Rapid Advancement for Process Intensification Deployment (RAPID)

DE-EE0007888
RAPID/American Institute of Chemical Engineers
March 2017 – March 2022

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U.S. DOE Advanced Manufacturing Office Program Review Meeting
Washington, D.C.
June 12, 2019

RAPID Overview

Timeline

- RAPID award issued March 2017
- Projected end date March 2022
- Project 45% complete

Barriers

- The key barriers to increased penetration of process intensification and modular process technologies were translated to 14 institute metrics and further refined through detailed road mapping efforts.

Budget

	FY 17 Actual Costs	FY 18 Actual Costs	FY 19 Planned Costs	Total Planned Funding (FY 20-Project End Date)
DOE Funded	$5.0M	$11.0M	$21.3M	$32.7M
Project Cost Share	$4.9M	$16.9M	$22.7M	>$40M

Partners

- RAPID operates within the American Institute of Chemical Engineers (AIChE) and is fully aligned with the AIChE mission to promote ChE education and practice
- RAPID has 77 institutional members who provide key support in governance, technology development, and outreach
  - 42% industrial, 45% academic, 13% other
  - Retention year 1 to 2 at 95%
  - Strong pipeline of potential members

RAPID—Advancing the DOE Mission Through Collaboration, Innovation, and Education

RAPID promotes AMO's mission to democratize energy efficient manufacturing technologies through the application of modular chemical process intensification (MCPI)

- MCPI is one of the 14 technology areas identified in the DOE AMO MYPP
- RAPID institute metrics align with the DOE FOA and are selected from the MYPP

RAPID's Mission

CONVENE private and public entities to co-invest in R&D projects that advance innovative technologies and address high-impact manufacturing challenges.

BUILD RAPID membership through an inclusive and attractive value proposition.

LEAD a national effort to research and develop high-impact modular chemical process intensification solutions for U.S. manufacturing.

ESTABLISH a technical education and workforce development program.

PROVIDE members with access to process intensification resources, tools, expertise, and facilities.

OPERATE the institute efficiently to benefit a wide range of stakeholders.

SUSTAIN the institute beyond DOE funding period.

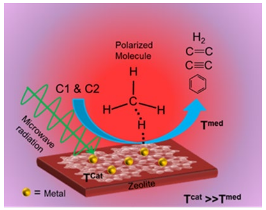
Developing New Tools to Enable Modular Chemical Process Intensification (MCPI)

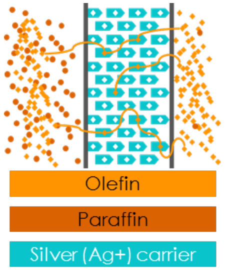
Process Intensification

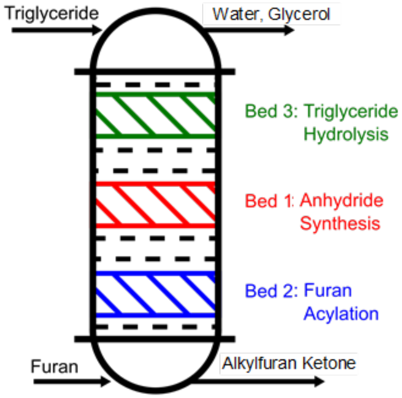
- Transition from pure unit operations thinking to more integrative approach
- Paradigm shift in process design and process development that leads to substantially smaller, cleaner, less capital intensive, and more energy efficient processes

Modular Processing

- Novel designs to bring distributed manufacturing to the process industries
- Factory fabrication of process equipment that reduces costs and allows scaling in number rather than volume







