RAPID
Transforming Process Industries

DRIVING INNOVATION IN PROCESS INTENSIFICATION

2018 ANNUAL REPORT

2018 WAS A YEAR OF INTENSE ACTIVITY MARKED BY KEY MILESTONES

As you read through our accomplishments, you will see collaboration and innovation in action. 2018 was a year of intense activity marked by key milestones, in which RAPID:

- Welcomed our 75th member, the Shepherd Chemical Company;
- Executed and completed all agreements for projects awarded during RAPID's first (2017) project call;
- Conducted a Department of Energy (DOE) Peer Review of the Institute and funded projects resulting in new initiatives to improve cross-project collaboration;
- Received Governing Board approval for our Sustainability Plan; and
- Drafted a comprehensive Process Intensification and Modular Chemical Process Intensification Body of Knowledge to move our educational programs forward and launched 11 webinars, a "Fundamentals of Process Intensification" eLearning course, and a summer internship pilot program.

Our greatest accomplishment is that we have built a strong and diverse community of members committed to sharing ideas and perspectives that advance our Process Intensification (PI) and modular processing efforts.

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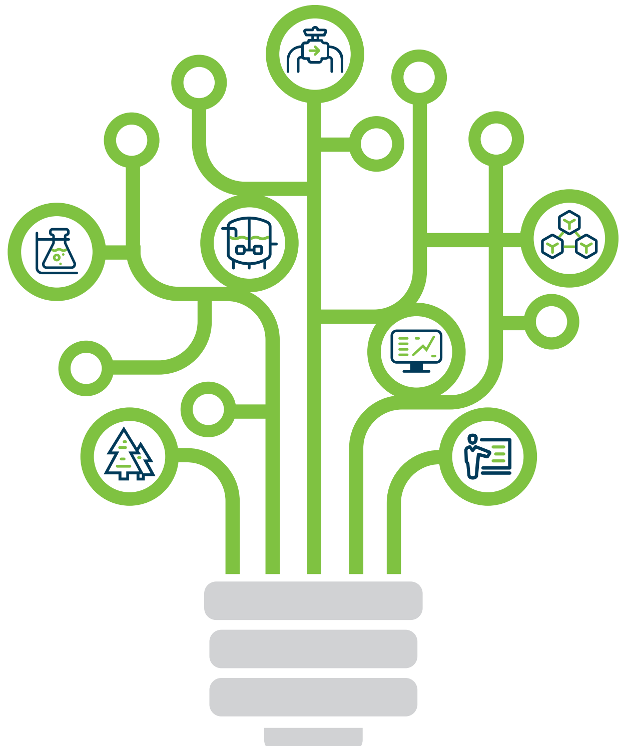
MISSION, VISION, & VALUES



Our Mission

- Lead a national effort to develop, demonstrate, and deploy high-impact process intensification and modular process technology solutions that reduce energy use, increase sustainability, and drive profitability for U.S. manufacturing.
- Bring together private and public organizations to co-invest in R&D, commercialization, and deployment of innovative technologies.
- Establish a community that enables access to resources, tools, expertise, and facilities.
- Establish a technical education and workforce development program.
- Leverage $70 million of federal funding and over $80 million in member cost share to fund the development of new technologies and educational offerings.

Our Industry-Led Vision

A dynamic network of partners who collectively build a sustainable ecosystem that:

- Researches, develops and advances new technologies for process intensification and modular processing
- Builds a strong portfolio of R&D projects and educational tools
- Delivers dramatic reductions in energy, environmental footprint, capital and operating costs
- Makes U.S. manufacturing and our workforce more competitive

Our Values

INNOVATION

Fostering new solutions and approaches using chemical engineering expertise and cutting-edge technologies.

INTEGRITY

Being honest, open, responsive, and fair.

ACHIEVEMENT

Empowering teams to take action; driving to achieve goals and meet commitments.

COLLABORATION

Building relationships for knowledge-sharing, innovation, and successful outcomes.

A MESSAGE FROM RAPID'S CEO

To Our Valued Members and Colleagues,

In RAPID's second year of operation, our team worked hard to develop a robust community of process intensification (PI) and modular process technology practitioners, and we met all of our important milestones. By the end of 2018, RAPID had 75 members, with 32 industry partners ranging from startups to multinational corporations, 31 universities, and 12 other organizations including national labs, nonprofit research institutes, and industry consortia. Together, RAPID and its members are unlocking the power of PI and modular process technologies to deliver energy efficiency, sustainability, and cost savings in the process industries.

Our project portfolio now numbers 35 total, and we are committing over $120 million in federal and member cost share funding to a diversified R&D and education project portfolio. Member projects are focused on areas that will prepare PI technologies for wide-scale adoption and commercialization—improving safety, reliability and performance, increasing efficiency, strengthening the supply chain, and educating an advanced manufacturing workforce that will be skilled in PI principles—and are generating significant research contributions. To date, members have authored over 35 articles and white papers in key publications, including our very first AIChE *Chemical Engineering Progress (CEP)* PI Supplement. The depth and merit of their research bolsters our knowledge on how best to approach and execute PI and modular process technology development with greater certainty and success.

We also very much appreciate the continued involvement of members in RAPID's Governing and Technical Advisory Boards. Throughout the year, the Governing Board helped guide our progress, working with me to refine our strategy and develop and approve a sustainability plan. The Technical Advisory Board worked with RAPID's technical team to ensure a strong R&D portfolio and select additional projects for funding.

Attendance at our Annual and Spring Meetings, which are the backdrop for our topical conference sessions, continues to grow, and in 2018, we added our first PI faculty workshop and module manufacturing workshop, as well as two signature events that served as additional networking opportunities. These events foster collaboration and knowledge-sharing among industry, university, and nonprofit members. This year, we also added value for our members with the creation of an online Members Directory, which will launch in 2019. This will enable members to network with one another and improve access to facilities, equipment and research-critical applications.

We also accelerated our Education and Workforce Development efforts, launching 10 PI webinars, one additional webinar on modular manufacturing and RAPID's first eLearning course, "The Fundamental of Process Intensification," to introduce key PI concepts to undergraduate and graduate students and working professionals. To further encourage future leaders in the field, RAPID piloted a Summer Internship Program, which will now become a year-round initiative in 2019, and we selected two hands-on training courses for development by members. The reception to our educational programming has proven so popular that we plan to launch another six webinars and up to six eLearning courses next year.

We hope this annual report provides a greater understanding of what drives RAPID. Our team is very proud of the groundbreaking work that's underway, and we are confident that it will strengthen the process industries and American manufacturing. We've come a long way in the past two years, and I look forward to RAPID's continued growth and achievement.

Sincerely,

WILLIAM GRIECO
Chief Executive Officer,
The RAPID Manufacturing Institute

FOSTERING INNOVATION AND UNLOCKING VALUE

PROCESS INTENSIFICATION

Visit any chemical plant in the U.S. today and you will find complex, large-scale equipment performing multi-step processes. Most of these processes were designed and built using standard unit operations and have been optimized by engineers over the decades to increase yield and reduce energy use. In many cases, that optimization has reached the limit of traditional engineering fundamentals, so engineers need new tools for process design and development.

Process intensification (PI) and modular processing are some of these important new tools. The concepts employ innovative approaches to system design and construction, as well as consolidation of chemical processes by exploiting new methodologies that are fast becoming the driving forces behind a new era in chemical engineering.

The many technologies enabling transformational growth in manufacturing include new membrane and catalyst technologies, microwave-assisted reaction chemistry, advanced modeling and simulation; 3D printing (additive manufacturing), predictive analytics, advanced materials, machine learning, and digital design—all ensuring that PI and modular processing are on their way to becoming an industry standard.

However, adopting PI and modular processing require organizations to think differently about their business models, products, capital cost expenditures and strategic partnerships to capture true value.

The following illustrate how RAPID is working to unlock value for industry, its members and society.

RAPID funding to IntraMicron supported the scale-up and modularization of this novel technology and allowed a SourCat™ pilot plant module to be deployed for field testing to a sour natural gas wellhead in Texas during 2018.

MODULAR NATURAL GAS SWEETENING AT THE WELLHEAD

Natural gas used by consumers is far different from the natural gas flowing from the wellhead. The wellhead product contains impurities, such as highly toxic hydrogen sulfide, that must be removed for natural gas to be safely distributed from the processing plant to the consumer.

To address these challenges, RAPID member, IntraMicron and its subsidiary Sour Gas LLC, developed the SourCat™ desulfurization system. This technology—a significant step forward for industry—offers an energy and cost-efficient alternative to traditional natural gas desulfurization approaches. SourCat™ selectively recovers elemental sulfur and has the ability to process natural gas feedstocks over a wide range of purities, including those with levels of sulfur that cannot be economically purified by traditional desulfurization approaches.

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Consequently, IntraMicron invited visitors to tour that desulfurization pilot plant site in Texas, demonstrating to industry executives and other RAPID members how their new technology enabled the sweetening of sour natural gas at the wellhead. IntraMicron and Sour Gas LLC believe that this modular technology could also be deployed for treatment of landfill gas, biogas, acid gas, and other process gas streams including those in offshore platform operations. This technology is also designed for easy maintenance and operation and is notable for its simple modular skid-mounted system, which is easily deployed to various field locations. Unlike other desulfurization processes, the SourCat™ system does not require a concrete foundation allowing for easy assembly and disassembly and movement among locations.

Dr. Paul Dimick, General Manager of IntraMicron, observed, "We have proven just how effective this patented technology is and hope to make it commercially available in 2019. Thanks to RAPID funding, we have delivered a viable system that is exceptionally well-suited to removing hazardous hydrogen sulfide (and mercaptans) at gathering points, sales points, compressor stations, and even directly at the wellhead."

DISTRIBUTED SOLAR-DRIVEN HYDROGEN PRODUCTION

Over 95% of hydrogen is currently produced using steam methane reforming (SMR). This energy intensive process is typically operated in large, centralized facilities that take advantage of traditional economies of scale. There is increasing interest in producing hydrogen through a more distributed infrastructure that takes advantage of low cost natural gas (e.g., SMR at the wellhead), brings hydrogen production closer to the consumer (i.e., enabling a more ubiquitous hydrogen economy), and capitalizes on low cost energy resources (e.g., low cost solar and wind generation resources). That distributed hydrogen production infrastructure will require new reactor designs with lightweight components manufactured using advanced materials and novel techniques.

