

RAPID MANUFACTURING INSTITUTE REPORT

FALL 2021



RAPID: By-The-Numbers

38
research projects

4
education and workforce
development projects

\$44.1M
federal funding

\$88.7M
cost sharing

6,700+
future workforce trained

3,500+
current workforce trained

22
patents applied for, pending
or issued

90+
institute members

4
technologies scaled from R&D
to commercialization

311
publications

10
new software tools developed

128
peer-reviewed journals

The RAPID Member Community

PREMIER

CHOICE

INDUSTRIAL ENABLING

ACADEMIC ENABLING

NON-PROFIT + NATIONAL LAB ENABLING

AFFILIATE

RAPID’s mission is to transform manufacturing in the process industries using the concepts of Modular Chemical Process Intensification (MCPI), which take advantage of both process intensification (PI) and modular technologies to reduce energy use and waste generation and improve capital and operating efficiencies. Modular platforms enable flexible, distributed manufacturing and allow a shift from traditional volume scaling that results in large, centralized manufacturing plants to one where manufacturers achieve scale by “numbering up” modular platforms. This approach allows technology developers to perfect operations in pilot modules that are identical to those run in commercial production and allows manufacturers to build capacity by adding modules run in parallel to meet market demand. PI is a rethinking and integration of traditional unit operations (e.g., the combination of reaction and separation or other operations) to break yield or productivity barriers imposed by equilibrium constraints or mismatched kinetics and transport timescales. The conversion from batch to continuous operation and integration of nontraditional processing (e.g., electrochemistry, microwave or induction heating, microreactor designs, etc.) are also important PI topics.



Bill Grieco
Chief Executive Officer



Ignasi Palou-Rivera
Chief Technology Officer



Kevin Chin
Chief Operating Officer



Ashley Smith-Schoettker
Director Outreach, Education,
Membership



Feri Farzad
Principal Program Manager



Liz Moore
Principal Program Manager



Fadhil Al-Aboosi
RAPID Fellow



Keith Joseph
Senior Education &
WFD Specialist

RAPID’s Impact To-Date

RAPID is a public-private partnership between the U.S. Department of Energy’s Advanced Manufacturing Office (DOE AMO) and the American Institute of Chemical Engineers® (AIChE). Currently in year five of operation, RAPID has built strong partnerships with its members to rethink how process development and manufacturing happens in the process industries. Among the current Manufacturing USA Institutes, RAPID is unique in its vision and focus. RAPID and its members are working to develop new PI-enabled and modular process operations that increase yield, reduce energy use and waste generation, and minimize capital and operating costs. Increasingly, the combination of PI and modular production are seeing application across industries. Particularly over the last year and in response to the COVID-19 pandemic, modular platforms have been proposed for flexible continuous manufacturing of in-demand products ranging from pharmaceutical active ingredients and the specialty chemical precursors used to make them to chemical disinfectants and sanitizers, to nonwovens for personal care and personal protective equipment; modular manufacturing may also be a lower cost and quicker pathway to reshore some production that is only now done outside the U.S. Beyond the pandemic, these platforms also offer the chance for U.S. manufacturers to change their approach to meeting aggressive sustainability targets. Modular technologies will enable distributed production options for upgrading of waste biomass and plastics to valuable products; bolt-on solutions for carbon capture and conversion to liquid chemicals and polymers; and new methods for domestic production of strategically significant critical materials, such as rare earth elements. The smaller footprint of these platforms also translates to lower risk—inherently safer designs to operate, distributed production with built-in redundancy for more resilient operations, and reduce financial exposure when the first production units are deployed—all of which increases the likelihood that these new advanced manufacturing processes will be commercialized. Most important, increased productivity and deployment of new domestic manufacturing capacity keeps the U.S. competitive, and it creates jobs and drive economic prosperity.