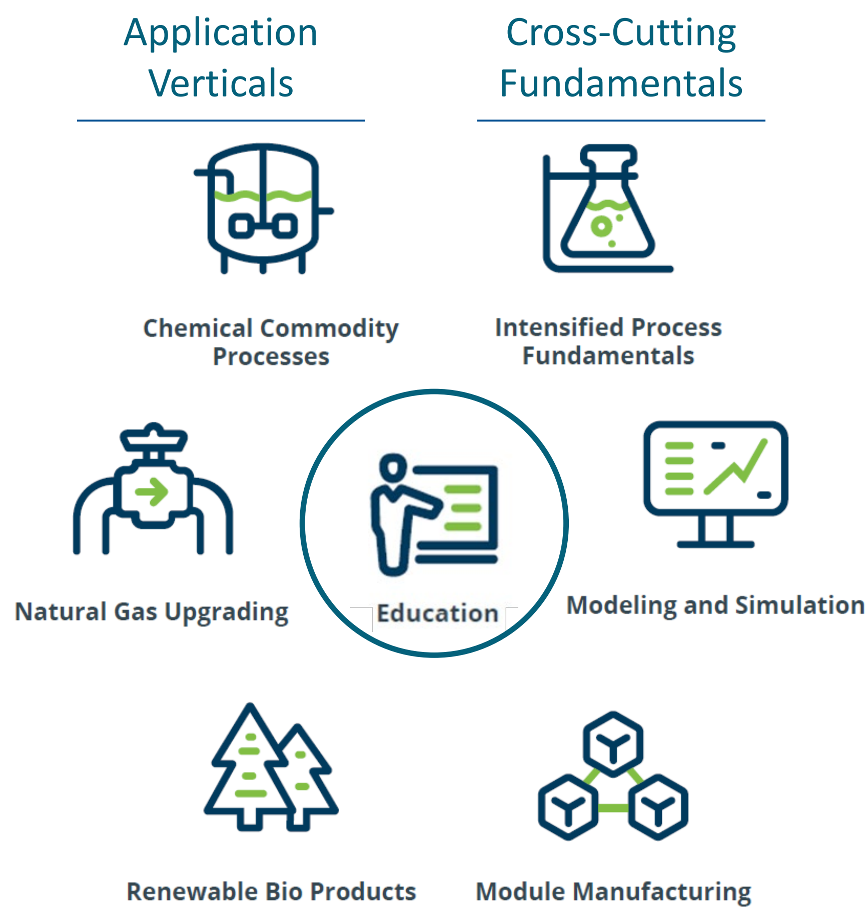
Innovation Guided by Focus Areas

A common approach has been used across all R&D activities within RAPID

1. Divide technical scope into industry-relevant focus areas (7 established)
2. Use structured roadmapping to define key technology gaps
3. Establish work plans linked to institute metrics & roadmapping
4. Create rigorous milestones to track progress
5. Define framework to ensure achievement of 14 institute metrics
6. Build educational content to underpin all areas