With funding from RAPID, Oregon State University (OSU) and Pacific Northwest National Laboratories (PNNL) are designing microchannel chemical reactors and heat exchangers with five to 10-fold reductions in size and weight, and they are using additive manufacturing techniques to build process components for this application. With OSU and PNNL, the spinout venture STARS Technology Corp. (STARS) is working to commercialize a process for solar-powered SMR production of hydrogen, where solar-to-chemical efficiencies greater than 70% have already been demonstrated. RAPID funding will also support the development of STARS pilot modules for proof-of-concept testing under field conditions. The STARS system uses a concentrator dish to focus solar energy on a nacelle that houses the SMR reactor and other components. To satisfy critical size and weight budgets on the solar nacelle, multiple microchannel reactor and heat transfer components are needed. These components need to be manufactured at low cost using materials that stand up to extreme reaction conditions.

Lowering the cost of microchannel components using Module Advanced Manufacturing (MAM) requires new powder metallurgy machine tools capable of printing novel materials in new, lower cost ways. Toward this end, OSU's Advanced Technology and Manufacturing Institute (ATAMI) is modifying a MAM tool to allow for the digital manipulation of metal powders (i.e., the precise addition of additives and use of an inkjet print head) prior to laser densification. This tool will be used in the RAPID program to produce new metal-matrix-composites with high-temperature strength and corrosion resistance and has the potential to cut component costs by 30%. As a result of its work, OSU received a High Impact Opportunity Project (HIOP) grant from the State of Oregon to develop new metal additive manufacturing processes, machine tools and materials that will be used to explore the development of Ni-based super-alloys with enhanced thermal conductivity.

RAPID-funded projects supplemented by state investments are helping to establish new supply chains for process intensified components, such as microchannel reactors and heat exchangers, that will be used in modular processes like the STARS systems. In the future, these supply chains may also impact the aerospace and biomedical insert markets. OSU professor Brian Paul—also RAPID's Modular Manufacturing Focus Area Leader—believes "the cumulative economic impact to these industries over time could be billions of dollars and thousands of high-wage jobs."

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SourCat^{TM} Pilot Facility

INSTITUTE OVERVIEW

PI dates back to the early 1970s and involves the development of new technologies or equipment that can potentially transform the process industries. The RAPID Manufacturing Institute leads a national effort to research and develop high impact PI and modular processing solutions for U.S. industry and operates the Institute to benefit a range of stakeholders from members in industry and academia to national labs and other nonprofit organizations. RAPID is also committed to advancing women-owned and minority-owned businesses in the emerging field of process intensification. The Institute's strength is its ability to build a community of members focused on developing new PI and modular process technologies and to provide those members with access to PI resources, tools, expertise, and facilities.

We strive to continually refine our technology roadmap that currently focuses on six key areas: chemical and commodity processing, natural gas upgrading, renewable bioproducts, intensified process fundamentals, modeling and simulation, and module manufacturing and to enable members to work on technology development projects that reflect those focus areas.

RAPID serves as a nexus between process innovation, economic development, and job creation. The technology development and educational programming we sponsor will increase energy and operational efficiencies, enhance productivity, and improve sustainability, making U.S. manufacturing in the chemical process industries (CPI) more competitive in the global market and developing the next generation workforce for these industries.

SECOND YEAR HIGHLIGHTS

In its first year (2017), RAPID started up quickly—staffing a core team; building out the Governing and Technical Advisory Boards; establishing legal, intellectual property and membership documents; and developing roadmaps for six technical focus areas as well as education and workforce development to guide R&D projects and educational content development. RAPID ran a project call during its first year that resulted in the funding of 25 R&D projects across all six technical areas and in 2018, added one cross-cutting project to develop and curate models and metrics for the Institute.

In its second year, RAPID streamlined its membership levels, amended the membership agreement, and refocused our membership goals to attract more industry members, particularly small and medium sized enterprises. RAPID worked with member project teams and DOE to put contracts in place for all of the projects from 2017 and to ensure that those projects met technical milestones. RAPID solicited proposals during a second call for both technical and educational projects and selected six additional R&D projects and two face-to-face course development projects for funding. RAPID's Education and Workforce Development effort hit its stride in 2018, launching 11 webinars, deploying the first "Fundamentals of PI" eLearning course, holding an instructor-led workshop to train faculty on the fundamentals of PI and modular processing, deploying a comprehensive Body of Knowledge to define PI and modular processing curriculum needs, and piloting a summer intern program. Finally, RAPID held problem discovery workshops at different events to uncover new areas of interest and new industry segments where PI and modular processing could have an impact.

In the latter half of 2018, RAPID led a benchmarking study to understand and promote best practices across DOE-funded institutes. Conducted in partnership with McKinley Advisors, the study assessed institute operations—including staffing, governance, funding models, project development, and contracting—and worked to understand the value that institutes bring to their members. The study revealed that members appear to value community creation, thought leadership, and Education and Workforce Development initiatives—all areas where RAPID excels—and showed that RAPID had among the lowest staffing of the DOE institutes, a testament to our ability to achieve more with less!

FINANCIAL SUSTAINABILITY

RAPID leadership developed a strategic plan for financial sustainability of the Institute beyond the initial five year DOE cooperative agreement. With facilitation help from AIChE, RAPID first held a workshop to brainstorm, sort, and prioritize key elements of the long-term value proposition that RAPID can offer to members. The RAPID leadership team then refined RAPID's vision and mission and defined a value proposition and designed potential offerings to suit different members. These offerings were captured in the RAPID Sustainability Plan. As RAPID evolves from a purely DOE-funded manufacturing Institute, the leadership team expects RAPID to operate as a member-focused Institute that (1) selects and manages technical development projects funded by members and supplemented with private and public sector support, (2) delivers content at meetings and via publications, (3) develops and distributes design guidelines and technical tools, (4) tests and grows an engineering services practice to help clients benchmark their existing processes and understand how best to deploy PI and modular process technologies, and (5) deploys premium Education and Workforce Development content to inform the process community.

The RAPID Governing Board approved the Sustainability Plan in October of 2018.

RAPID AND THE MANUFACTURING EXTENSION PARTNERSHIP (MEP)

The Manufacturing Extension Partnership (MEP) Network with offices around the country is funded by the National Institute of Standards and Technology (NIST), and has played a pivotal role in RAPID's growth and outreach efforts. A strong advocate of process intensification, MEPs contribute by engaging prospective new members, as well as enhancing the projects of current members.

Through the work of our MEPs located in Oregon, New York (ITAC) and Iowa, we have been successful in attracting minority-owned and women-owned businesses, as well as smaller niche manufacturers and supply chain partners. During the course of the year, RAPID's MEP colleagues were instrumental in adding five new members to our community.

They also provided key manufacturing expertise and facilitated project proposals. Most recently, they helped us brainstorm ways to overcome barriers to modularization and numbering up at a module manufacturing workshop held during the AIChE Annual Meeting in Pittsburgh. They have continually encouraged RAPID's attendance at events such as NYSTAR's (Empire State Development's Division of Science, Technology and Innovation) EXPO and Meeting, enabling us to interact with New York State companies and academic institutions.

MEMBERSHIP

RAPID brings together recognized process technology experts from industry, academia, national laboratories, research institutes and other organizations to create a rich community that collaborates on R&D and education projects and provides thought leadership on PI and modular processing.

At the end of our second year, RAPID membership consisted of 32 industry partners, 31 academic institutions, 4 government labs and 8 nonprofit organizations.

Benefits of Membership in RAPID include but are not limited to:

- Networking with a diverse community of subject matter experts
- Building partnerships to access government funding (both through RAPID's current DOE contract and through other agencies) to move concepts from ideation to reality
- Developing, licensing and commercializing valuable intellectual property
- Accessing potential customers and supply chain partners
- Participating in workshops and webinars on the latest developments in Process Intensification and Modular Processing
- Utilizing AIChE's valuable resources such as conferences and publication

RAPID'S IMPACT

33
research projects

124
project proposal submissions

$150+M*
public-private partnership

>1900
people trained***

1 x 10⁸
MMBTU/yr energy saved

14
students participated in RAPID's Intern Program

2
Education and Workforce Development projects

11
Webinars

7
eLearning Courses**

**Over RAPID's Projected Lifetime*
***Projected for 2019*
****Targeting 1900 people trained over five years*

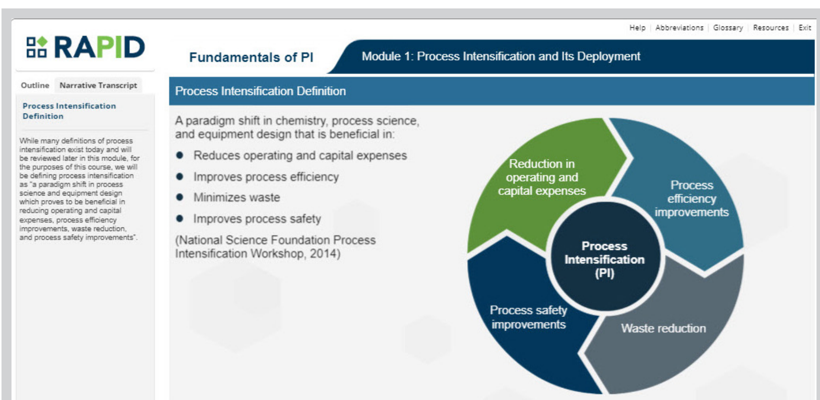
EDUCATION AND WORKFORCE DEVELOPMENT (EWD)

Developing new PI and modular process technology solutions requires a cultural change that is aligned with how industrial processes are designed and implemented. To drive this change, we must have a workforce trained in these technologies. Only then can PI and modular processing become an essential part of the engineer's standard toolset when designing processes.

RAPID's Education and Workforce Development mission is to establish a technical education and workforce development program that leverages existing resources to train and educate the workforce, which can then research, develop, design, and operate processes that incorporate new PI technologies and modular process designs in the U.S.

To meet our objectives, RAPID:

- Produced and rolled-out a 10-part webinar series on the Fundamentals of PI as well as an 11th webinar on Module Manufacturing. A total of **1,505** participants—among them **604** industry professionals, **432** students, **228** faculty members, and **241** others representing government, nonprofit and retirees—registered for these webinars.
- Promoted Annual and Spring Topical Conference sessions and specialized seminars that resulted in a total reach of **2,664** participants.
- Launched the first PI-specific eLearning course, ELA300: RAPID's Fundamentals of PI.
- Rolled-out a comprehensive Body of Knowledge in Chemical Process Intensification and Modular Equipment Design.
- Convened a panel exploring the challenges of EWD in PI & Modular Processing.
- Initiated a highly successful Summer Intern Program.



