SAINT-GOBAIN RESEARCH & DEVELOPMENT CENTER

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Development of Agile and Cost Effective Routes for Manufacturing Reliable Ceramic Components for SOFC Systems

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CERAMIC MATERIALS SAINT-GOBAIN

OUTLINE

- Background
- Technical approach
- Project objectives
- Project structure
- Project tasks
- Project schedule
- Project budget
- Project management plan
- Key risks and mitigation

BACKGROUND

The lack of availability of durable, low-cost system and balance of plant (BOP) ceramic components represents a critical barrier to the widespread commercialization of the solid oxide fuel cell (SOFC) technology. Current ceramic manufacturing based on either “green machining,” or higher volume processes such as injection molding, have high CAPEX or tooling costs, limited flexibility for design modification, and lack a robust domestic supply chain. Saint-Gobain (SG) proposes to develop and test novel forming methods for the manufacture of ceramic BOP components critical to the design of robust SOFC platforms.

TECHNICAL APPROACH

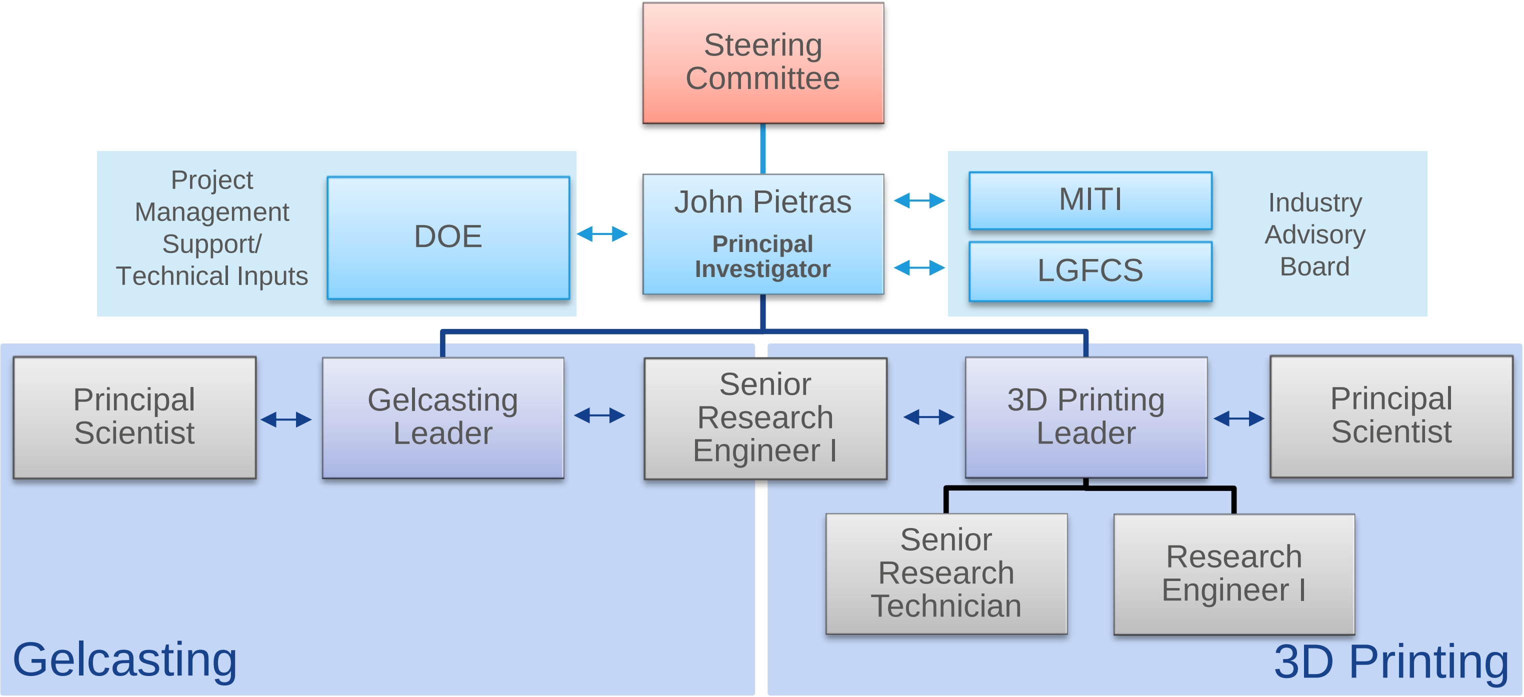
Manufacturing by gelcasting and 3D printing (3DP) show substantial, complementary promise for BOP components. These techniques have potential for fast prototyping, low cost production, and manufacturing at scales ranging from single unit to 100,000s/year with a high degree of flexibility. The SG team will utilize an industrially preferred ceramic material, magnesia-magnesium aluminate spinel (MMA), which shows high suitability for thermal and mechanical requirements of SOFC systems while offering low material costs.

