RADICALLY ENGINEERED MODULAR SYSTEMS
BREAKING THE COAL CONVERSION MOLD

NETL

NATIONAL ENERGY TECHNOLOGY LABORATORY

MISSION

The National Energy Technology Laboratory (NETL) aims to revolutionize designing and building coal conversion reactors and plants to make them economically attractive, create new coal market opportunities, and significantly reduce the greenhouse gas emissions of fossil energy use.

Electricity and liquid transportation fuels will be the primary products; coal will be the primary feed. Co-production of high-value chemicals, creation of high-value carbon storage products, and use of biomass—and perhaps low-cost natural gas—are all part of the vision.

GENERAL APPROACH

The general approach is to create distributed, cost-competitive coal conversion plants by: (1) optimizing the whole plant (not just the reactors), (2) using simulations to reduce the reactors' and plants' development time and cost, (3) using recent advances in manufacturing to reduce capital costs, (4) leveraging both technical breakthroughs and amenable commercial technologies, (5) using a modular approach to increase plant availability, (6) making greenhouse gas emission reduction an integral part of research and development (R&D) and plant design and (7) ensuring the first small-scale field test facilities will be useful to the local community.

The primary goal of the Radically Engineered Modular Systems (REMS) Initiative is to reduce the cost and global warming impact of coal conversion to useful products, beginning in niche applications and/or small markets. This initial work will create a "tool box" for REMS development including new computational toolsets; reactor characterization techniques; advanced manufacturing methods; and R&D on alternative energy use, flexible feed technologies, solid carbon capture, co-product optimization, catalyst technologies, and system analysis optimization. The tools, knowledge, and expertise developed during the initial niche applications can be applied to mainstream applications, greatly reducing the cost and risk of larger-scale REMS plant development.

To control the cost of tool box development, and to ensure efficient execution of the initial REMS activities, emphasis will be placed on holistic pilot-plant development in a few relatively specific locations. Whole pilot plants, not only the reactors, will be designed with focus on how advanced manufacturing, modularization, and simulations can improve all aspects of the pilot plant, including integration of reactors, balance of plant equipment, and more market-competitive products. Ideally, the pilot plants will provide a useful function beyond the project test phase.

The reactor design approach will be unique for each application—focused on locally available coal and other opportunity inputs such as biomass, natural gas, or solar power. The most economically competitive products will be considered, and techno-economic systems analysis will be performed periodically as the REMS are developed to refine the slate of created products, to evaluate potential economic performance, and to show where more development work is needed.

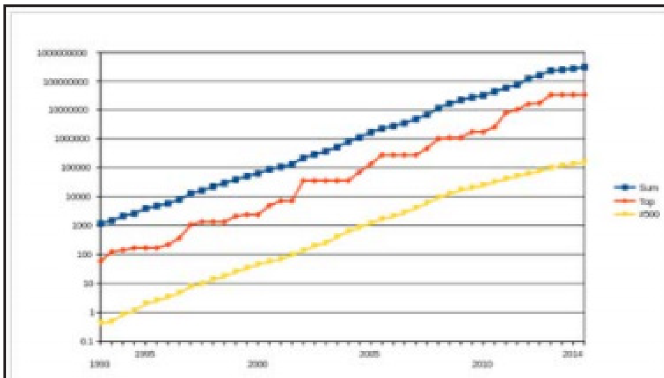
BACKGROUND AND TECHNICAL DETAILS

Traditional reaction and chemical process engineering starts at laboratory scales and gradually builds up to larger systems. The typical R&D development cycle for the conception of a new chemical process and its industrial-scale deployment is approximately 20–30 years in length, occurs in several stages, and requires enormous capital investment. Furthermore, these long cycles force the developer to incur large financial risks during this process due to the potential for technologies to fail during scaling.

Simulation-based reactor design will be used to better predict reactor behavior and results, and advanced manufacturing techniques will enable rapid prototyping of concepts. This approach should lead to significantly reduced times for new reactor development.

Once perfected, multiphase and kinetic modeling, plus supporting data, will provide accurate predictions of where in the reactor desired and undesired reactions occur, and allow researchers to virtually test feed- and product-specific reactor designs. Furthermore, as computing power continues to increase, these reactor simulations will become increasingly fast and realistic, while reducing in cost. A physical example is the desktop computer of the early 1990s compared to smartphones of today.