LOOKING AHEAD

RAPID plans to introduce:

- 4–6 eLearning courses
- 6 webinars
- A year-round Intern Program (covering spring, summer, and fall terms)
- A Modular Chemical Process Intensification Boot Camp pilot for members, educators and trainers
- A PI Train-the-Trainer Workshop at the AIChE Annual Meeting
- Short videos demonstrating the impact of PI and modular processing

DEVELOPING FUTURE LEADERS THROUGH RAPID'S SUMMER INTERN PROGRAM

RAPID's inaugural Student Intern Program launched in June 2018. The program's goal was to develop and train future leaders in PI and Modular Processing and was a resounding success with over 86% of participants stating that the program had an impact on their educational goals and career aspirations. RAPID set the conservative goal of four interns participating in the summer pilot, but we greatly underestimated interest. In fact, 14 interns from five RAPID member institutions participated in hands-on internships supporting RAPID projects for 10 weeks. These are just some of positive comments from participants in RAPID's inaugural Student Intern Program which launched in June 2018.

"I'm more interested in designing systems now. I see more opportunity than before because of this program."

— RAPID Student Intern

The interns were nominated by member organizations through an online nomination process. Nominating organizations were responsible for hiring the interns, providing a technical mentor, and ensuring that the intern met program qualifications.

RAPID created a dynamic intern experience which provided not only an in-depth understanding of PI and Modular Processing concepts and how these concepts could be applied to industry but also provided professional and leadership development content, feedback and career guidance. Another unique benefit was RAPID's "virtual community," an online forum where interns could share perspectives on their work in the lab and outside of it. Without this forum, the cohort of interns would likely not have connected with each other, developed as professionals, or learned about the opportunities available in PI. Feedback from interns was overwhelmingly positive.

QUICK FACTS

- 14 interns from five RAPID member organizations; the class overall was predominately male, predominately undergraduate students, and predominately Chemical Engineering students. Survey data reveals the following additional insights:
- Students had an average class GPA of 3.56
- 43% had no prior hands-on research experience
- 92% of interns said they would recommend the program to a friend

"Originally, I wanted to work for a company in mass transportation, but now I would like to work for a company that specializes in biorenewables and sustainability."

RAPID Student Intern

THE TOP THREE RESPONSES GIVEN WHEN INTERNS WERE ASKED WHAT TYPE OF EMPLOYER THEY WERE INTERESTED IN PURSUING:

PRIVATE OR FOR-PROFIT COMPANY
64%

COLLEGE OR UNIVERSITY
29%

DOE NATIONAL LABORATORY
29%

RAPID BY THE NUMBERS

10
MEMBERS
OF FORBES 2000

30
WEB ARTICLES

PLUS

Strong social media presence via LinkedIn

Key Collateral: Annual Reports & fact sheets

Chemical Engineering Progress (CEP) PI Supplement

MEMBERS YEAR END 2018
75

TOTAL PROJECT PORTFOLIO
35

R&D TECHNICAL PROJECTS
33

EDUCATION, WORKFORCE DEVELOPMENT PROJECTS
2

INTERN PROGRAM STUDENT PARTICIPANTS
14

THOUGHT LEADERSHIP EFFORTS

35

WEBINAR, CONFERENCE AND ELEARNING PARTICIPANTS

4,223

CROSS-CUTTING METRICS AND MODELING

1

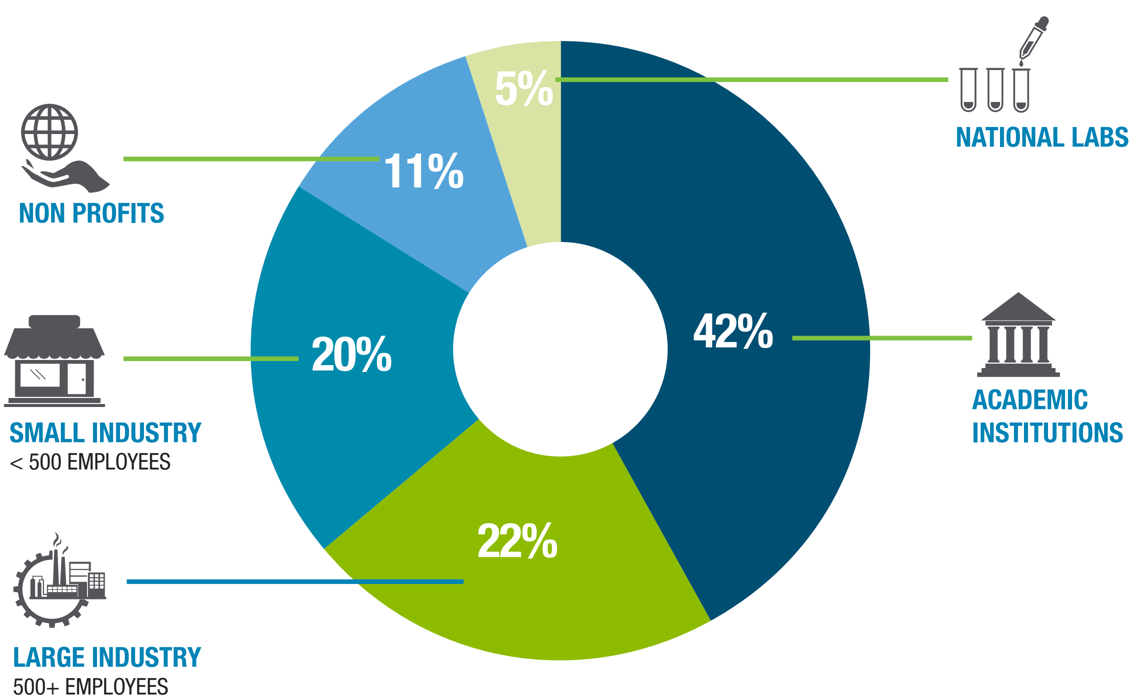
20+

NEWSLETTER ISSUES

58%

OF MEMBERS PARTICIPATING ON RAPID PROJECTS

RAPID MEMBERSHIP IS DIVERSE:



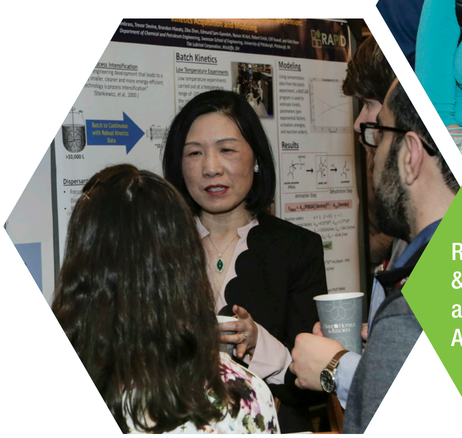
BUILDING A COMMUNITY OF INNOVATORS

In 2018, RAPID launched a broad array of initiatives to drive us toward our ambitious goal of creating a vibrant community of PI and modular process technology professionals. We were able to focus our efforts for maximum impact by developing meaningful signature events such as RAPID's Technology Speed Dating, a poster session, specialized workshops, panel discussions, topical conference sessions and more.

We were gratified to learn that at the end of our events, members walked away with greater knowledge, better insights, and new connections to help them navigate the expanding world of PI and modular processing.

> "Signature events such as RAPID's poster session provided an ideal informal venue for connecting with other organizations who were interested in what we are working on. We had several promising discussions that we look forward to following up on."
>
> — Hannah Murnen, Compact Membrane Systems

RAPID Technology Speed Dating Event at the 2018 AIChE® Spring Meeting



RAPID Networking & Poster Session at the 2018 AIChE® Annual Meeting

BOOTH DEMONSTRATIONS ON PI IN ACTION

RAPID Members Council Meeting Attendees

> Taking a leadership role in PI means making information readily available to our community through education and workforce training and information exchanges such as poster sessions and workshops. Innovation and big ideas don't just happen in a bubble; they have to coalesce while solving very real industry problems. That is what RAPID is all about—bringing together the right members in a community dedicated to problem-solving.

— William Grieco, RAPID CEO

> Membership and active participation in the RAPID Manufacturing Institute has been the key catalyst for introducing the concepts of process intensification into our corporation and our successful collaboration with the University of Pittsburgh.

— Clifford Kowall, Lubrizol Corporation

CONGRESSIONAL BRIEFING AND EXPO IN WASHINGTON, D.C.

RAPID at the 2018 AIChE® Spring Meeting Booth

A MESSAGE FROM RAPID'S CTO

To Our Valued Members and Colleagues,

An important feature of intensified process equipment is that it can accomplish several critical tasks at a time, and the same could be said of the RAPID Manufacturing Institute in 2018. Gathering steam in its second year, the Institute refined roadmaps, hosted workshops, convened meetings, and published content. But above all, RAPID's second year was marked by significant and exciting growth in its research project portfolio and educational offerings.

When I joined RAPID in April of 2019, I encountered a diverse and vibrant community of industry professionals, researchers and educators. My predecessor, James Bielenberg, had prepared a solid foundation and framework for me to build upon. I am also honored to work with a talented group of individuals from our parent AIChE, our RAPID staff, our members, our project teams, and our partners at the Department of Energy.

In 2018, external drivers continued to prompt rethinking in the chemical process industries (CPI). These drivers included the rise of shale oil and gas, increased pressure to reduce environmental footprints, and the availability of cheap renewable power. In response to these challenges and opportunities, our RAPID community worked diligently to devise processes that are smaller, cheaper, cleaner, and smarter.

Many of the projects we sponsor have enormous potential to create technology and equipment for wider adoption and commercialization. These projects were chosen not only to help reduce costs, improve productivity, and increase energy efficiency for industry but also to ensure that safety and sustainability are always at the forefront of our project work. For example, our project teams are working to transform biomass to useful intermediates, find alternatives to energy-intensive distillation columns at refineries, reduce the environmental impact of hydraulic fracturing, create chemical building blocks from stranded natural gas, and reduce the amount of water and energy needed to make paper products.

The transformational work we foster among our community of members is impressive and noteworthy. Our second year saw us hitting our stride as we race toward the breakthroughs that are sure to come.

Paul Yelvington

PAUL YELVINGTON
Chief Technology Officer,
The RAPID Manufacturing Institute

RAPID PROJECT PORTFOLIO

Chemical and Commodity Processing

Education and Workforce Development

Intensified Process Fundamentals

Modeling and Simulation

Modular Manufacturing

Natural Gas Upgrading

Renewable Bioproducts.

