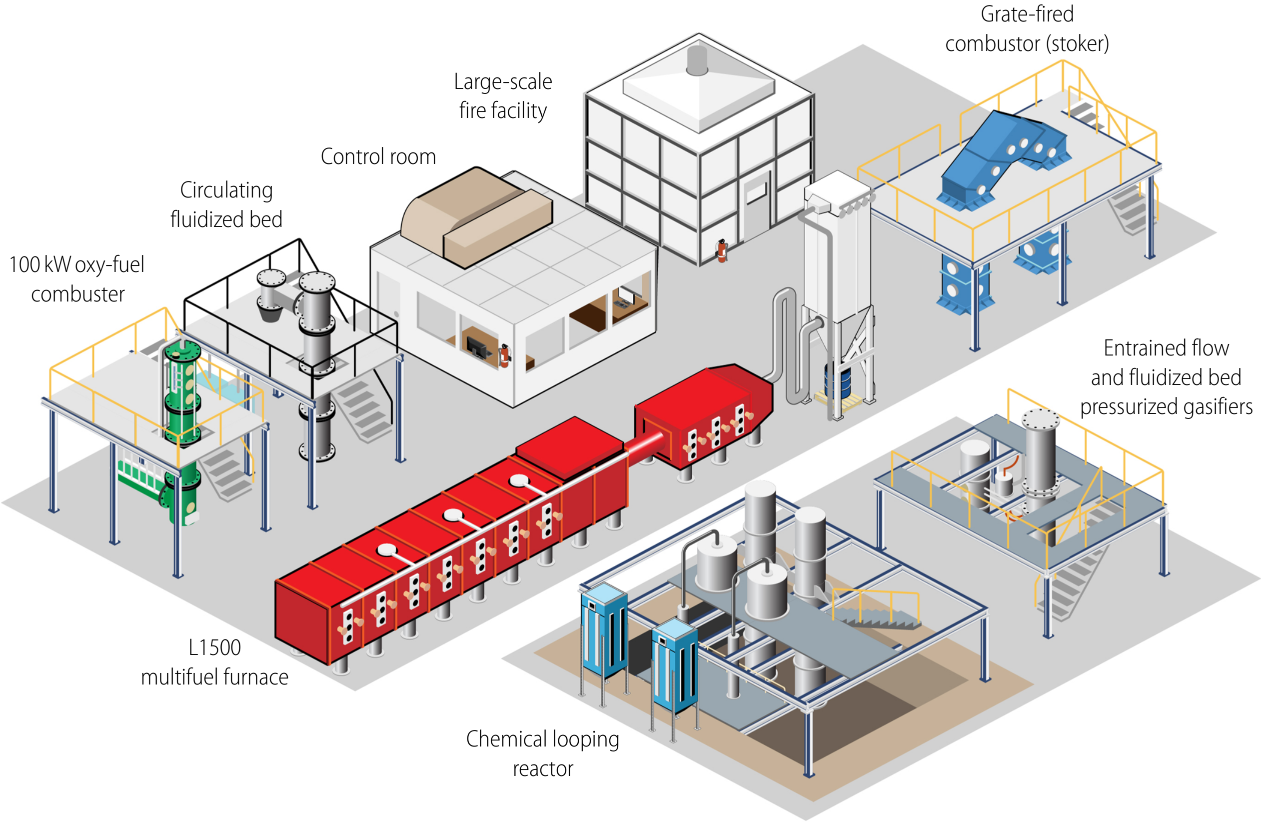

Figure 1: The ICGRF at the University of Utah performs research on coal, shale oil, biofuel, municipal waste, and other fuels for the U.S. Department of Energy, major U.S. utilities, Praxair, and other companies. The entire facility is controlled by Opto 22 automation systems.

pilot-scale reactors and numerous small research and support facilities (Figure 1). The original facilities were controlled and monitored by Opto 22 automation systems and, as the facility grew, more Opto 22 systems were installed. The current project with Opto 22 consists of removing all legacy control hardware and updating it with the latest SNAP PAC System hardware and software to form a modern, integrated automation system.