Looking Forward

With these successes under our belt, RAPID continues to evolve. The current funding agreement with DOE AMO will sunset in early 2023, so 2022 is expected to be an important transition year for the Institute. To ensure long-term financial health of the organization, RAPID is focused on seeking new government-funded research on PI and modular technology development projects that RAPID has proposed with selected members. So far, six of these projects are funded with support from the Office of Naval Research (ONR), the Defense Advanced Research Projects Agency (DARPA), and DOE; many other proposals are in process. Equally important, RAPID is working with industry members on funding of private, precompetitive projects, in which a group of corporate sponsors will support important work—ranging from technology roadmapping and landscape analysis, to modeling and simulation, to field demonstrations of new process technology—done collaboratively in a precompetitive environment. The goal is to pool resources and capabilities to allow a team of members and RAPID to deliver more impact than any one organization might do alone. Together, RAPID and its member organizations are driving impact.

RAPID: Measuring Our Success

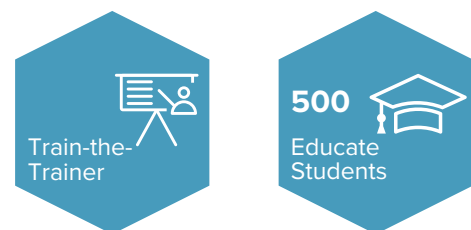
Energy & Waste Reduction Metrics

Reducing the use of energy and minimizing emissions and waste in the process industries through significant increases of energy efficiency and/or energy productivity and simultaneous to reductions of waste and emissions when compared to commercial state-of-the-art.



Education & Workforce Development Metrics

RAPID was tasked to train 50 professionals and 500 students in MCPI concepts by Year 3 of the Institute's operations. Beginning in Year 2 of RAPID's operation, Institute webinars and eLearning courses have averaged 820 registrations from professionals and 1,600 registrations from students per year.



Capital/Footprint Metrics

Designing and deploying processes with fewer unit operations and/or modular production platforms so that overall capital cost per unit production is significantly reduced, and demonstrating these processes under pilot or field conditions.



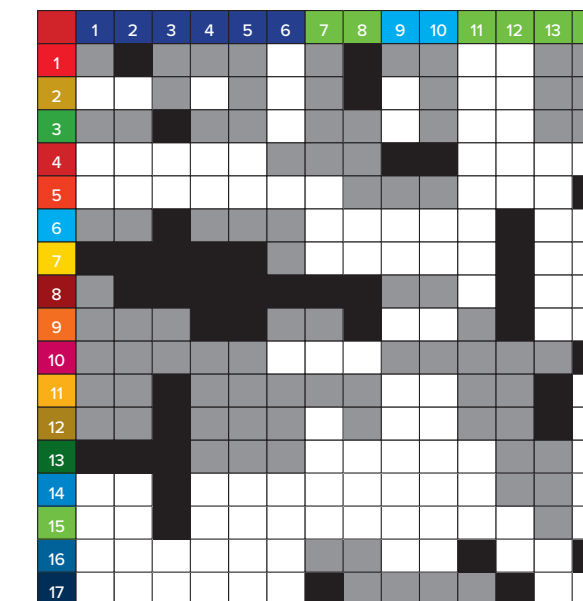
Institute Operation Metrics

RAPID's success as an Institute is measured through a number of efforts contributing to institute operations such as the development of an industrial roadmap, the health of its project portfolio, the development and execution of RAPID's financial sustainability plan, as well as the institute's commitment to diversity, equity and inclusion.



Mapping RAPID Metrics to UN Sustainable Development Goals

In addition, because RAPID recognizes the importance of the UN SDGs, we map our institute metrics to those. Our projects are helping RAPID and our members achieve impact and progress toward these targets.



RAPID METRICS



= Projects Addressing

Credit: <https://sdgs.un.org/goals>

RAPID: Connecting Our Members

RAPID brings together recognized process technology experts from industry, academia, national laboratories, research institutes, and other organizations to create a rich and diverse community that collaborates on projects and contributes to the advancement of PI and modular processing concepts. Additionally, through its membership and ongoing events, RAPID convenes these innovative organizations and individuals who provide value to one another through existing facilities, capabilities, and expertise.

How RAPID Makes Connections Between and Among Members:

Monthly Technology Showcases

RAPID Technology Showcases provide our members with a platform to talk with one another and present their capabilities and technology to highlight potential partnership opportunities.