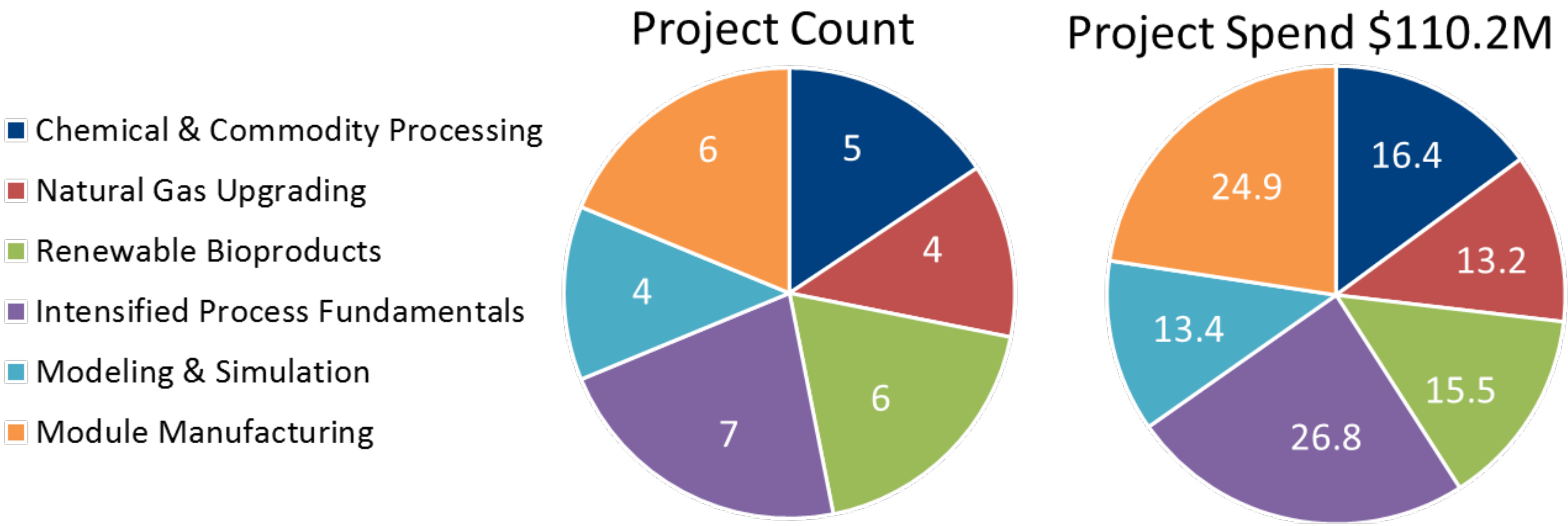
Key Institute Technical Challenges

- Ensuring relevance and controlling scope
  - Maintain strong member engagement
- Building cohesiveness among projects
  - Focus area and thematic reviews



Innovative Project Portfolio

- 32 research project spanning all technical focus areas
- $36.6M federal share, $73.6 cost share allocated to current projects
- Project summaries can be found at www.aiche.org/rapid/projects/list



- Cross-cutting Center for Process Modeling project defines and curates models and metrics for all projects ($6.9M federal share, $5.9M cost share)