Chemical and Commodity Processing

Dynamic Intensification of Chemical Processes

TEAM
University of Texas at Austin
Dow

SUMMARY
A significant portion of commodity products are manufactured in large facilities that operate at steady state. In many ways, the traditional chemical industry has reached a plateau in terms of productivity and energy efficiency in such facilities. Improvements based on existing technologies and unit operations are mostly incremental and unable to address fundamental transport limitations that drive process efficiency. Process intensification, largely based on reducing transport and transfer limitations, has the potential to take bulk and specialty chemical production to new levels of economic efficiency. However, process intensification has thus far largely focused on the redesign of process hardware, requiring significant capital investments to realize benefits.

This project looks to use modeling and optimization to define PI opportunities in existing hardware. In particular, it takes a general look at dynamically forcing a process to take advantage of nonlinear systems responses. In certain cases, this mode of operation can deliver significant improvements in performance. The goal of the project is to provide a general theoretical framework for dynamic intensification, as well as using divided wall column operation as a test case to practice dynamic intensification at the pilot scale.

POTENTIAL IMPACT
Changes in operating strategy can potentially lead to considerable energy savings. This can be achieved without substantial process hardware changes and with low capital expenditure. In the context of a divided wall column application, the implementation of these ideas can be a true game changer for energy consumption in the U.S. chemical industry (there are around 40,000 distillation columns in operation, accounting for about 40% of the energy consumption for the chemical process industry). The project's technology transfer plan will directly translate into a "first" industry application.

Para-Xylene Selective Membrane Reactor

TEAM
University of Minnesota
ExxonMobil

SUMMARY
The current approach to p-xylene production includes an isomerization step that gives a nearly equilibrium distribution of mixed xylenes, followed by an energy intensive simulated moving bed (SMB) adsorption process to separate and recover p-xylene and recycle of p-xylene depleted product for further isomerization. This project aims to develop and validate para-xylene ultra-selective zeolite membranes (particularly defect free membranes with thickness of ≤100 nm) and integrate them with an appropriately designed isomerization catalyst in a membrane reactor to accomplish selective para-xylene production (both isomerization reaction and separation in one step).

A successful membrane reactor will increase the yield of para-xylene beyond the limits of equilibrium by selectively removing para-xylene from the reactor as it is produced. Increased productivity and reduced separation energy, capital intensity, and greenhouse gas emissions are the key drivers for developing such an approach. Recent breakthroughs introduced by the University of Minnesota for the synthesis of zeolite membranes using ultrathin zeolite crystals (2-dimensional zeolites and zeolite nanosheets) enabled unprecedented mixture separation factors for para-xylene over its isomers (up to 10,000). This ultra-selective performance has been validated by measurements at ExxonMobil Research and Engineering Company and membranes are currently being tested at temperatures, compositions and pressures relevant to membrane reactor operation.

POTENTIAL IMPACT
As the global para-xylene demand grows and the world drives toward a low carbon economy, decreasing the energy demand associated with hydrocarbon separations will be increasingly important. This project not only provides significant economic benefits and energy savings for the specific process of para-xylene production (by reducing or eliminating separation costs) but it also serves as a test-bed for a novel membrane-reactor technology based on ultra-selective membranes that can be coupled with high-temperature and high-pressure catalytic reactors.

Modular Conversion of Stranded Ethane to Liquid Fuels

TEAM

North Carolina State University

SUMMARY

Ethane can represent up to 20 vol. % of shale-gas, exceeding the 10 vol. % allowed in "pipeline-quality" natural gas. Each year, over 210 million barrels (liquid equivalent) of ethane are rejected in the lower 48 states, particularly at stranded shale gas production sites. Upgrading low- to negative-value ethane to easily transportable liquid fuels is a promising solution to this supply glut. The key to this process is development of modular systems that can operate economically at stranded sites. Conventional gas-to-liquids (GTL) technologies face significant challenges such as high capital cost and limited efficiency.

This project will develop a fundamentally improved modular ethane-to-liquids (M-ETL) concept. The proposed M-ETL technology uses a modular Chemical Looping-Oxidative Dehydrogenation (CL-ODH) system to convert ethane and natural gas liquids (NGLs) efficiently into olefins (primarily ethylene) via cyclic redox reactions of highly-effective redox catalyst particles. The resulting olefins are converted to gasoline and mid-distillate products via oligomerization. The proposed project will also advance the M-ETL technology to make it ready for full-scale demonstration. A pilot-scale testbed will be designed and constructed for CL-ODH demonstration. The reactor channels of the testbed will be at a scale comparable to those of the proposed modular system.

POTENTIAL IMPACT

The M-ETL technology can lead to 80% reduction in energy demand for ethane conversion. This will also result in corresponding reductions in carbon dioxide and NOx emissions. Due to the simplified process scheme compared to conventional GTL, ≥20% savings in capital cost can also be achieved, and the modular system is particularly well suited for upgrading of ethane at stranded shale gas sites. Also, significant improvements in energy productivity is expected from M-ETL, and the CL-ODH component of the process can also be potentially used for polymer grade olefin production in traditional centralized facilities with significantly reduced energy intensity and emissions compared to existing approaches.

Energy Efficient Separations of Olefins and Paraffins through a Membrane

TEAM

Compact Membrane Systems,
Dow
University of Minnesota

SUMMARY

Throughout the petrochemical and refining industry, the separation of olefins and paraffins is generally performed via distillation, a costly and energy and capital intensive method, particularly for light olefins. This project uses a silver-incorporated custom amorphous fluoropolymer membrane to separate olefins and paraffins. Compared to previous attempts using facilitated transport membranes, this membrane has shown very good longevity in laboratory settings and has been tested with reasonably-expected process poisons. The objective of this project is to gain a better understanding of the membrane performance in realistic operating conditions through both real world testing and fundamental modelling of the membrane system. It targets the case of integrating a membrane module in a process to recover propylene from propane in a polymerization reactor purge stream, with the propylene recycled to the polymerization reactor.

POTENTIAL IMPACT

Light olefins are among the highest volume chemicals manufactured globally, approaching 200 million metric tons of propylene and ethylene production in 2018, and are extremely important building blocks for numerous petrochemicals including polyethylene and polypropylene. Currently, these light olefins are separated from each other using distillation, an energy-intensive process that is estimated to consume 0.3% of the world's energy, so new low energy separations processes promise to have a major energy impact. While many of the early applications will take place in combination with existing distillation processes, the membrane technology developed under this project may direct compete with distillation for new builds as becomes more accepted and proven.

Intensified Commercial Scale Production of Dispersants

TEAM

University of Pittsburgh
Lubrizol

SUMMARY

This project will demonstrate conversion of a large-volume chemical commodities process from batch to continuous processing. It is focused to create an order of magnitude reduction in equipment size (and associated capital cost) by transitioning the traditionally batch production of succinimide dispersents into a continuous process. Succinimide dispersenents are a relatively large volume family of products that vary by molecular weight and structure. Application and adoption of intensified, continuous processing principles offers the prospect of revolutionizing their manufacture.

The project will look to establish a firm kinetic understanding of the relevant chemistry and to develop reactor modeling tools so that reaction and mass transfer requirements can be balanced while minimizing system volume, ultimately to support the construction and demonstration of an industrial pilot plant. Successful demonstration of a batch to continuous process and previous unrealized scales could open the door for a broader shift to continuous processing in the fine/specialty chemical industries.

POTENTIAL IMPACT

The project will enable the first full-scale realization of an intensified, continuous process in the lubricants and dispersants market, and one of the first demonstrations of transition from batch to continuous processing in the U.S. Such a transition offers the opportunity to reduce energy consumption by more than 25% and lower operating and capital costs by more than 20% and 30-50%, respectively. A successful demonstration is expected to quickly translate to other large volume additives and the manufacture of similar specialty chemicals, such as performance coatings and personal/homecare products.

Education and Workforce

Modular Chemical Process Intensification (MCPI) Boot Camp at the Advanced Technology and Manufacturing Institute

TEAM

Oregon State University (OSU)

SUMMARY

Oregon State will develop a four day "boot camp" for professional engineers interested in advancing PI and modular process technology in the chemical industry.

POTENTIAL IMPACT

By demonstrating how PI can help advance module manufacturing through better economics due to size and weight reduction of components, engineers will receive actionable insights enabling implementation of PI and modular process technologies in their organizations. A pilot offering of the course is targeted for late summer 2019.

RAPID Integrated Course: Emerging Membrane Processes for Water Purification

TEAM

University of Arizona

SUMMARY

University of Arizona will develop a four-day face-to-face course enabling both professional engineers and graduate students to compare and contrast the uses of conventional membrane processes over emerging membrane processes for water purification applications.

POTENTIAL IMPACT

In this project-based course, attendees will brainstorm a treatment process, design and perform experiments while testing their hypotheses in a state-of-the-art pilot scale wastewater treatment facility, model the process using simulation software by Chemstations, update their hypotheses per data results, and establish the practical viability of their hypotheses using available software. A pilot offering of the course is targeted for late fall 2019/ early winter 2020.

Intensified Microwave Reactor Technology

TEAM
University of Delaware
United Technologies Research Center
Rutgers University

SUMMARY
This project looks to develop both foundational hardware and modeling tools for microwaves as a non-conventional energy input source - a key theme in process intensification - for reactions across chemical conversions and materials synthesis. The project develops scalable microwave technology across industries and RAPID focus areas and demonstrates its diverse applications with different spatial, temporal, and phase characteristics, often combined with additional process intensification technologies. It also looks into the development of software for optimization and design, followed by module fabrication and demonstration.

POTENTIAL IMPACT
This project promises to overcome today's most critical barrier for microwave powered reactor technology by developing general scalable design techniques for improved energy efficiency, enhanced selectivity and reduced deactivation for energy intensive processes across industry sectors. The impact can range from food to commodity chemicals to shale gas. Given the revolution in shale gas in the US, on-demand alkane to alkene conversion in modular systems for use at the wellhead is of tremendous interest. Success of this program will revolutionize modular and robust manufacturing of valuable liquids for transportation from shale gas and biogas in remote locations to improve rural economy.

Microfibrous Entrapped Sorbents for High Throughput Modular Process Intensified Gas Separation and Ion Exchange

TEAM
Intramicron
Savannah River National Lab
University of South Carolina
Auburn University
Oregon State University (OSU)
Apache
BASF

SUMMARY

This project utilizes microfibrous entrapment of small particulate sorbents or ion exchange (IX) resins to overcome physical barriers and technology gaps that currently prevent energy efficient and cost-effective wellhead CO_2/CH_4 separations through pressure swing adsorption (PSA) and Cs+ removal from nuclear fuel processing streams. Commercial cyclic adsorption processes are currently limited by heat and mass transport restrictions occurring in large particle (1-4 mm diameter) packed beds.