PROJECT OBJECTIVES

Objectives

- ❖ Development of gelcasting and 3DP methods for the production of ceramic stack and BOP components with MMA material
- ❖ Mapping and analysis of capabilities and limitations of this method to relevant SOFC design dimensions and features in order to establish their breadth of utility and specific cost advantage for SOFC manufacturers
- ❖ Establishing the benefits of these manufacturing methods for producing the SOFC manifolds and heat exchangers in commercial SOFC platforms through a validated techno-economic analysis

PROJECT STRUCTURE



ADDITIONAL RESOURCES

- Competency Research Lab (component testing, lab services, machining)
- Consultation from internal experts

PROJECT TASKS

Task 1.0 Project Management and Planning

Task 2.0 Gelcasting of dense MMA components for SOFC applications

- **Subtask 2.1:** Slurry development for gelcasting of MMA using ISOBAM
- **Subtask 2.2:** Development of sintering cycle of gelcast MMA parts
- **Subtask 2.3:** Determination of design constraints for gel cast MMA parts
- **Subtask 2.4:** Manufacturing of MMA dense manifolds through gel casting

Task 3.0 3D printing of dense MMA components for SOFC applications

- **Subtask 3.1:** Development of 3D printing process for MMA
- **Subtask 3.2:** Development of the sintering cycle of 3D printed MMA parts
- **Subtask 3.3:** Determination of design constraints for 3D printed MMA
- **Subtask 3.4:** Manufacturing of MMA dense manifolds through 3D printing

Task 4.0 Comparison of gelcasting and 3D printing

- **Subtask 4.1:** Comparison of the shape processing capabilities
- **Subtask 4.2**: Comparison of the cost of the manufacturing routes

	Team Members	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
		Oct-17	Nov-17	Dec-17	Jan-18	Feb-18	Mar-18	Apr-18	May-18	Jun-18	Jul-18	Aug-18	Sep-18	Oct-18	Nov-18	Dec-18	Jan-19	Feb-19	Mar-19
1. Project management and planning	Pietras																		
M1: Project Management Plan		◊																	
Quarterly report				X			X			X			X			X			X
2. Gelcasting of dense MMA components for SOFC application																			
2.1 Slurry development	GL, PS																		
M2: Matrix summarizing results from task 2.1							◊												
2.2 Development of sintering cycle	GL, PS																		
2.3 Determination of design constraints	GL, SREI, PS																		
M4: Dense crack free samples for SOFC application													◊						
2.4 Full size dense MMA manifold for SOFC application	GL, SREI, PS																		
3. 3D printing of dense MMA components for SOFC application																			
3.1 Slurry development	3DPL, SRT, PS																		
3.2 Development of sintering cycle	3DPL, SRT, PS																		
M3: Slurry composition									◊										
3.3 Determination of design constraints	REI, SREI, PS																		
M5: Dense crack free samples for SOFC application													◊						
3.4 Full size dense MMA manifold for SOFC application	REI, SREI, PS																		
4. Comparison of gel casting and 3D printing																			
4.1 Comparison of the shape processing capabilities	Pietras, GL, 3DPL, REI, PS																		
4.2 Techno-economic Analysis	Pietras, GL, 3DPL, REI, PS																		
M6: Comparison of gelcasting and 3D printing																			◊

PROJECT BUDGET

PROJECT FUNDING		
Total	Gov't Share	Cost Share
$ 359,020	$ 287,216	$ 71,804

		FY 2018	FY 2019
PLANNED COSTS	Gov't Share	$ 218,725	$ 68,493
	Cost Share	$ 54,682	$ 17,125

		Q1	Q2	Q3	Q4	Q5	Q6
PLANNED COSTS	Gov't Share	$ 60,636	$ 54,140	$ 54,140	$ 49,809	$ 44,189	$ 24,304
	Cost Share	$ 15,160	$ 13,535	$ 13,535	$ 12,452	$ 11,048	$ 6,077

PROJECT MANAGEMENT PLAN

The PI will work with the team leads for each task to manage and direct the project to meet all technical, schedule, and budget objectives and requirements. For each task, the team leader will ensure that project plans, results, and decisions are appropriately documented and that project reporting requirements are satisfied.

Communication between Saint-Gobain and the DOE Program Management will be maintained through the reporting structure and quarterly reports, with semi-annual and annual updates as required and needed owing to major decisions. Internally, the PI will establish bi-weekly conference calls and quarterly presentations.