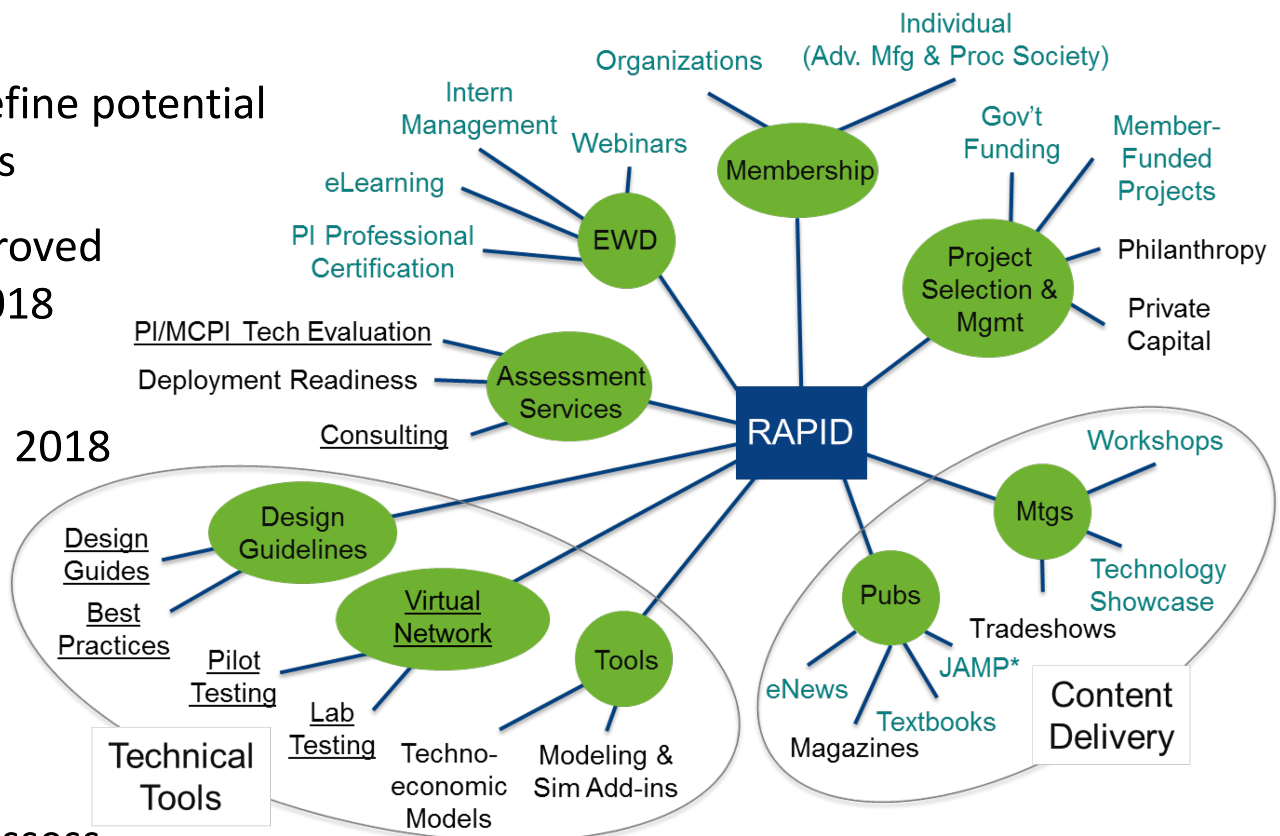
Multidimensional Sustainability Plan

2018

- Worked with members to define potential product and service offerings
- RAPID Governing Board approved Sustainability Plan in Nov. 2018
- AIChE approved initial educational offerings in Dec. 2018

2019

- Implementing educational & content offerings
- Using AIChE rigorous new business review process to assess addition technical tool and assessment service offerings



*Journal of Advanced Manufacturing and Processing

Project Management & Budget

- 60 month project (March 2017 – March 2022)
- SOPO tasks & milestones approved at Institute and project team levels for all five budget periods
- Quarterly project and Institute milestone reviews monitor progress
- Periodic award modifications account for project level changes

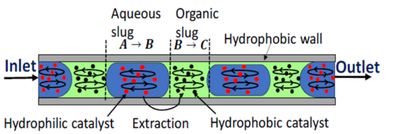
BP3 (FY2019) Major Milestone	
Execute on sustainability plan.	**On-track. Multiple new offerings rolled out.**
100% project review at Go/No Go milestone points.	**On-track**
RAPID reviews operational efficiency of AIChE Support.	**On-track**
In partnership with DOE, complete a comprehensive Institute peer review.	**On-track. Scheduled for Nov. 2019.**
Annualize RAPID internship program.	**On-track. Targeting >30 students for 2019.**
Maintain ≥$600,000 member dues and ≥50% industry organization membership.	**On-track**

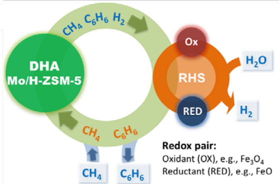
Total Project Budget	
DOE Investment	$70M
Cost Share	$84.5M
Project Total	$154.5M

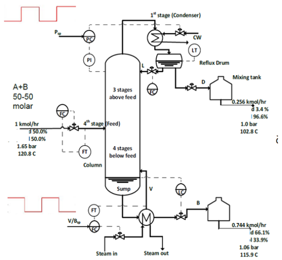
RAPID Transforming Process Industries

Substantial Progress in R&D and EWD

- Strong membership base – 77 and growing
  - Focus on engaging more industry players
- Initial “JumpStart” projects and two calls for projects built strong innovation portfolio
  - 32 R&D projects
  - One cross-cutting metrics review project
  - 55 publications by project teams to-date
  - Successful DOE Peer Review in July 2018; next review planned for Nov. 2019
- Strong success in Education & Workforce Development (EWD)
  - 11 webinars in 2018; 6 additional webinars in 2019
  - “Fundamentals of PI” eLearning course launched in 2018; five additional courses in development for 2019
  - Developing PI Professional Certification program
  - Successful student intern program annualized – targeting 30 interns in 2019
  - Face-to-face course development underway – Oregon State developing modular processing boot camp; Univ. of Arizona developing membrane separations course