ICGRF CAPABILITIES

The ICGRF comprises three buildings near the University of Utah campus, each roughly 11,000 square feet, plus an office building with a conference room. The ICGRF houses numerous combustion and gasification test facilities with capacities ranging up to 1.5 MW (5.1 MM BTU/hr).

Figure 2: The pressurized fluidized bed gasifier processes solid fuels such as biowaste to investigate fuel reactivity, tar production, and quality of synthesis gas.

The facility employs full-time operators with many years of experience running these types of equipment, along with analytical engineers experienced in sampling and data acquisition. The efforts of these full-time employees are supplemented by students, particularly in the area of automation systems.

Research performed at the ICGRF includes:

- Underground thermal treatment of coal and oil shale for the production of gaseous and liquid fuels.
- Investigating CO_2 capture combustion technologies including oxygen combustion, gasification, and chemical looping combustion.
- Fuel switching and combustion of multiple fuel blends, including coal, petroleum coke, fuel oils, natural gas, biomass (hog wood, algae, switch grass, bagasse, pelletized biomass, corn stover, etc.), municipal waste, biohazardous waste, and many other fuels.

Process equipment to perform this research includes entrained and fluidized bed gasifiers, grate-fired and oxy-fuel combustors, a circulating fluidized bed reactor, chemical looping systems, diesel engines, fire test facilities, and process heaters. This equipment provides comprehensive capabilities for gas- and liquid-phase analysis and particle characterization.

The pressurized fluidized bed gasifier (Figure 2), for example, processes solid fuels such as biomass and unreactive fuels requiring a long solids residence time. The gasifier is capable of gasifying up to 32 kg/hr of fuel with steam or air, with or without adding oxygen.

The reactor is built in five sections and consists of a gas distributor, bed section, and freeboard. Fuel is fed directly into the bed where it is converted into a hydrogen-rich synthesis gas. Eighty heaters located within the bed allow it to be indirectly heated if desired. A pressurized lock hopper system at the bottom of the bed allows automatic removal of bed solids.

The ICGRF uses the gasifier to test conditions favorable for synthesis gas production and to measure pollutant emissions, deposition, and conversion efficiency for coal and various biomass fuels. The other combusters, gasifers, and processing equipment at ICGRF perform similar analyses on various fuels.

PROJECTS PAY OFF WITH RESEARCH RESULTS

Research performed in this lab is funded by both industrial and government entities. The goal of each project depends on the funding institution. For example, from 2008 to 2013 ICGRF had a large research grant from the U.S. Department of Energy (DOE) for a program entitled "Characterization of Oxy-combustion Impacts in Existing Coal-fired Boilers."

More than 12 institutions and companies from the U.S. and overseas participated in this program. The purpose was to establish feasibility and identify any potential roadblocks for retrofitting the most common type of coal utility boiler in the U.S. with a technology to reduce or eliminate emissions, which included CO_2 capture and storage. The motivation for this research was reducing greenhouse gas emissions and mitigating climate change.

This program was a precursor to the FutureGen 2.0 project, a full-scale demonstration of this technology funded by the U.S. DOE. Results from this program were used in decision making for the FutureGen program. Experimental work for this program was conducted on the oxy-fuel combustor and 1.5 MW multi-fuel furnace.