Using smaller particles (10-150 μm diameter) eliminates previous intraparticle mass transport restrictions, and particulate entrapment within sinter-locked networks of micron-diameter metal fibers (microfibrous entrapped sorbent, MFES) provides packed bed thermal conductivities that are up to 250-fold higher than those of typical packed beds. Higher thermal conductivity affords near-isothermal operation and more rapid and higher duty cycles, reducing the required sorbent load and increasing the overall output of the unit. Entrapment of particulates within a flexible fibrous structure eliminates shrink/swell problems and bed channeling while maintaining a low pressure drop. For IX processes, the reduction in particle size provides an order of magnitude enhancement in IX kinetics and allows new IX resin powders to be quickly adopted without having to undergo the lengthy, expensive, performance-limiting penalties associated with large bead formulations.

POTENTIAL IMPACT
The size, capital and operating costs, energy consumption and performance of traditional IX and PSA systems are limited by the heat and mass transport and hydrodynamics associated with traditional designs. Implementing MFES technology to improve upon traditional packed beds will result in 50%-75% reductions in capital cost and 65%-85% reductions in operating costs. With knowledge gained from this project, the reduced size and cost of MFES-based approaches will facilitate the further commercialization of intensified modular process units which are critical for purification and waste treatment applications. This MFES methodology enables many new IX formulations to be rapidly evaluated for facile transition to the commercial scale. For PSA-based natural gas treatment applications, the anticipated 10-fold throughput enhancement will enable the production of cost-effective modular units for gas purification that can be implemented at distributed production sites.

Thermoneutral Propane Dehydrogenation via a Solid Oxide Membrane Reactor

TEAM

University of Michigan
ExxonMobil

SUMMARY

This project uses solid oxide membrane reactors for chemical transformations that are critical to the seamless integration of shale gas and liquids into the chemical industry supply chain. The project is particularly interested in the distributed production of propylene from propane. Current propylene production occurs primarily via naphtha steam cracking, a highly energy intensive process that is not amenable to distributed operations, which are highly desirable when shale gas and liquid is used as the carbon source. This technology can apply to distributed operation and can operate at dramatically lower temperatures than steam crackers.

The technology will apply perovskite solid oxide membranes which can simultaneously conduct oxygen and hydrogen ions. On one side of the membrane reactor, air is used as an oxygen source to the perovskite. Oxygen anions are conducted across the membrane where they react with propane at the interface of the perovskite and small Pt alloy catalysts in an exothermic partial oxidation process. In addition, the process of propane dehydrogenation takes place at the same side of the membrane yielding hydrogen ions, which are conducted in the opposite direction back across the membrane. By adjusting the external conditions, as well as the membrane and catalyst design, the flux of oxygen and hydrogen ions in the opposite directions of the membrane can be controlled. This control allows the development of a highly selective thermo-neutral process operating at lower temperatures, driving equilibrium conversion forward while avoiding the deleterious further reaction to unselective combustion products.

POTENTIAL IMPACT

Current propylene demand is growing at about 4.6% per year. Due to the abundance of cheap natural gas and the demands of the developing world for high performance plastics, growth is expected to further increase in near term future. Given this anticipated growth in demand, new supply capacity must be built. A typical steam cracker unit may take 7-8 years for construction, so development and deployment of alternative technology is viable in this space. The energy footprint for operation of a typical steam cracker is 300 MW for a 1 Mt/yr propylene plant to overcome the reaction endothermicity alone. Even mitigating a fraction of the energy costs would result in a more environmentally friendly and sustainable process. The process intensified modular reactor design of this technology will allow significant improvements in energy efficiency compared to current state-of-the-art technologies.

Multiphase Microchannel Separator

TEAM

Oregon State University(OSU)

SUMMARY

In conventional two-phase separation, mass transport between the two phases can be intensified via increased surface area, usually in the form of smaller droplets or bubbles, resulting in higher energy cost due to agitation or mixing and slower processing time as the smaller droplet phase requires more time to separate. One can increase processing speed in centrifugal extractors but this, in turn, increases energy requirements significantly. Often, microscale process intensification is at odds with macroscale energy efficiency in conventional systems. From a capital cost perspective, current separation methods are more economically feasible at large scale due to the inherent cost scaling of hardware manufacturing for traditional unit ops. As a result, they can be prohibitively difficult to translate into smaller modular systems.

This project is working on the development of a flexible, standardized platform for multiphase separation utilizing microchannel processing technology (MPT). Multiphase Microchannel Separation in MPT systems directs flow of each phase by creating a capillary force gradient via size and spacing of micro-scale architectural features, thereby controlling interfacial curvatures and thus capillary forces. With a proper choice of surface properties, the system is designed so that a selected phase cannot overcome capillary forces in one direction of the gradient with inertial and viscous forces, guiding the fluid towards a selected outlet stream. Additionally, a flat plate design can accommodate a larger processing throughput per layer of the device and reduce manufacturing complexity compared to single microchannel devices.

POTENTIAL IMPACT

This technology has demonstrated three to four orders of magnitude reduction in power input per liquid volume compared to conventional technology and has shown a 500x increase in mass transfer coefficient, resulting in faster processing and higher throughput per unit. This will allow the hardware to be significantly smaller and less expensive to produce. Microchannel systems are scalable, making them highly suitable for modular chemical processing. This technology has significant potential to de-risk capital cost associated with downstream separations in small to medium chemical plant applications.

Energy Efficient Technology for Metals Separation

TEAM

University of Alabama
Metcer Coatings Solutions, LLC
Secat, Inc.
Idaho National Laboratory (INL)

EXECUTIVE SUMMARY

This project aims to develop and demonstrate a novel low cost, low energy electrochemical process for the separation of metals from mixed scrap using ionic liquids (ILs) at low temperatures. By comparison, conventional separation of aluminum involves scrap metal melting at 800°C resulting in high losses in metal values (about 46%), high energy consumption and the generation of greenhouse gases including CO_2 and fluorides that require post-combustion and flue gas cleaning processes. In the proposed electrochemical separation process, the separation will be carried out at temperatures below 120°C, at metal recovery above 99%, with low energy consumption, and no greenhouse gases generation. The electrolyte and residue of the process are recycled. This project will take the technology from bench to pilot scale.

POTENTIAL IMPACT

Separation of aluminum from mixed scrap using ionic liquids will result in major energy saving. The new aluminum separation technology developed in this project will have an energy consumption of 9.5 kwh/kg of Al ($1.10/kg of Al) as compared to the industrial best process is 13.64 kwh/kg of Al ($1.64/kg of Al) which translate to 30.4% energy reduction in US industrial energy intensity. The energy savings of 38.1% and a carbon dioxide reduction of 56.1% are estimated from the commercialization of this project.

Modular Mechanical Vapor Compression-Membrane Distillation (MVC-MD) for Treatment of High TDS Produced Water

TEAM

Texas Tech University
University of Arkansas
Apache
W.L. Gore

SUMMARY

This project aims to integrate mechanical vapor compression with membrane distillation (MVC-MD) to intensify the treatment of produced water resulting from hydraulic fracturing of shale oil and gas. In particular, MD is interesting because it offers a viable pathway to treat concentrated high salinity brine streams, and it has the potential to be utilized for near-zero liquid discharge. However, MD in its current state is handicapped by significant energy intensity due to loss of heat of evaporation and fouling due to scaling.
This project will address the energy intensity issue by integrating MD with MVC to recover the latent heat of evaporation. It also proposes a facile aluminum electrocoagulation (EC) pretreatment to remove up to 95% of total suspended solids and organic compounds. The proposed aluminum EC can effectively mitigate membrane scaling for long-term applications.

POTENTIAL IMPACT

This project will not look to improve MD membranes but will instead focus on novel electrocoagulation pretreatment and improved stack/system designs. The net results will be a MVC-MD system that is intrinsically more energy-efficient, smaller, and more flexible to serve a wide range of applications.

Modular Catalytic Partial Oxidation Reactors Using Microstructured Catalyst Structures with Combined High Thermal Conductivity and Flame Extinction Capacity to Enhance Process Safety Margins and Enable High Per Pass Conversion and High Selectivity of Non-Diluted Reactants

TEAM
Auburn University
Intramicron
University of South Carolina

SUMMARY
This project uses Intramicron's platform technology of microfiborous entrapped catalysts (MFEC) to create a safer and more efficient process for the production of ethylene oxide. Ethylene oxide is produced via the exothermic reaction of oxygen with ethylene. Because of the poor heat transfer and flow distribution in current packed bed reactors, hotspots form in the bed resulting in poor selectivity. To mitigate these issues, EO processes are typically operated with substantially sub-stoichiometric oxygen concentrations resulting in only a 10-12% ethylene conversion per pass. The use of thermal buffering inerts, such as CH_4, and operating at low per pass conversion results in significant downstream costs associated with separations, recycle, balance of plant costs, and operating costs.

POTENTIAL IMPACT
This project will apply a microfibrous entrapped catalyst (MFEC, TRL 8) with high thermal conductivity and inherent flame arresting (safety) propensity to safely increase single-pass conversion and transcend the intrinsic operation boundaries of current ethylene epoxidation processes (TRL 9). IntraMicron's MFEC is a structured catalyst with an effective thermal conductivity 250 times higher than a typical packed bed. Due to its high thermal conductivity and highly porous nature, MFEC provides a near-isothermal intrabed temperature profile and prevents hotspot formation, autoignition, and explosions.

Modeling and Simulation

Synthesis of Operable Process Intensification (SYNOPSIS)

TEAM
Texas A&M University
Georgia Tech
Auburn University
Dow
Shell
Process Systems Enterprise

SUMMARY
The SYNOPSIS project aims to achieve the aggressive goal of discovering potential process intensification (PI) and modular process configurations that are both safe and operable based on using existing modeling approaches. The team will link together and expand upon existing modeling tools that are in various stages of development to create an environment that can define potential PI and modular process solutions without needing to define potential process schemes. This approach to process synthesis is high risk but could create unanticipated and highly valuable solutions. As test chemistry, the team will look at hydrogen production approaches to define potential PI and modular process options that improve upon conventional steam methane reforming.