Member Directory + Quarterly Members Meetings

In addition to an online member directory which provides members a way to connect with each other throughout the year, RAPID convenes representatives from each of its 90+ member organizations on a regular basis to communicate Institute updates, provide opportunities for networking, and providing an open forum platform for members to share success stories, opportunities, and updates with one another.

 **90+**
institute members

DEPLOY Conference Series

The RAPID DEPLOY Conference Series offers attendees an invite-only opportunity to engage in a mixture of invited talks and active workshop-style sessions culminating in a synthesis activity and an actionable report out. To-date, RAPID has hosted two Virtual DEPLOY events: one focused on modular technologies for converting waste-to-x and another focused on modular technologies for capturing and converting waste carbon.



RAPID Poster Session at AIChE's Annual Meeting

Each fall at the AIChE Annual Meeting, RAPID welcomes all employees from Member organizations to a Poster Session & Member Mixer which includes posters from active RAPID projects, from members advancing intensified and modular technologies, and past and current RAPID interns.



Lucas Freiberg, Oregon State University, presents his team's poster on RAPID Project 8.6 "Multiphase Microchannel Separator" at the 2019 RAPID Poster Session & Member Mixer.

RAPID: Providing Technical Tools To Members

Through an online Members-Only portal, RAPID Members have exclusive access to technical tools and resources which can enable the development and deployment of intensified and/or modular processes.

RAPID Test Network

A database for Members to identify pilot- and demonstration-scale testing capabilities across the US and help you find locations to test your process and process equipment. It is a living document that will be continually updated and refined.

RAPID Software Toolbox

Software tools, models and data to enable MCPI technologies from the RAPID Community.



60+
pilot and demonstration sites
catalogued in RAPID Test Network

RAPID Review

Launched in 2020, The RAPID Review is a recurring report that summarizes the progress of research projects funded through the institute.



RAPID: Educating The Workforce

RAPID, through projects, initiatives, and the development of educational resources, prepares the current and future workforce to develop and deploy advanced process technologies including process intensification and modular processing technology.

ChemE Cube™

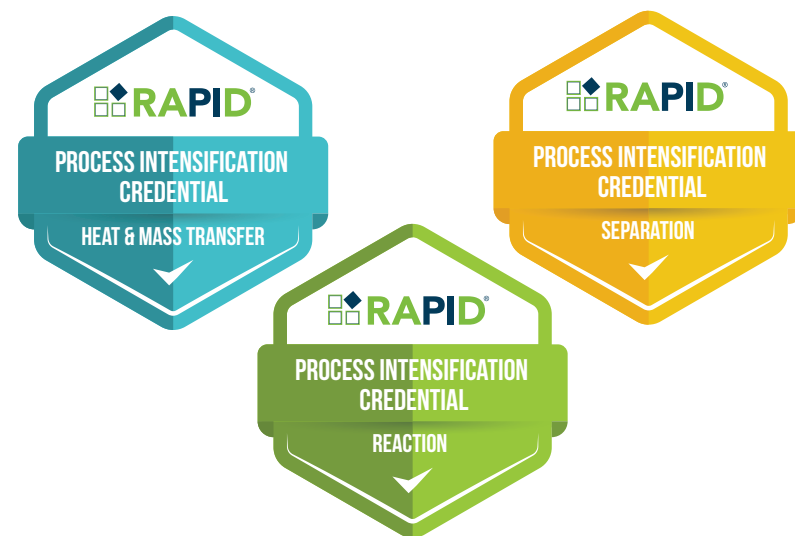
Launched in 2020, the ChemE Cube Competition is a modern competition that prepares students for the workforce by providing them with the opportunity to participate in an innovative, team-oriented, hands-on design project to manufacture a chemical process that fits in a one-foot cube.



RAPID Process Intensification Credential Program

Process intensification (PI) and modular chemical process intensification (MCPI) technologies have the potential to transform the process industries by radically re-thinking conventional processes resulting in increased energy efficiency, reduced CAPEX and OPEX, and increased resiliency. PI and MCPI also presents new opportunities for the current and future workforce.