RAPID Institute Metrics

Institute Deliverable	Progress	Outlook
1. Technology - Energy Efficiency	22 projects beginning in 2018 that have potential to meet this metric	Positive
2. Technology - Energy Productivity	9 projects beginning in 2018 that have potential to meet this metric	Positive
3. Technology - Intensified Process Modules	18 projects beginning in 2018 that have potential to meet this metric	Positive
4. Technology - Cost-Effective Module Manufacturing	8 projects beginning in 2018 that have potential to meet this metric	Positive
5. Technology - Potential for Cost Effective Deployment	6 projects beginning in 2018 that have potential to meet this metric	Positive
6. Technology - R&D Portfolio	9 projects beginning in 2018 that have potential to meet this metric	Positive
7. Build Industrial Partnership and Ecosystem	31 member companies, 35 of 35 projects with joint industry/academic participation	Addressing
8. Self-Sustainment	Annual membership dues to exceed $0.6M. Executing on financial sustainability plan	Positive
9. Train the Trainers	Faculty training workshop Fall 2018 & 2019. Face-to-face short course in development at Oregon State and Univ. of Arizona	Positive
10. Educate Students	11 webinars hosted in 2018 with 1,730 registrations to-date. "Fundamentals of PI" eLearning course launched with 191 registrations to date. Highly successfully student intern program annualized for 2019 (targeting 30 students for 2019).	Positive
11. Annual Planning Process	Well-defined process for updating strategic and operating plans and ensuring strong engagement with members and market	Positive
12. Industrial Roadmap	Focus on refining and expanding existing roadmap to include food, agriculture, pharma/biotech, pulp & paper in 2019	Addressing
13. Emerging Supply Chain	Running workshops to engage equipment, tool, sensor, etc. suppliers to enable the module manufacturing supply chain	Addressing
14. Diversity	With MEP network, engaging minority- and women-owned businesses and small/medium-sized firms as member prospects	Addressing

Questions?

Additional Information

Road Mapping of Focus Areas

Applications Verticals

Cross-Cutting Fundamentals

- **Rxn/Separation**

Novel reaction/separation schemes that are scalable and drive process efficiencies (*e.g.*, membrane-,or sorption enhanced reactors). Applications include processing light paraffins to olefins, Increase p-xylene yield vs conventional processes, hydrogen production, managing oxygen supply to reactions, etc.

- **Non-Thermal Drivers**

Use of alternative, non-thermal driving forces to activate chemical systems at the appropriate (atomic/molecular) scales.

- **Batch Systems**

Intensification schemes for batch systems. Transferring concepts largely developed for continuous processes to the batch realm could result in increased productivity/lower cost for specialty/fine chemicals.

- **Selective Conversion**

Concepts that show dramatic increases in desired product yields via fundamental improvements in catalysis, heat and mass transfer, and process concepts. This could include include alternative energy inputs and/or the use of novel reaction systems.

- **Separations**

Energy efficient separations technology to purify the reaction product mix, condition the feed in preparation for conversion, and to generate co-reactants for participation in natural gas conversion gas.

- **Process Consolidation**

Process consolidation and modularity to reduce total installed cost by reducing the total number of unit operations and by reducing the amount of field fabrication.

- **Primary Separation**

Technologies to reduce energy demand in primary separation process steps designed to recover organic molecules and biomass components from water.

- **Water management**

Low capital and energy intensive solutions for dewatering and drying of biomass feedstocks, water removal and drying in pulp and paper process, and drying and removal of low levels of residual water from end products.

- **Couple Rxn/Spn/Hxt**

Use of novel chemistries and MCPI strategies to couple heat transfer and reaction in thermal processing of biomass and/or novel applications of reactive separation technologies in biological conversion technologies such as fermentation.