POTENTIAL IMPACT
There is no current commercial software available that allows for novel conceptual process designs without requesting equipment and flowsheet structures beforehand and, at the same time, provides a specialized PI model library. The tools developed in academia either disregard process intensification or are incapable of encompassing the whole roadmap required for an operable process design. Hence, the resultant design procedures, software prototype, and model library generated within this program will be unique with its holistic view on PI via integrating the process synthesis, design, optimization, and control tasks in a single software platform. The application showcase on thermal decomposition of methane will provide commercially promising pathways for large-scale production of high-quality carbon materials. SYNOPSIS will contribute to bridging the gap between lab scale and commercial application of methane pyrolytic conversion by combining process synthesis, reaction engineering, and heat management. In doing so, it will demonstrate a generic process for employing PI to challenges across industry.

Optimization Modeling for Advanced Syngas to Olefins Reactive Systems

TEAM

Dow
Carnegie Mellon University

SUMMARY

Advanced reactor designs with multiple catalysts are game-changers for process intensification. These reactors transform large, complex processes with multiple reactors to one-shot reactors, where complex reaction mechanisms can be exploited within a single unit. Such designs lead to layered and mixed catalyst beds that overcome equilibrium limitations, manage heat effects and improve product selectivity. These graded bed reactors have been considered for a number of reactive systems, ranging from Fischer-Tropsch synthesis, benzene hydrogenation, oxidative coupling of methane, and steam reforming.

This project develops and applies a new approach for the optimization of graded bed systems, based on EO-based optimization of fully discretized differential-algebraic equations and partial differential-algebraic equations models. Known as direct transcription, this approach has been widely applied to challenging dynamic optimization problems, adapted to large-scale optimization software and is generally much faster and more reliable than with standard commercial tools. In particular, for graded beds, this approach stabilizes exponential forward modes and applies specialized regularization strategies in order to handle singular problem characteristics. As the target application, this project is especially devoted to improving the design and optimization methodologies for syngas to olefin (STO) processes, with emphasis on producing light (<C5) olefins. Here, the optimization process significantly advances the synergies between methanol synthesis catalysts for syngas reactions and zeolite catalysts that produce light olefins.

POTENTIAL IMPACT

The simultaneous dynamic optimization approach, coupled with a bi-level formulation for singular control, forms the core technology to determine optimal catalyst and temperature distributions for graded beds. A study for partial oxidation reactors has shown that the graded bed optimization increases the yield up to 34%, through the design of optimal catalyst and temperature distributions profiles within the reactor, without any added capital expense. The impact is also significant for new plant designs, where traditionally multi-reactor beds can be simplified to a single vessel, offering potential capital and energy savings, in addition to chemistry yield improvements.

RAPID Reaction Software Ecosystem

TEAM

University of Delaware
Process Systems Enterprise
Dow

SUMMARY

Intensified processes are spatially and/or temporally coupled systems. New modeling tools that go beyond systems analysis and that integrate reactor models with molecular scale models of chemical reactions are needed to describe these systems. Current software at the quantum scale (e.g., density functional theory) and the reactor scale (e.g., computational fluid dynamics) are widespread. In contrast, kinetics codes, especially for heterogeneous catalysis are at the proof-of-concept level due to outstanding technical barriers.

This project will overcome these barriers by integrating existing software components and building missing ones from available prototypes. It will develop an open-source chemical kinetics software and data hub (OpenCK) as a transformative, cross cutting platform to address one of the most pressing gaps in process intensification and modular processing, namely the lack of a kinetics multiscale modeling software to plug and play (i.e., analyze, design, optimize, and control), along with an associated hub of documented and validated models and data, a catalyst discovery 'engine', and toolkits for error analysis and assimilation of experimental data.

POTENTIAL IMPACT

The proposed software and data-hub will fill in a critical gap across chemical industry. It will catalyze innovation cycles by replacing empiricism and shorten time to market, e.g., by potentially minimizing intermediate scale-up steps and by accelerating catalyst development. These outcomes can in turn have significant technical and economic benefit, impacting the $10 trillion combined markets for petroleum, chemicals, energy, and food. The project can, within a short time period, build the cyber-infrastructure-enabled data hub and software to accelerate these economically vital sectors of the U.S., including emerging distributed resources (e.g., shale gas, CO_2 reduction, biogas, bioproducts), with obvious ramifications for economic development and job creation.

An Experimentally Verified Physical Properties Database for Sorbent Selection and Simulation

TEAM

Georgia Tech
Dow
Praxair
AspenTech

SUMMARY

The lack of reliable adsorption models and validated adsorption data in currently available simulation packages limits design options for and commercial acceptance of adsorption processes versus incumbent distillation separations processes. This project uses meta-analysis of adsorption data available from existing databases to determine which data can currently be used with statistical confidence in its accuracy. Additionally, the project will also look to perform selected experiments to validate confidence in and enhance this data set, and it will carry out simulations (validated by the data set that has been established) to further enhance the availability of a broad class of adsorption input data for process models.

POTENTIAL IMPACT

The project is expected to provide publically available data that will strongly incent software providers to include widely accessible process design modules for adsorptive separations in their products. Basing these simulation modules on real materials for which validated adsorption data will be presented should motivate users across the chemical industry to consider adsorptive separations as an alternative to distillation in the early stages of process design. Individual software providers will be able to create distinctive value for their products by the functionality and ease-of-use of their design tools for adsorptive processes, which require cyclic processes and typically offer many design alternatives.

Module Manufacturing

Cross-Cutting Institute-Wide Metrics Project RAPID Center for Process Modeling

TEAM

Texas Tech University
Clemson University
Savannah River National Laboratory (SRNL)

SUMMARY

RAPID aims to improve energy efficiency, reduce feedstock waste, and improve productivity by promoting modular chemical process intensification (PI) for processing industries in the U.S. manufacturing sector. To facilitate consistent and objective evaluation of performance metrics of various PI projects, RAPID has established this program to support and/or perform first principles-based process modeling for both baseline and intensified processes. Representing an alliance of academia, national laboratories, and industry, this project establishes a Center for Process Modeling (CPM) responsible for process model-based metrics evaluation under RAPID sponsorship. The CPM objectives include: 1) to standardize and advance process modeling methodology for evaluating DOE performance metrics: 2) to validate and capture PI insights for RAPID PI projects with process models; and 3) to serve as the repository for RAPID process models for distribution, education, and continual refinement.

POTENTIAL IMPACT

The CPM develops novel process modeling methodologies for non-traditional chemical processes that build off existing process modeling tools. First principles process modeling is the best way to capture PI insights and fundamentals, which further provide guidance to the intensification of other processes with similar process operations. In addition, novel process modeling methodology advances for non-traditional chemical processes will have broad and lasting impact beyond the RAPID PI projects for the U.S. industry.

Manufacturing Supply Chain Development for the STARS Technology Modular Solar-Thermochemical Conversion Platform

TEAM

Oregon State University (OSU)
Pacific Northwest National Laboratory (PNNL)
STARS

SUMMARY

This project looks to improve the manufacturing readiness level of a high TRL technology to open the door for broad deployment of modular processes. In particular, the team at PNNL and OSU is carrying out a cost/manufacturability study on the piloted STARS technology for solar-powered steam methane reforming. The results of this study will define key economic break points in the production number of STARS process modules that point to "best" methods of mass manufacturing (such as additive manufacturing for production runs on the order of 100 -1000). Within each of these target methods, a cost analysis is carried out to determine where the largest cost drivers exist (e.g., raw material costs) and then modified production approaches are proposed to address these issues and move toward desired production cost targets.

POTENTIAL IMPACT

The STARS technology offers a new and unique means for converting solar energy into chemical energy, is inherently modular, and relies on process intensification to channel point source solar heat into an onboard reactor. Scale up of STARS technology is achieved by "numbering up" since each STARS unit is based on a single parabolic dish concentrator with integrated reactor for conversion of solar to chemical energy stored in synthetic gas or liquid fuels. This approach addresses a key constraint with centralized processing, where upfront capital can be prohibitive (hundreds of millions of dollars for gas-to-liquids systems and similar processes). Numbering up allows production to be expanded as demand grows without a large upfront capital expense. The key benefit to STARS from the proposed project is the reduction of equipment capital cost and establishing a supply chain for sourcing components, such that commercial adoption can be accelerated.

Development and Demonstration of Novel Thermal Technologies for Enhanced Air-Side and Two-Phase Performance of CPI-Relevant Heat Exchangers

TEAM

Georgia Tech
University of Illinois at Urbana-Champaign
Heat Transfer Research, Inc. (HTRI)

SUMMARY

Almost every process in the chemical and processing industries (CPI) involves heat transfer. Integrated functioning of a variety of heat exchangers with gas, liquid, and vapor/liquid flows of single- and multi-component working fluids is critical in any processing plant. Improving air-side and/or process-side performance can significantly reduce energy consumption and capital costs.

This project focuses on novel geometries and mechanical actuation (including passive methods to enhance turbulence, as well as active ultrasound processes to alter bubble formation and surface area) to enhance heat exchanger performance. The level of improvement, and approach to modification will facilitate the design of both "bolt on" process enhancement for existing equipment and the design of standardized modular heat exchangers. Significant effort in this project will address establishing cost effective and scalable manufacturing approaches for technologies that are demonstrated in the lab.

POTENTIAL IMPACT

The proposed novel heat transfer approaches have the potential to transformatively enhance performance of a broad class of heat exchangers currently used in a wide range of applications across the CPI. They also have the potential to enable new applications, including natural gas upgrading by cryogenic distillation, multifunctional modules, and utilization of renewable bioproducts, as well as for integration of multiple processes (e.g., separation and heat transfer for binary and multi-component liquids). The higher energy efficiency and energy productivity will allow for new trade-offs between reduced size/volume/footprint (and hence lower capital cost), and higher throughput (allowing for de-bottlenecking). The potential for bolt on retrofit of existing heat exchange equipment is also particularly attractive.

Modular Catalytic Desulfurization Units for Sour Gas Sweetening

TEAM

Intramicron
Auburn University
Sour Gas LLC
Oregon State University

SUMMARY

This project focuses on overcoming manufacturing and supply chain issues associated with a modular process technology for sour gas desulfurization. The team is working to take an existing technology for sour gas cleanup (processing scale on order of 1 ton/day sulfur production or 1 million standard cubic ft/day gas processed) and improve the cost-benefit profile through pilot testing to improve performance and manufacturing design/analysis to determine the highest leverage cost reduction steps. The resulting technology will be piloted in a field test to confirm economic assessments.

POTENTIAL IMPACT

The project offers an economical means to sweeten sour gas resources, especially those at small scales or with high sulfur content. Because the intensified desulfurization process enables significant reductions in capital cost (77%) and operating cost (97%), as well as reduced waste generation (60-95%) compared to current processes at similar scales, sour wells that have previously been capped or neglected due to their high sulfur contents or low production rates can be turned into valuable resources. This will directly benefit the US oil and gas industry, allowing previously stranded and uneconomic resources to be produce natural gas cost effectively.