KEY RISKS AND MITIGATION PLAN—GELCASTING

Risk assessment table

Risk #	Expected risks	Probability	Impact	Risk mitigation	Risk mitigation task	Progress
1	Cracks during drying for gelcasting with ISOBAM-based slurry	Low	High	-Use higher solids loading to reduce shrinkage -Concentrate efforts on epoxy-based system that has been demonstrated successfully through drying process without cracks	2.1	
2	Cracks during firing cycle for gelcast parts	Moderate	High	-Optimize cycle for minimal release rate of water and organics by slowing down the heating rates and/or introducing holds -Concentrate efforts on ISOBAM-based system if demonstrated up to drying since it is less likely to crack in binder burnout because the gelling agent content is lower -Optimize part design (e.g. wall thickness) -Sinter subcomponents of the parts then glass bond using already developed technique at Saint-Gobain -If cracking is due to hydrolysis of magnesium hydrate, concentrate efforts on powder which does not experience the same sensitivity to water (e.g. alumina, zirconia)	2.2	
3	Cracks during sintering of larger gelcast parts	High	High	-Further optimize the sintering cycle for minimal release rate of water and organics by slowing down the heating rates and/or introducing holds -Adapt the part design to accommodate the process limitation -Use multi-part sintering and bonding	2.3	

KEY RISKS AND MITIGATION PLAN—GELCASTING

Risk assessment table

Risk #	Expected risks	Probability	Impact	Risk mitigation	Risk mitigation task	Progress
4	Low green strength limiting features for gel cast parts	Low	Moderate	-Adapt the part design to accommodate the process limitation -Concentrate efforts on epoxy-based system that has been demonstrated successfully in drying process without cracks -Adjust binder content to increase the green strength	2.1	
5	Open porosity in parts prepared through gelcasting route	Moderate	High	-Improve slurry to eliminate any potential issue from de-airing -Optimize sintering cycle for higher densification -Add sintering aids if needed -Increase solids loading	2.2	
6	Gelcasting method cannot achieve target dimensions and features	Low	Moderate	-Green machine critical features -Produce manifolds with closest analogue features	2.3	
7	Problems sintering large complex manifold	High	High	-Change sintering configuration to reduce stresses where cracking or warping of shape occurred -If due to binder burnout issue, reduce the heating rates and/or introduce holds	2.4	
8	De-airing issue with large complex manifold	Moderate	High	-Decrease the viscosity of the slurry by lowering the solids loading to avoid air pockets when pouring the mold	2.4	
9	De-molding issue with large complex manifold	Low	High	-Increase the flexibility of the mold material -Redesign mold to optimize feature, parting line, gate, and riser position to facilitate part removal	2.4	

KEY RISKS AND MITIGATION PLAN—3D PRINTING

Risk assessment table

Risk #	Expected risks	Probability	Impact	Risk mitigation	Risk mitigation task	Progress
1	Fast settling of the slurry for 3D printed MMA	Low	High	- DOE matrix of slurry compositions designed in subtask 3.1 in order to maximize chances of solution - Focus efforts on gelcasting route	3.1	
2	Open porosity in parts prepared from 3D printing	Moderate	High	- Increase solids loading - Optimize sintering cycle for higher densification - Add sintering aids if needed - Focus efforts on gelcasting route	3.2	
3	Cracks during sintering of large 3D printed parts	High	Moderate	- Further optimize the sintering cycle for minimal release rate of organics by slowing down the heating rates and/or introducing holds. - Adapt the part design to accommodate the process limitation	3.2 & 3.3	

4	Leak of complex manifold	Low	High	- If due to densification issue
				    - Optimize sintering cycle for higher densification
				    - Add sintering aids if needed
				- If due to sealing, improve design
					3.4	

KEY RISKS AND MITIGATION PLAN—ENVIRONMENT, HEALTH, AND SAFETY

Risk assessment table

Risk #	Expected risks	Probability	Impact	Risk mitigation	Risk mitigation task	Progress
1	Inhalation of fine powder	Low	Moderate	-Use proper PPE and dust hoods when working with fine powders	continuous	
2	Skin contact with photo-curable resin	Low	Moderate	-Use proper PPE to avoid skin contact	continuous	
3	Particulate contaminated water pollution	Low	Moderate	-Collect waste water after process and dispose through licensed third party service provider	continuous	
4	Metal oxides and polymers pollution	Low	Moderate	-Collect liquids at a satellite accumulation area and transfer to the main hazardous waste accumulation area to be removed by a third party vendor	continuous	

KEY RISKS AND MITIGATION PLAN—RESOURCE AND MANAGEMENT

Risk assessment table

Risk #	Expected risks	Probability	Impact	Risk mitigation	Risk mitigation task	Progress
1	Additional or different equipment, facility, or researchers required	Low	Moderate	-Utilize Saint-Gobain's technical resource portfolio in advanced ceramic materials and manufacturing to source required equipment, facilities, or researchers -Communicate with task teams and DOE Program Management regarding changes	continuous	
2	Communication loss between teams	Low	Moderate	-Maintain reporting structure and quarterly reports between Saint-Gobain and the DOE Program Management -Update the DOE Program Management semi-annually and annually as required and needed owing to major decisions -Establish internal bi-weekly conference calls and quarterly presentations	continuous	
3	Timeline delay due to project start before paperwork completed	Low	Moderate	-Track and document progress of the established milestones and deliverables	continuous	