- **Scale-Out Methods**

Scale out methodologies and models to predict performance of alternative energy input approaches for reactions and mixing and determine the suitable scale for modular manufacturing.

- **Fundamental Data Acquisition/Modeling**

Approaches to address key issues with lack of data on fluxes, adsorption, and catalyst kinetics for wide classes of materials, enabling model development and experimental testing of novel materials as adsorbents, membranes, catalysts and their integration.

- **Predictive Models**

Modeling capabilities to screen concepts and configurations of all types and predict optimal structures.

- **PI Software Tools**

Software tools for integrated reaction and/or separation processes and/or cyclic process such as pressure swing adsorption (PSA) or temperature swing adsorption (TSA). Such tools must be widely accessible and capable of integrating MCPI solutions with existing unit operations.

- **Data Availability**

Modeling approaches coupled with data generation and/or analysis to generate databases of physical parameters enabling design with mass separating agents.

- **PI Assessment Tools**

Tools to assess safety, sustainability, and control in PI and MCPI applications, including tools that address unique issues of uncertainty and reduced control variable options that are present in PI and MCPI applications.

- **Intensified Components**

Intensified components that drive down the cost of module pre-assembly, transportation, and installation, while driving significant energy savings in chemical processes.

- **Standard Designs**

Design approaches that limit the amount of non-recurring engineering — during systems integration and installation — needed to support customized modules. This could include standard modules that enable economies of mass production and/or designs that enable incremental capacity additions.

- **Distributed Processing**

Module design and manufacturing approaches to enable distributed chemical processing. These will provide new paths to capital cost reduction and innovative techniques for maintenance and remote access and monitoring.

Example: Chemical & Commodity Processing

Olefins

Steam cracking of naphtha streams or light gas streams is the dominant commercial process for the production of olefins. This process is both energy- and capital-intensive.

- Feed Preparation
- Reactions
- Product Separations
- Other Separations
- Other Steps

Aromatics

Aromatics production, particularly the production/ separation of para-xylene, requires high levels of product recycle driven by equilibrium limitations — making this process energy intensive.

- Feed Preparation
- Reactions
- Product Separations
- Other Separations
- Other Steps

H_2/Syngas & Ind Gases

H_2 production and industrial gas processing have common challenges, including the need for high-purity separation of light gas components, which requires compression and cryogenic distillation.

- Feed Preparation
- Reactions
- Product Separations
- Other Separations
- Other Steps

Ammonia

Existing processes for producing ammonia operate at high temps and pressures due to kinetic and equilibrium restrictions — making this area fertile ground for MCPI.

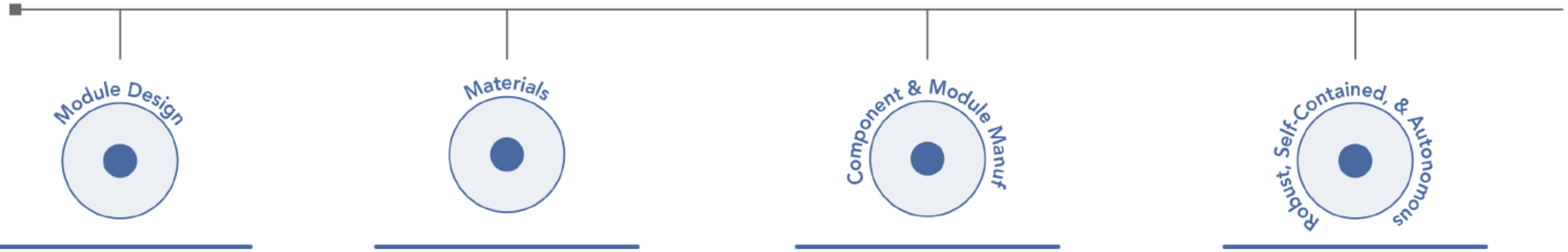
- Feed Preparation
- Reactions
- Product Separations
- Other Separations
- Other Steps

Fine Chemicals

In fine chemical production, the primary driver for MCPI-derived value stems from the ability to couple reaction with separation.