On Demand Treatment of Wastewater Using 3D-Printed Membrane

TEAM

University of Pittsburgh
Lubrizol

SUMMARY

This project will demonstrate on-demand separation of multicomponent and multiphase water-oil mixtures using 3D-printed membranes. It is focused on wastewater treatment that is critical to the chemical industry. Application and adoption of intensified process design and 3D-printed membranes offers the prospect of revolutionizing the multicomponent and multiphase water-oil separation.

While conventional membranes have been used in oil-water separation for some time, demonstration of 3D-printed membranes with well-controlled local structure, which allows for tuning of the membrane selectivity, is still lacking. Moreover, wastewater treatment often involves many steps and a more intensified process, which is enabled by a single multi-selectivity membrane, is highly desirable. The driving force for the proposed membrane is surface selectivity and topology rather than pressure and has been demonstrated in the laboratory. The project aims to be a first-of-a-kind demonstration of the validity of the above-mentioned concept for the chemical industry.

POTENTIAL IMPACT

Conventional technologies, including flocculation, centrifugation, and filtration, are capital and operating cost intensive and are energy intensive when water recycle and pumping costs are considered. When applied to wastewater treatment, the tuned selectivity 3D-printed membranes offer a low energy, gravity flow driven method to separate complex water-oil mixtures.

Deploying Intensified, Automated, Mobile, Operable, and Novel Designs (DIAMOND) For Treating Shale Gas Wastewater

TEAM

Texas A&M University
University of Pittsburgh
University of Texas at Austin
US Clean Water Technology (USCWT)

SUMMARY

One of the key technology gaps identified in the RAPID roadmap was the development of design tools and practices that would reduce the need for non-recurring engineering design costs in modular applications. This project focuses on developing integrated design and operating approaches for modular systems that can be deployed in the treatment of flowback and produced water resulting from shale gas production. Because of the highly distributed nature and variable characteristics of shale-gas wastewater (SGWW), there is a unique opportunity to deploy modular systems. There is also a major challenge in developing tailored designs for each source of wastewater.

POTENTIAL IMPACT

A combination of systems engineering approaches and experimental/pilot-scale work will be used to generate commercially viable design and operational strategies. This integrated theoretical-experimental project will: 1) Assess, screen and integrate commercially-viable conventional and emerging technologies for wastewater treatment, 2) Develop computer-aided modeling, design, operation, scheduling, and costing approaches for non-recurring engineering needed to deploy the SGWW treatment systems, and 3) Demonstrate proof-of-concept via applications to a broad range of SGWW samples.

Natural Gas Upgrading

Natural Gas Upgrading Nitrogen Removal from Natural Gas

TEAM

Praxair (now Linde)
Georgia Tech

SUMMARY

Low permeability natural gas reservoirs are being developed across the world using fracturing technologies. The most common approach for fracturing uses water with friction reducing agents and thickening polymers. However, this approach requires approximately 400 tanker trucks to bring millions of gallons of water to a well head and results in millions of gallons of contaminated water that must be treated before going back into the natural water cycle. A second approach to fracturing uses high pressure gases such as nitrogen (N_2) or carbon dioxide (CO_2), but produces natural gas with unacceptably high levels of N_2 and CO_2 contamination requiring producers to divert initial natural gas production to a flare until N_2 and CO_2 gas concentrations drop below allowable limits for feeding into the natural gas pipeline network. Flaring results in a loss of natural gas that would otherwise go to the pipeline and in additional greenhouse gas emissions.

This project aims to address the loss of hydrocarbon energy and the associated CO_2 emissions related to N_2 fracture operations by utilizing a new adsorbent developed by Praxair in a modular Pressure Swing Adsorption (PSA) system capable of recovering N_2 from produced gas at wellhead locations. Technology development in this area will address the specific problem described above and will shed light on the challenges of modular processing of distributed resources in general.

POTENTIAL IMPACT

The adsorbent and pressure swing adsorption system provides an opportunity to significantly mitigate and even eliminate flaring of natural gas hydrocarbons associated with nitrogen fracturing. It is estimated that between 50% and 80% of the hydrocarbons can be recovered. This would reduce or eliminate the estimated 600 kilotons of CO_2 emitted annually in the U.S. from current N_2 fracking operations while maintaining the water savings that results from replacement of water fracturing activities with nitrogen fracturing.

Efficient Chemicals Production via Chemical Looping

TEAM

University of Delaware
Dow

SUMMARY

This project will develop chemical looping technology (CLT) into a general process intensification (PI) strategy for modular upgrading of natural gas to commodity chemicals. Nonoxidative upgrading of methane, ethane and propane to alkenes and aromatics is often limited by equilibrium. CLT is an effective PI strategy to circumvent such limitations by either reactive separation or selective oxidation of a subset of products from the reaction mixture to restore the thermodynamic driving force. CLT also allows for efficient heat utilization/management among different reaction steps, thus enhancing the overall energy efficiency of the process.

The commercial potential of CLT is underexplored primarily because of the high cost in the design and prototyping of automated continuous systems. This project aims to demonstrate the generality of chemical looping technology (CLT) as a process intensification strategy by advancing chemical looping for methane dehydroaromatization (DHA) and alkane (ethane and propane) dehydrogenation (DH) at yields well in excess of one-pass thermodynamic limits. In each of these chemical looping processes, an increase in per pass conversion, a dramatic simplification of separation, and heat integration are all addressed in a single system, which makes them ideal for being deployed in standard reactors modules at remote natural gas extraction sites.

POTENTIAL IMPACT

Chemical looping technology offers a unique and effective approach to overcome thermodynamic limitations in nonoxidative upgrading of natural gas to high value aromatic products, e.g., benzene and toluene. It also has the potential to increase the energy efficiency through more efficient heat management. Since natural gas extraction sites are often located in remote areas, the ability to produce easy-to-transport liquid aromatic products, rather than gaseous products, will drastically reduce the transportation cost. Further, the development of modular reactors, a customizable control mechanism and a predictive computational model for materials screening will accelerate and reduce the cost of the prototyping of chemical looping processes for applications beyond natural gas.

Advanced Nanocomposite Membrane for Natural Gas Purification

TEAM

University of Texas - Austin

SUMMARY

For distribution from the wellhead to pipeline, natural gas must be purified to remove contaminants including acid gases, such as CO_2. Current processing uses amine absorption, but the associated processing systems suffer from corrosion problems, involve complex process design, are often unsuitable for offshore gas processing platforms, and are less efficient than membranes at high CO_2 concentrations. Membrane systems for natural gas purification are growing and account for 10% of worldwide annual market for new natural gas separation equipment. However, current membrane systems, most often based on asymmetric cellulose acetate polymers, suffer from lower CO_2/CH_4 selectivity and lower fluxes than are needed for more general adoption, resulting in expensive recompression and recycling to increase natural gas recovery and higher waste than is desired.

This project will prepare and characterize novel nanocomposite membranes based on recently discovered metal organic framework (MOF) materials and related nanoparticles that have outstanding separation properties for removal of acid gases (e.g., CO_2) from natural gas. The project aims to demonstrate advanced nanocomposite membranes with much higher flux and selectivity than commercial state-of-the-art membranes when separating CO_2 from mixtures with CH_4 and mixtures containing aromatic contaminants. The resulting membrane systems would be several times smaller than existing systems to process comparable amounts of gas, resulting in lower hydrocarbon losses, increased energy efficiency, and minimized emissions and waste.

POTENTIAL IMPACT

Relative to conventional cellulose acetate membranes, the proposed MOF membrane materials would have improved separation properties, excellent stability in process environments, and the ability to be manufactured as thin-film composite or asymmetric membranes. This will markedly reduce the size and weight of the systems. It will also eliminate the need for multi-stage processes, simplifying the process and decreasing emissions and waste and reducing energy consumption per unit mass of pipeline-grade natural gas produced. The proposed nanocomposite membranes systems will have 10x higher flux and will be 10x smaller and lighter (important for offshore applications on platforms) with hydrocarbon waste and emissions reduction by 50%.

Microwave Catalysis for Process Intensified Modular Production of Value-Added Chemicals from Natural Gas

TEAM

West Virginia University
University of Pittsburgh
Shell
National Energy Technology Laboratory (NETL)

SUMMARY

Given the currently strong supply of U.S. natural gas and the related challenges and costs associated with transporting natural gas from wellhead to pipeline, there is a need for efficient and economic processes to convert natural gas to liquid products. Indirect routes, such as gasification, that first produce syngas and require subsequent conversion to liquid products, are generally energy inefficient and capital intensive. In contrast, direct non-oxidative natural gas conversion eliminates the syngas production step and required oxygen generation. However, these technologies have not been commercialized because of technical challenges such as low selectivity; heat management; and catalyst coking, deactivation, and regeneration.

The goal of this project is to develop and demonstrate an innovative modular system intensified with microwave catalysis, which allows simultaneous production of high value chemicals (e.g. aromatics) and hydrogen generation via direct non-oxidative natural gas conversion. Specifically, the technology will synergistically integrate microwave reaction chemistry with novel with zeolite catalysts that selectively activates natural gas. The microwave catalysis will enable direct, non-oxidative natural gas conversion under mild conditions with high product yield.

POTENTIAL IMPACT

The conventional indirect conversion process via syngas is capital intensive and energy inefficient. Direct non-oxidative methane conversion to aromatics eliminates costly syngas production, resulting in up to 63% improvements in energy efficiency, 51% capital cost reduction due to the reduction in the number of unit operation, and 4X improvements in energy productivity due to elimination of syngas production.

Renewable Bioproducts

Autothermal pyrolysis of lignocellulose wastes to sugars and other biobased products

TEAM

Iowa State University

SUMMARY

Deconstruction of lignocellulosic biomass into fermentable sugars is among the major challenges in producing cellulosic biofuels and biobased products and in enabling a true bioeconomy. Current pretreatment methods are expensive, accounting for as much as 30% of the cost of producing cellulosic biofuels, water intensive, and inefficient.

The goal of this project is to develop a pyrolysis-based Modular Energy Production System (MEPS) for the thermal deconstruction of lignocellulosic biomass into sugars and other value-added products. Thermal deconstruction uses thermal energy instead of enzymes or chemicals to produce free sugars and phenolic oil. It has the prospects for intensifying and modularizing biorefineries, especially through pyrolysis innovations including biomass pretreatments to increase cellulosic sugar production and autothermal pyrolysis to simplify design and increase feedstock throughput.