RAPID leads the way in process intensification excellence in the U.S and has developed a Process Intensification Credential Program which provides the current and future workforce the opportunity to demonstrate their competency in PI and MCPI concepts.



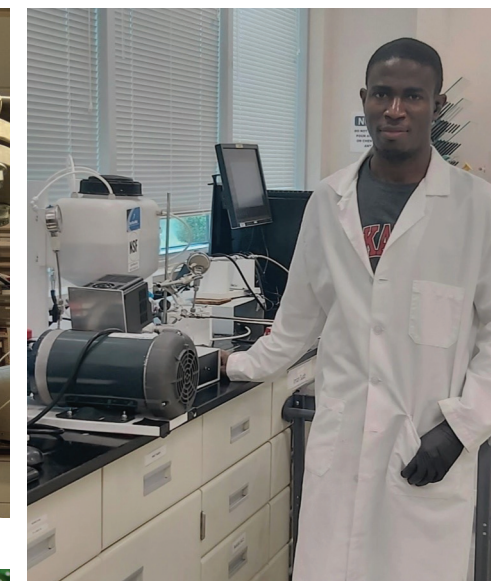
Visit www.iche.org/picredential

RAPID Intern Program

Launched in 2018 with over 100 students participating, the RAPID Intern Program is a virtual leadership development program taking place over the course of 10 weeks. The program provides students working on technical project at RAPID member organizations with 18+ hours of virtual PI leadership training.



Brian Bick



Saubana Olorunsola Dada



Rajasi Shukre



Danny Shade



Megan Evans

eLearning courses

In partnership with leading Subject Matter Experts, RAPID has developed eight eLearning courses on the following topics. All employees of RAPID Member organizations receive a course discount.

ELA300:
Fundamentals
of Process
Intensification

ELA301:
Intensified
Reaction
Processes

ELA302:
Process
Intensification
in Separation
Processes

ELA303:
Fundamentals
of Intensified
Heat and Mass
Transfer

ELA304:
Intensified
Distillation
Processes

ELA350:
Process Design
for Process
Intensification

ELA351:
Modeling and
Simulation
for Process
Intensification

ELA352:
Introduction
to Modular
Chemical
Process
Intensification

Face-to-Face Courses

Through projects funded in-part by RAPID, four multi-day face-to-face courses have been developed which focus on training attendees on key PI and MCPI concepts.

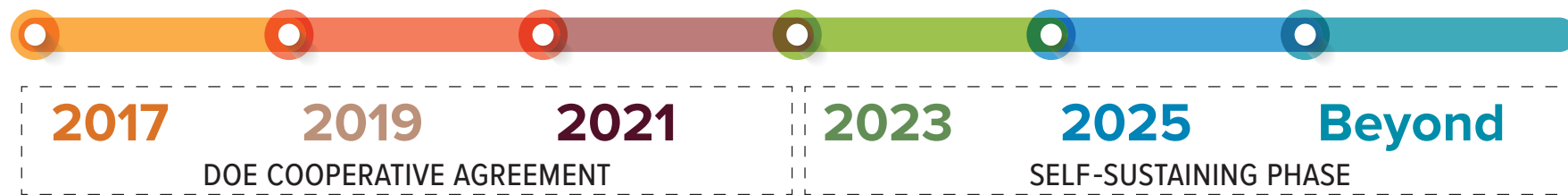
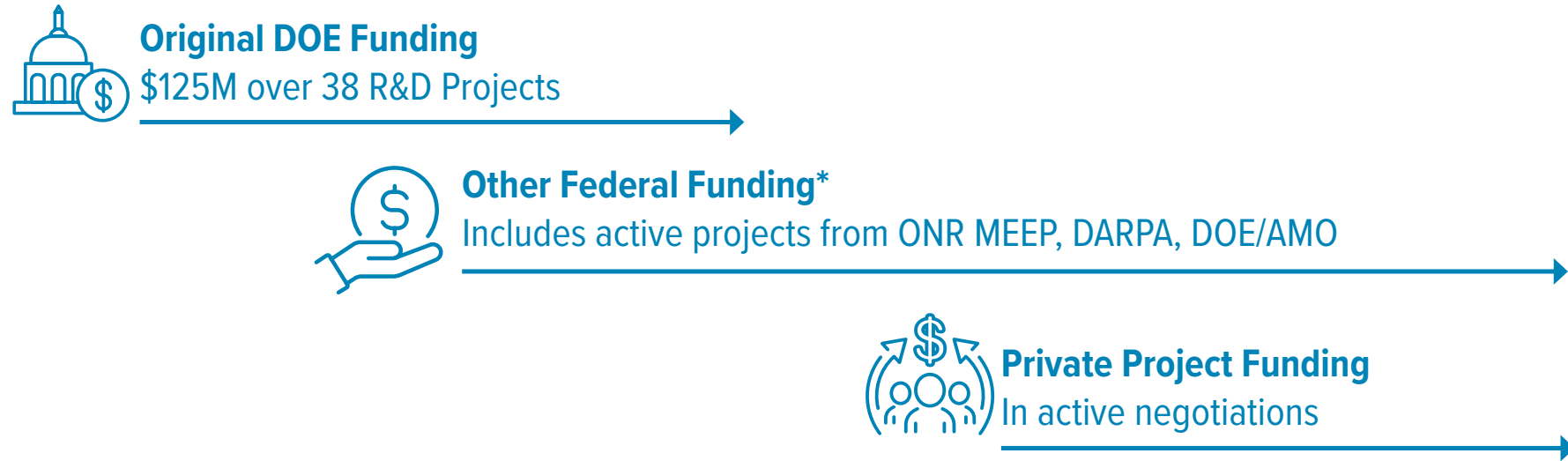
CH375: Modular Chemical Process Intensification Boot Camp