- Feed Preparation
- Reactions
- Product Separations
- Other Separations
- Other Steps

Example: Module Manufacturing



The biggest challenge in module design is the need for customization. Efforts are needed to identify opportunities for modularization and standardization.

- Distributed Processing
- Centralized Processing

The costs of component and module manufacturing — using the required materials of construction — must be reduced.

- Distributed Processing
- Centralized Processing

Reductions in the cost of intensified components and modules will accelerate market adoption of MCPI.

- Distributed Processing
- Centralized Processing

Distributed processing applications of MCPI require modules that are stand-alone, able to operate without significant input from process engineers and maintenance technicians.

- Distributed Processing
- Centralized Processing

Education & Workforce Development

Initiative	Details	Impact as of 04/30/2019
Webinar Series	2018: 11 deployed 2019: 6 planned	1,730 registrants for live & archive
EWD Project Call for Face-to-Face Lab-Based/Project-Based Courses	2018: 2 projects 2019: project review underway	1. MCPI Boot Camp – Oregon State (7 registered to-date, set for Sep 2019 launch) 2. Membrane Processes for Water Purification – U. Arizona (set for Jan 2020 launch)
Student Intern Program*	2018 Pilot 2019 Full Year Plan	14 interns 6 interns in Spring, 15 registered for Summer; 8 planned for Fall
eLearning Courses	2018: 1st course 2019: 5 courses planned	2018: Fundamentals of PI, 191 registrants to-date 2019: Intensified Reaction Processes, Intensified Heat and Mass Transfer, Process Design for MCPI, Modeling & Sim for PI, Intro to Module Mfg
Faculty Workshops	2018 @ Annual 2019 @ Annual	2018 Fundamentals of PI: 25 attendees 2019 Module Manufacturing: in development phase
Body of Knowledge	Launched Dec 2018	Full curriculum plan rolled out to all members

Body of Knowledge Development	**$100,000**
Webinars	**$60,000**
eLearning Course Development	**$81,000**
Faculty Workshop	**$6,000**
Intern Program	**$35,000**

*Piloting separate company-paid intern/co-op training and development program with selected members.

RAPID
Transforming Process Industries

Technical Approach

RAPID Institute Milestones

1. Energy Efficiency: Demonstrate MCPI with >20% energy efficiency / 1st-of-kind pilot demo within 5 years. Demonstrate an order of magnitude improvement in energy productivity in 1 or more processes within 10 years.

2. Energy Productivity: Demonstrate a doubling of energy productivity by a combination of capital ($/kg per day) and operating cost related to improved feedstock and fuel efficiencies.

3. Individual Process Modules: Demonstrate 1,000 pilot hours in 1 or more processes with 10x reduced capacity cost ($/kg per day), 20% improvement in energy efficiency and 20% lower emissions/waste relative to commercial state-of-the-art.

4. Cost-Effective Module Manufacturing: Demonstrate technologies to scale-out module manufacturing that reduce by over 20% cost/unit, with each doubling in module manufacturing production.

5. Potential for Cost Effective Deployment: Develop tools to reduce the cost of deploying MCPI in existing processes by 50% in 5 years. Be on pathway for installed & operating cost parity for MCPI at full scale in one or more applications.

6. R&D Portfolio: Establish a portfolio of enabling technologies for next generation PI with quantitative goals

7. Build Industrial Partnership and Eco-System: Demonstrate potential for industry adoption of MCPI.

8. Self-Sustainment: Establish a portfolio of external support that directly replaces the initial Federal funding of $14 million/yr, starting in Year 6.

9. Train the Trainers: Train at least 50 professionals per year in MCPI by year 3.

10. Educate Students: Train at least 500 students per year in MCPI by year 3.

11. Annual Planning Process: Develop an annual planning process & funding - how new ideas & partners will be included, and how changes to plan will align with roadmaps and enable partnerships with other Fed agencies.