POTENTIAL IMPACT

The technologies proposed in this project are a transformative departure from traditional lignocellulosic processing systems which feature large, custom, “stick-built” plants. Based on Modular Energy Production Systems (MEPS), unit operations are configured as modules sized to fit in standard shipping containers, mass produced and integrated in the field to form fully operational biorefineries at a smaller and on-demand scale. Distributed processing with modular pyrolysis units deployed at multiple locations decreases logistical costs/hurdles for both feedstock and products. Success in modular manufacturing is dependent on technologies that can achieve “process intensification,” allowing enhanced output at reduced cost. If the thresholds for process intensification proposed here can be achieved, modular energy production systems can reduce carbon intensity in energy production and can unlock distributed biomass as a viable feedstock for energy and chemicals productions.

Robust Membranes for Black Liquor Concentration

TEAM

Georgia Tech
APPTI

SUMMARY

Black liquor (BL) is a high-volume byproduct of lignocellulosic biomass pretreatment (i.e., wood pulping) in the Kraft process for papermaking and is a corrosive, toxic, and complex mixture. About 500 million tons/yr of BL are produced in more than 200 kraft process units worldwide, including 99 in the US. Currently, BL concentration is performed by multi-effect evaporators and is one of the most energy-intensive industrial separation processes (about 0.2 quads/yr energy are spent for BL concentration in the U.S.). Development of a more efficient BL concentration technology is a high priority for the forest products industry, with membrane technology being a particularly feasible alternative. However, a viable membrane technology has been elusive because of the lack of a long-lived/stable, low-cost, high-performance membrane.

This project will develop and demonstrate a bench-scale modular graphene oxide (GO)-based membrane system that substantially improves the energy efficiency of concentrating Kraft black liquor (BL) from 15 wt% solids (lignin, organic molecules, and inorganic salts) to 30 wt% solids by removing water. The key innovation is the development of BL-stable, scaled-up, GO-based nanofiltration and reverse osmosis membranes on macroporous polymeric (polyethersulfone, PES) supports for dewatering black liquor. The challenge is in developing and scaling up low-cost membranes that are long-lived in the corrosive conditions. Recent work on this project promises successful development and scale-up of BL-stable graphene oxide (GO) membranes that will allow this technology to be quickly integrated into existing Kraft processing facilities to leverage existing assets.

POTENTIAL IMPACT

This project will make a critical leap on the path to industrializing a membrane-based process intensification technology for a key process in the renewable bioproducts industry and has the potential to reduce energy consumption in the pulp and paper industry by more than 20%. The work on BL-stable GO-based membranes will create a body of new knowledge on how these membranes can be engineered to deliver performance and stability in challenging applications once considered "out-of-bounds" for membranes. This approach uses a combination of low-cost macroporous supports and thin GO membrane coatings deposited by benign and low-cost vacuum filtration processes to produce membranes that can deliver high performance in harsh environments and may also offer the capability to inexpensively purify components such as lignin and smaller organic molecules from lignocellulosic biomass.

Sugars-to-Bioproducts Scalable Platform Technology

TEAM

University of Delaware
Rutgers University

SUMMARY

While tremendous progress has been achieved on creating routes for production of chemicals and fuels from lignocellulosic biomass, many of these processes are not economic due to the number of process steps required and the need for significant inter-stage separations. This project is developing a modularized chemical process intensification technology for the production of bio-para-xylene (biopX) from glucose. This process has received significant attention as a route to meet the high growth rate of the para-xylene market (CAGR = 7%), which is experiencing declining petroleum-based para-xylene production in North America due to a reduction in naphtha cracking, and as an approach to meet rising consumer demand for sustainably produced materials.

POTENTIAL IMPACT

The proposed process will enhance the reaction rate, minimize total reaction and heating time from hours to seconds, improve carbon efficiency, minimize separation complexity, and increase energy efficiency. These improvements enable >20% reduction in biopX minimum selling price - from the current estimated value of ~$1300/ton - and 20% energy savings, potentially making bioPX production commercially viable. Furthermore, the proposed technology may be extended to other bio-products, such as bio-acrylic acid, bio-jet fuels, bio-surfactants, and bio-lubricants.

Three-Way Catalytic Distillation to Renewable Surfactants via Triglycerides

TEAM

University of Minnesota
Sironix
University of Delaware

SUMMARY

Renewable feedstocks, including triglycerides and lignocellulose-derived sugars, can be converted to a new class of ionic surfactants, called "oleo-furan sulfonates" (OFS) by multi-step solid acid catalysis. The renewable OFS surfactant exhibits superior properties relative to conventional fossil-derived materials with higher micelle-forming efficiency, stability in cold water, and resistance to hard water. The sequential synthesis process includes catalytic hydrolysis of triglycerides, fatty acid dehydration to anhydrides, and furan acylation with anhydrides to form alkylfuran ketones, the key precursor to OFS surfactants. This technology has been demonstrated as a three-step process with independent reactors.

This project aims to more efficiently prepare oleo-furan sulfonate (OFS) surfactants by combining all three chemistries (hydrolysis, dehydration, and furan acylation) into a single reactor-separator that permits integrated separation of byproduct water. All three reactions will be conducted in a vertical column containing packed trays to promote selective vaporization of light components (i.e., water). Spatially distributed throughout the column will be three catalytic zones containing hierarchical solid acid zeolite catalysts, each of which promote the chemistry specific to the composition of that zone. Water liberated from the acylation and dehydration steps at the bottom of the reactor flow upward to promote triglyceride hydrolysis, while fatty acids and anhydrides flow down to promote furan acylation. At the conclusion of this project, a detailed design of a reactive distillation system permitting tunable extents of each of the three chemistries, such that various grades of OFS surfactants can be manufactured. The project is also looking into advancing the lab scale demonstration to the pilot scale production.

POTENTIAL IMPACT

Intensification of three process steps into a single device condenses three reactors and separation systems into one unit and has the potential to achieve single-step processing of natural oils to surfactant precursors, thereby eliminating as much as two-thirds of the processing costs. This approach also further enhances the capability for rapid design and deployment by advancing design techniques of process intensified catalytic systems.

High purity Ethanol without distillation: Carbon nanotube Enabled Ethanol Dewatering

TEAM

University of Connecticut
Fraunhofer USA
Mattershift

SUMMARY

Biofuels produced from fermentation processes have long been processed using decades-old distillation technology. Distilling a minor component of this broth to a high purity requires substantial amounts of energy that can lessen the net-energy and profitability of the fuel produced. This work will demonstrate a new technology concept using a carbon nanotube (CNT) membrane to selectively extract the biofuel, in this case ethanol, from a fermentation broth. Due to the unique chemical and structural features of the nanotubes, ethanol selectively permeates through the membrane, leaving water behind. Mattershift has developed the first ever hollow fiber CNT membrane for this task, and this work will demonstrate its effectiveness at selectively removing ethanol directly from fermentation broths.

POTENTIAL IMPACT

This project will demonstrate that CNT membranes have exceptional performance in ethanol extraction from fermentation broths using pervaporation. The unique chemical and structural features of carbon nanotubes allow ethanol to selectively permeate through the CNT membranes, leaving water behind. These membranes are expected to take low concentration ethanol solutions (between 5 and 40%) and selectively extract it to above 80% in a single pass. Application of this technology could reduce energy consumption in bioethanol production by up to 90%.

Use of Power Ultrasound for Nonthermal, Nonequilibrium Separation of Ethanol/Water Solutions

TEAM

University of Illinois at Urbana-Champaign
Carnegie Mellon University
Flint Hills Resources

SUMMARY

Separation of liquid mixtures, frequently by distillation, consumes large amounts of energy in the chemical and process industries. This project proposes to develop, test, and demonstrate a continuous-flow, scalable, non-thermal, nonequilibrium liquid separation for the test case of ethanol and water that uses ultrasound and avoids the heat transfer losses and azeotropic bottleneck of distillation. The basis of the separation is straightforward. When ultrasound passes through a nominally quiescent liquid with a free surface above, droplets are produced to form a mist. Previous work in this area shows that in aqueous ethanol solutions, removal of these droplets using a carrier-gas flow provides a liquid in which EtOH is significantly enriched relative to the initial bulk solution. Successful deployment of this technology could result in significant savings in energy and capital costs for this high-volume separation and will lay the groundwork for similar separations in a broad class of other binary (and potentially multi-component) systems, including those forming azeotropes.

POTENTIAL IMPACT

The process will yield large reductions in energy consumption, likely greater than 20% when deployed at scale, and provide significant savings in size and capital cost. The methodology will be applicable to methanol/water, butanol/water, and other binary and multicomponent systems.

Modeling the Total Cost of Ownership for Scaling-Up via Modular

TEAM

Construction Industry Institute, University of Texas at Austin, Oregon State University (OSU)

SUMMARY

This project represents a collaboration between the RAPID Module Manufacturing Focus Area (MMFA) and the Construction Industry Institute, within the Cockrell School of Engineering at the University of Texas at Austin. The research objective is to model the total cost of ownership (TCO) for scaling up via PI and modular processing and apply this model to four RAPID projects over the remaining course of the effort. This research is important for capturing the lessons learned within module manufacturing activities ongoing within RAPID and providing a rationale for numbering up via modular process technology. The work plan involves a first year in which the model is developed including literature review and interviews with companies currently engaging in modular process technology development to identify opportunities for case study development. The second year will involve execution of formal data collection and analysis to understand the TCO for individual modular process system implementations.

POTENTIAL IMPACT

The project aims to show how PI and modular processing can be a winning strategy for pursuing new specialty chemical markets resulting in lower Total Cost of Ownership (TCO) and increased Return on Capital Employed (ROCE), when all aspects of “numbering up” are considered. Further, this research will help RAPID to apply a consistent means for quantifying the costs involved in PI and modular processing, as well as helping the MMFA understand cost drivers as impediments to PI and modular process technology adoption.

PROJECT FINANCIALS

We are pleased to report that in 2018, RAPID projects met their cost share requirements. Specifically, total Technical Project federal funding was $5.70M (including RAPID's national laboratory partners), which was matched with $15.72M of cost share, resulting in a cost share ratio of 73.4%. This allowed the Institute to meets its goal of a 60% overall cost share ratio for 2018.

As a point of comparison, in 2017, total Technical Project federal funding was $1.13M with an additional $2.35M provided as cost share (67.5% versus 50% goal).

In 2019, as RAPID projects enter more mature stages, we anticipate that spending on Technical Projects (excluding EWD) will be $13.3M in federal funding and $25.19M in cost share (65.4% cost share, surpassing our 2019 goal of 57%).

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