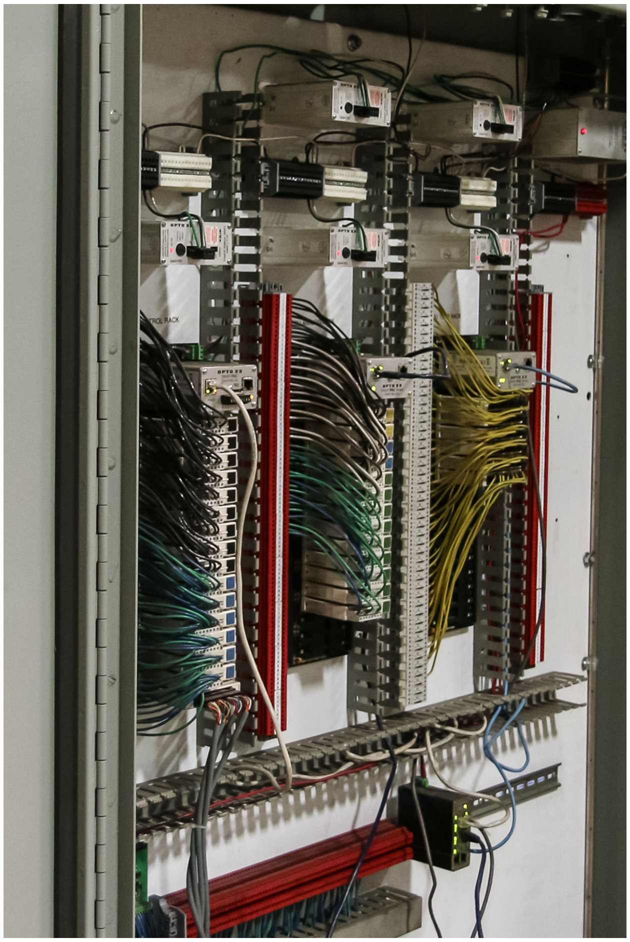

Figure 3: Updating the I/O and controls with Opto 22 SNAP PAC hardware was a simple replacement process.

There have been several programs of this magnitude in the lab's history which were funded by the U.S. DOE. Subjects studied ranged from reducing emissions from coal-fired utility boilers to producing data sets detailing heat transfer in jet fuel pool fires.

GROWTH PROMPTS SYSTEM UPGRADES

As the ICGRF grew, improved control systems were needed. The legacy Opto 22 automation systems did a good job controlling individual systems, but a plant-wide automation system was needed so operators and research engineers could control, monitor, and coordinate all equipment and processes from a central location.

The upgrade path ICGRF took is similar to the one followed by many commercial facilities where islands of automation are joined together, making the upgrade project particularly relevant to students and research partners.

"One might assume," says Fry, "that upgrading seven separate automation systems and 1,360 total I/O points would be a major undertaking." Some equipment was controlled by legacy Opto 22 mistic G4 control systems, and many of the newer furnaces had more recent versions of Opto 22 hardware and software. However, Fry found that replacing the older hardware with modern SNAP I/O and SNAP PAC System controls (Figure 3) was largely a straightforward and uncomplicated effort.

For both the legacy and the newer Opto 22 automation hardware, students were able to perform system design and programming without needing to attend cost-prohibitive training courses. They instead were able to learn everything they needed to know by taking advantage of Opto 22's extensive online training and free phone support.

One reason why replacing the older Opto 22 hardware was relatively simple is that both modern and legacy Opto 22 equipment share the same programming and configuration procedures. This made it relatively easy to set up new control programming and I/O on older systems. This common foundation between new and old systems allowed students to install and configure the hardware without having to learn a plethora of different standards, networks, and procedures.