12. Industrial Roadmap: Develop a roadmap for MCPI that is updated annually, using a process that engages key stakeholders, including Institute members and subject matter experts

13. Emerging Supply Chain: Document the existence of the domestic supply chain for MCPI. Assess its health annually and document Institute capabilities supporting the supply chain.

14. Diversity: Demonstrate participation of SME's, MOBs, WOBs in technology development, workforce development and Institute governance.

RAPID
Transforming Process Industries

Technical Approach

Addressing Institute Milestones

Focus Areas		Projects	Institute Metrics 1	2	3	4	5	6
Chemical & Commodity Processing	5.4	Dynamic Intensification of Chemical Processes						X
	5.5	Para-Xylene Selective Membrane Reactor	X			X	X	
	5.6	Modular Conversion Of Stranded Ethane To Liquid Fuels	X	X	X			
	5.7	Energy-Efficient Separation of Olefins And Paraffins Through A Membrane	X	X	X			
	5.8	Intensified Commercial Scale Manufacture of Dispersants	X	X	X			
Natural Gas Upgrading	6.4	Adsorptive Nitrogen from Natural Gas			X			
	6.5	Efficient Chemicals Production Via Chemical Looping	X	X	X	X	X	
	6.6	Advanced Nanocomposite Membranes For Natural Gas Purification			X			
	6.7	Microwave Catalysis for Process Intensified Modular Production of Value-Added Chemicals from Natural Gas	X	X	X			
Renewable Bioproducts	7.4	Autothermal Pyrolysis Of Lignocellulosic Wastes To Sugars And Other Biobased Products	X	X	X		X	
	7.5	Robust Membranes for Black Liquor Concentration	X			X		
	7.6	Sugars-to-Bioproducts Scalable Platform Technology	X		X			
	7.7	Three-Way Catalytic Distillation to Renewable Surfactants via Triglyceride	X		X		X	
	7.8	High purity ethanol without distillation; carbon nanotube-enabled ethanol dewatering	X			X		
	7.9	Use of power ultrasound for nonthermal, nonequilibrium separation of ethanol/water solutions	X					X
Intensified Process Fundamentals	8.3	Intensified Microwave Reactor Technology	X					X
	8.4	Microfibrous Entrapped Sorbents for High Throughput Modular Process Intensified Gas Separation and Ion Exchange	X	X	X			
	8.5	Thermoneutral Propane Dehydrogenation Via A Solid Oxide Membrane Reactor	X		X			
	8.6	Multiphase Microchannel Separator				X		X
	8.7	RAPID MCPI - Energy Efficient Technology for Metals Separation	X		X			
	8.8	Molecular mechanical vapor compression-membrane distillation (MVC-MD) for treatment of high-TDS produced water	X			X		
	8.9	Modular catalytic partial oxidation reactors using microstructured catalyst structures with combined high thermal conductivity and flame extinction to enable high per pass conversion of non-diluted reactants above the LEL	X		X			
Modeling & Simulation	9.3	SYNOPSIS–Synthesis of Operable Process Intensification Systems	X	X				X
	9.4	Optimization Modeling For Advanced Syngas To Olefin Reactive Systems			X	X	X	
	9.5	RAPID Reaction Software Ecosystem						X
	9.6	An Experimentally Verified Physical Properties Database For Sorbent Selection						X
Module Manufacturing	10.4	Modular Chemical Process Intensification Institute For Clean Energy Manufacturing						X
	10.5	Development and Demonstration of Novel Thermal Technologies for Enhanced Air-Side and Two-Phase Performance of CPI-Relevant Heat Exchangers	X				X	
	10.6	Modular Catalytic Desulfurization Units For Sour Gas Sweetening			X	X		
	10.7	On demand treatment of wastewater using 3D-Printed Membrane	X	X	X			
	10.8	Deploying Intensified, Automated, Mobile, Operable, and Novel Designs "DIAMOND" for treating shale gas wastewater	X		X			
	10.9	Modelling the total cost of ownership for scaling up via modular process intensification						X