CH376: Emerging Membrane Processes for Water Purification

CH377: Strategies for Computer-Aided Process Intensification

CH378: Fundamentals of Batch to Continuous Process Conversion in Specialty and API Chemistries

RAPID: Advancing Technology Through Collaboration



NOTE: RAPID membership agreement has IP, confidentiality provisions. Project teams retain IP rights.

*Office of Naval Research Manufacturing Engineering Education Program (ONR MEEP), Defense Advanced Research Projects Agency (DARPA), Department of Energy Advanced Manufacturing Office (DOE AMO)

Focus Area: Chemical Commodity Processing

Number of Projects	6
Completed Projects	2
Typical Initial TRL	3-4
Typical Current/Final TRL	4-5
Average Funding Per Project (Million \$)*	2.7

Focus Area: Natural Gas Utilization

Number of Projects	6
Completed Projects	1
Typical Initial TRL	3
Typical Current/Final TRL	4-5
Average Funding Per Project (Million \$)*	2.3

Focus Area: Renewable Bioproducts

Number of Projects	6
Completed Projects	1
Typical Initial TRL	4
Typical Current/Final TRL	5-6
Average Funding Per Project (Million \$)*	3

Focus Area: Intensified Process Fundamentals

Number of Projects	8
Completed Projects	0
Typical Initial TRL	3
Typical Current/Final TRL	4-5
Average Funding Per Project (Million \$)*	3.9

Focus Area: Modeling & Simulation

Number of Projects	5
Completed Projects	0
Typical Initial TRL	3
Typical Current/Final TRL	4
Average Funding Per Project (Million \$)*	3.1

Focus Area: Module Manufacturing

Number of Projects	6
Completed Projects	1
Typical Initial TRL	4-5
Typical Current/Final TRL	5-6
Average Funding Per Project (Million \$)*	4.4

*Average Funding Per Project includes both federal and cost share funding commitments.

Original DOE Funding (2017-2022)
In its initial five years of operation, RAPID is using the large majority of funding from a cooperative agreement with DOE AMO to select and run 38 R&D projects. One project is a cross-cutting software development and metrics project run by RAPID and Texas Tech, while the other 37 projects are advancing technologies in the focus areas listed at left.