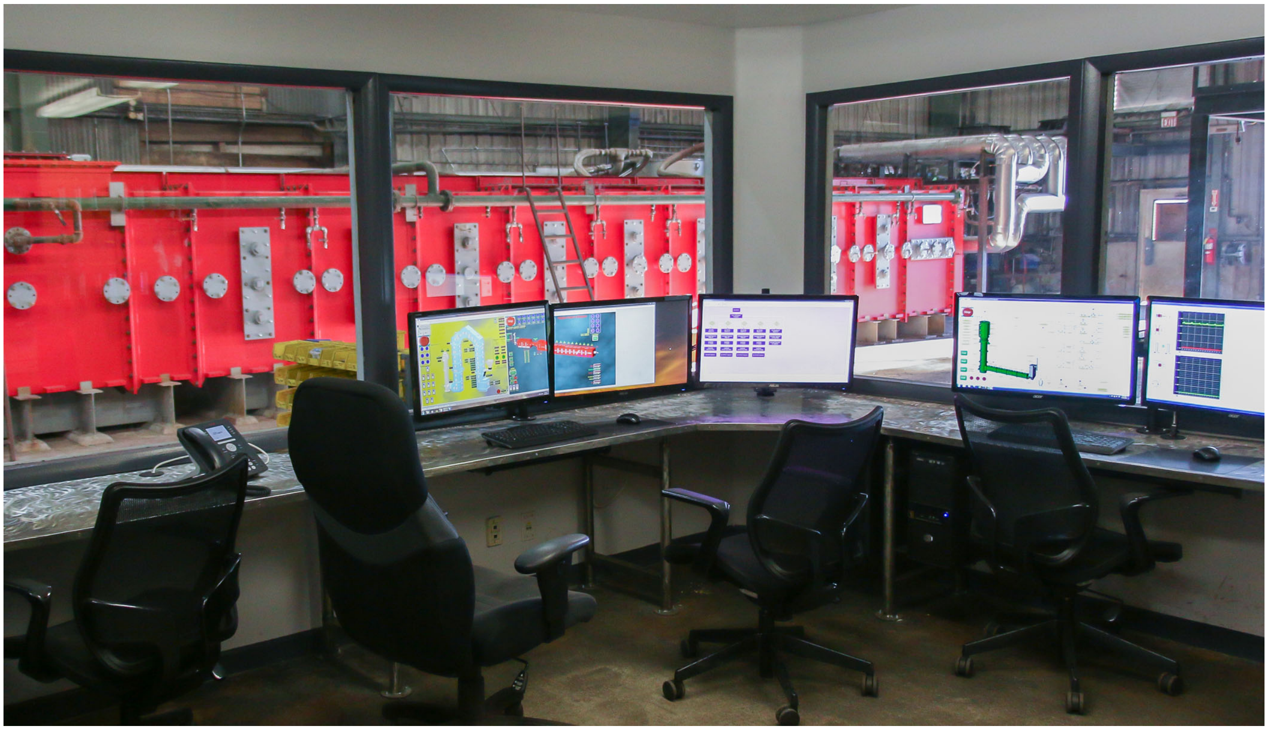

Figure 4: All operations of process equipment at ICGRS can be monitored and controlled from this central control room.

Opto 22 hardware supports Ethernet communications, which made it easy to connect peripheral equipment such as analyzers, chromatographs, remote I/O, and similar devices. Ethernet also made it feasible to network all the remote systems into a central control room (Figure 4).

STEPS TO A SYSTEM UPGRADE

The upgrade process was executed primarily by four students—two undergraduates, one PhD student, and one post-doctoral researcher. None of these students had previous experience with instrumentation and controls, and only two of them had previously taken a course in controls.

The first step in the upgrade was to review the old control programs and account for all the I/O points involved. This included three control programs for the 1.5 MW multi-fuel furnace (L1500), circulating fluidized bed combustor, and grate-fired combustor (stoker) plus building services and analyzers for 422 individual I/O points.

A list of I/O points was created so new hardware could be ordered. One goal of the upgrade project was to be as minimally invasive as possible to the existing wiring.

Fortunately, the engineer who originally set up the automation systems had done a good job of wiring I/O points to terminal blocks instead of directly to the control modules, facilitating reuse of existing wiring.

However, there was no documentation describing the mapping of the wiring, so one of the undergraduate students mapped and labeled all wiring. Once that was completed, both undergraduates removed all of the old control hardware.

The next step was to install and wire the new control hardware for the building services and the L1500 multi-fuel furnace, a task assigned to the post-doctoral researcher and the PhD student. Due to the earlier preparation, this went fairly quickly and smoothly.

The following step was to troubleshoot each of the control points. This step took a bit longer. Some of the 4–20 mA analog points had to be rewired because they were not all uniform in their power and grounding requirements. This turned out to be a valuable troubleshooting exercise for the students.