Rapid prototyping, such as inexpensive 3D plastics printing of cold flow reactors, will be used to quickly test the unique reactor designs. Additive manufacturing and other advanced manufacturing techniques for metals and ceramics will be used to rapidly translate proven cold-flow unique reactor designs into reactors for hot-flow validation, and for final manufacturing of coal conversion reactors for deployment.



Rapid growth of supercomputer performance, based on data from top500.org site. The logarithmic *y*-axis shows performance in GFLOPS.

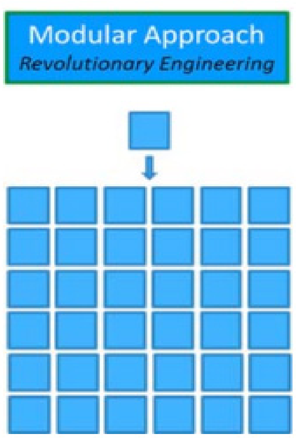
- Combined performance of 500 largest supercomputers
- Fastest supercomputer
- Supercomputer in 500th place

Metal additive manufacturing using a laser.

The REMS reactors will:

- Have optimal configuration and size for conversion of specific coal type and other feedstock (biomass, municipal solid waste, etc.) to the target product(s).
- Combine multiple chemical reactions and separation systems into one reactor or process, as much as practical.
- Be amenable to modular deployment.

REMS technical breakthroughs, combined with a modular approach, will be able to overcome the traditional economies of scale. Academic research on the economics of smaller and more modular systems cite a variety of contributing factors for these changing economic and business models:



- Small, modular reactors and plants with common components can be mass produced quickly, prefabricated, and dropped in at a desired site, which reduces build and maintenance costs, compared to constructing a traditional coal conversion plant.
- Modular plants will have higher availability because equipment failure will only slow production, rather than halt it, as is often the case in conventional plants with limited equipment redundancy.

The "right-sizing" of reactor systems by coupling several small, prefabricated, modular, reactors can allow one to effectively service markets that were previously too small to be economically attractive for large, traditional plants.

Another advantage relates to global warming rather than cost: smaller systems will enable a higher proportion of biomass use, since biomass transportation costs are too high to support use in large power or coal-to-liquids plants bound by economies of scale. This same principle is true for other opportunity fuels, such as municipal solid waste.

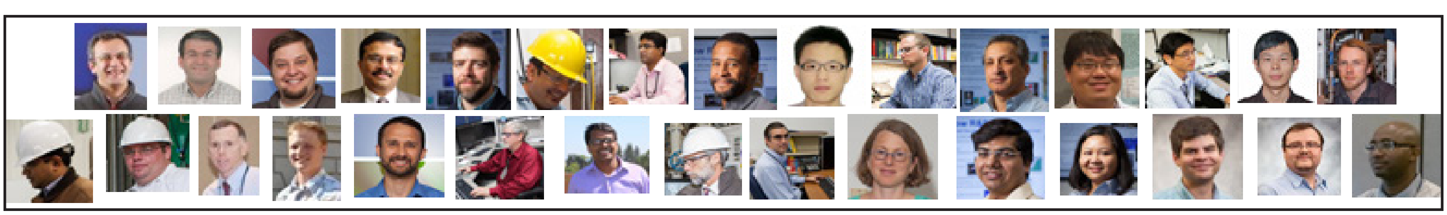
Carbon fiber additive manufacturing

Institute for Advanced Composites Manufacturing Innovation

The REMS approach is actively seeking technologies that can lower greenhouse gas (GHG) emissions. In addition, small, distributed plants favor the use of biomass. Therefore, co-feeding of biomass to reduce net GHG emissions is both more feasible and more important than in larger coal conversion systems or power plants.

Other methods being explored to reduce CO_2 emissions include carbon removal from coal. For instance, excess carbon can be removed in char or heavy coal tars, which could then be converted into high-value products with near permanent capture. This solves two problems at one time: increasing plant market competitiveness while storing carbon before it becomes a GHG.

Outreach and communication to foster collaboration on R&D and manufacturing techniques, and using commercial technologies applicable to REMS plants will be an active and ongoing part of the REMS initiative.



NETL's Multiphase Flow Modeling Team

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