Other Federal Funding (2019-Ongoing)
Over the last two years, RAPID successfully partnered with members to build project teams that received funding from other federal agencies (including the Manufacturing Engineering Education Program via the Office of Naval Research, Defense Advanced Research Projects Agency, and DOE AMO) for a number of R&D and education projects. RAPID is in a unique position to convene members and create winning teams with strong industry participation and support. The RAPID team looks forward to increased collaboration in the future.

For more information on the R&D projects, please visit aiche.org/rapid/projects/list

Project 7.4 – Autothermal Pyrolysis of Lignocellulose Wastes to Sugars and Other Biobased Products

Team

Iowa State University
Stine Seeds

Executive Summary

Biomass has long promised to be a source for low cost, sustainable feedstocks—particularly C5 and C6 sugars—for production of specialty chemicals and performance materials. However, the breakdown of lignocellulosic biomass into fermentable sugars is among the major challenges in producing sustainable products such as cellulosic biofuels and other biobased products. Typical pretreatment methods (e.g., enzymatic hydrolysis) used to convert biomass to sugars are energy intensive and expensive, accounting for as much as 30% of the cost of producing cellulosic biofuels. Further, most pretreatments do not completely fractionate cellulose and lignin, the latter of which interferes with enzymatic hydrolysis.

In this project, a team led by Professor Robert Brown at Iowa State University, in partnership with Stine Seeds, developed a pyrolysis-based Modular Energy Production System (MEPS) for the thermal deconstruction of lignocellulosic biomass into C5 and C6 sugars and other value-added products, including phenolic oil. Thermal deconstruction uses a thermochemical process instead of enzymes or chemicals to fractionate lignocellulose into solubilized carbohydrate and phenolic oil. The MEPS concept promises to intensify and modularize biorefineries, particularly through innovations including biomass pretreatments to increase cellulosic sugar production and autothermal pyrolysis to simplify design, reduce energy consumption, and increase feedstock throughput. In the MEPS concept, mass-produced modules are sized to fit in standard shipping containers and ready for field integration to form fully operational biorefineries at a smaller footprint and on-demand scale. MEPS will allow for distributed processing of biomass at point of generation to significantly reduce logistical hurdles and costs for both feedstock and products.

The Iowa State and Stine Seeds team has recently built and installed MEPS modules to create a pilot biorefinery at a test location on Iowa State's campus. Lab and pilot scale results for the autothermal pyrolysis process were consistent and successful across a range of biomass feedstocks. The team also extended the process to demonstrate conversion of waste plastics feedstock to oxygenated bio-oils (e.g., fatty acids, carbohydrates, and other related compounds). In collaboration with RAPID, Clemson University, and Sandia National Laboratory, Iowa State won funding for a project from the DARPA ReSource program to convert warfighter generated plastic to fermentable products for eventual conversion to protein-rich foodstuffs for human consumption.