Next, the PhD student recreated the old control strategy in the new software. Some of this was performed by importing parts of the existing strategy into the new software, but much of the original strategy had to be recreated. Once this step was completed, an undergraduate student duplicated the process for the stoker furnace. With minimal direction, the student was able to install and wire the new hardware, troubleshoot it, and create the control strategy. This same student is currently working on the display strategy for both furnaces.

Fry provided guidance during the upgrade, and there were many meetings focused on wiring diagrams and I/O point manufacturer spec sheets, but Fry says he has yet to touch a tool on the retrofit project since students were able to perform the required work themselves. He did install one of Opto 22's *groov* Box hardware appliances and build a *groov* View HMI, a process he found straightforward.

"*groov* View gives us the new capability to securely monitor and control our equipment from off-site using a PC, tablet, or smartphone," Fry says (Figure 5). "This remote access is an important capability, as we have to leave furnaces running in our facility with no supervision during the heat-up and cool-down phases of a project."

CENTRAL CONTROL ROOM

The ICGRF control room has four HMI stations, each with its own PC and either two or three monitors. Any HMI station can be used to control any reactor or furnace, which allows several pieces of equipment to be operated at once while the control strategy on another piece of equipment is being modified. The HMIs run Opto 22 PAC Display HMI software, which students learned to use by following Opto 22's online training. Also located in the control room are the analyzers that determine the composition of the combustion gases.

Fry says ICGRF is always looking to control costs, and Opto 22 assisted greatly in this by supporting the university with much of the automation system hardware.

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>
> **- Dr. Andrew Fry, ICGRF Director**

Figure 5: Operators and engineers monitor processes from a PC, tablet, or smartphone.

"Because their automation systems use open architectures," he adds, "we're able to use off-the-shelf PCs and Ethernet networking hardware, greatly reducing expenses. Students generally have a great deal of familiarity with PCs and with Ethernet, making the learning process for these critical automation system components relatively straightforward."

In addition to a local operator interface at the central control room, remote monitoring and control is critical. This is provided by Opto 22's *groov* View mobile interface, which allows secure browser- or app-based access from virtually any device connected to the Internet including remote PCs, tablets, and smartphones. Remote access and an operator interface are simultaneously provided to any number of devices on a royalty-free basis.

SUMMARY

What could have been an overwhelmingly complex project to upgrade seven automation systems with 1,360 I/O points and integrate them into a plant-wide system turned out to be a fairly straightforward exercise accomplished by student engineers, thanks to the open architecture, common software, and remote access capability of Opto 22 automation components.

Currently, each year approximately 70 chemical engineering students at the university conduct experiments or examine a process controlled by Opto 22 automation systems as part of a senior design capstone course. This exposure provides students with a unique opportunity for hands-on experience with industrial-grade automation and data acquisition systems before entering the workforce.

"We find these activities greatly enhance the presentation of a wide variety of chemical engineering principles, including separation, heat transfer, and process control," says Milind Deo, professor and chair of chemical engineering at the University of Utah. "Most students cite this class as the most important part of their curriculum. It's clear these educational experiences make a long-lasting impact on our students and serve them throughout their careers."

ABOUT OPTO 22

Opto 22 was started in 1974 by a co-inventor of the solid-state relay (SSR), who discovered a way to make SSRs more reliable.

Opto 22 has consistently built products on open standards rather than on proprietary technologies. The company developed the red-white-yellow-black color-coding system for input/output (I/O) modules and the open Optomux® protocol, and pioneered Ethernet-based I/O.

In early 2013 Opto 22 introduced *groov* View, an easy-to-use IoT tool for developing and viewing mobile operator interfaces—mobile apps to securely monitor and control virtually any automation system or equipment.

Famous worldwide for its reliable industrial I/O, the company in 2018 introduced *groov* EPIC® (edge programmable industrial controller). EPIC has an open-source Linux® OS and provides connectivity to PLCs, software, and online services, plus data handling and visualization, in addition to real-time control.

All Opto 22 products are manufactured and supported in the U.S.A. Most solid-state SSRs and I/O modules are guaranteed for life.

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The company is especially trusted for its continuing policy of providing free product support, free online training, and free pre-sales engineering assistance.

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