Project 9.3 SYNOPSIS – Synthesis of Operable Process Intensification

Team

Texas A&M University
 Georgia Tech
 Auburn University
 Dow
 Shell
 Siemens PSE

Executive Summary

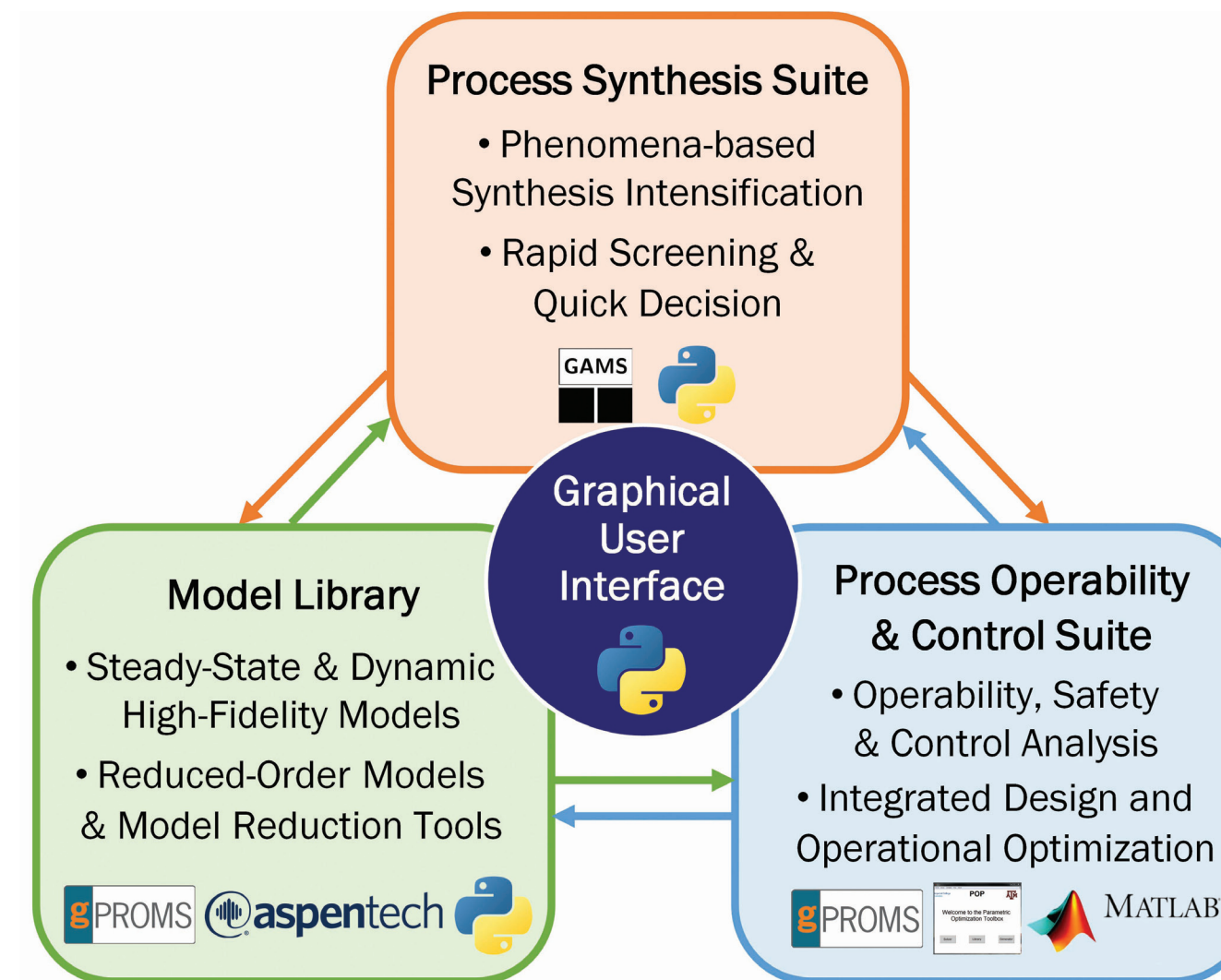
The goal of the SYNOPSIS (SYNthesis of Operable ProcesS Intensification Systems) project is to develop a systematic framework for the discovery of highly-intense, verifiable, operable and safe chemical process systems. The proposed framework stands on three pillars of research and development:

- The first pillar (Component 1) is a process synthesis representation suite for rapid identification of truly potential intensification pathways while considering the combinatorial design space.
- The second pillar (Component 2) is a comprehensive library suite of both high-fidelity and reduced-order models for the accurate prediction and in silico performance validation of process flowsheets.
- The third pillar (Component 3) is an operability suite that integrates process design and optimization with dynamic analysis, control, and safety.

The capabilities of the framework are being demonstrated on methane pyrolytic conversion process for hydrogen and carbon products (Component 4), including in silico and experimental validation.

SYNOPSIS will deliver generic software platforms, operability assessment tools, and model libraries for intensified operable modular chemical processes. Additionally, the test bed facility will incorporate suggested operable designs from in silico framework for scalable, operable, intensified, and modular methane pyrolytic conversion process by addressing intensification principles.

The SYNOPSIS team is currently finishing up a user-friendly demonstration software prototype tool with a Python-developed Graphical User Interface controlling the three distinct toolkits (process synthesis, model library and operability suite) as well as integrated functionality (starting with synthesis with operability, and design and control optimization.)





For information on RAPID membership, contact us at rapid@aiiche.org or visit our website at www.aiiche.org/rapid