Performance and Reliability Advancements in a Durable Low Temperature Tubular SOFC

DE- FE0028063

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Contents

Atrex Energy Commercial Product Background

Atrex currently provides products targeting remote applications that need 100 to 4500W power

Clean, Quiet & Efficient

- 30% system efficiency
- Minimal emissions = “Green”
- Small footprint
- No hydrogen needed
- Runs on natural gas or propane w/ no external reformer required
- Follows load, no need to set manually
- Remote monitoring

Reliable Power

- Outputs from 100W up to 4500W at 2VDC up to 60VDC
- Continuous duty, onsite power
- High availability
- Grid-independent, backup capability

Cost-Effective

- Low-maintenance
- Scalable
- Hi fuel efficiency = low fuel consumption
- Competitive “Total Cost of Ownership”

Key Feature - Scalable with Minimal Maintenance

- Replaceable cartridge , 3 year expected life
- Upgradable - The 250 watt unit can be upgraded to a 500 watt output and the 1000 watt unit can be upgraded to a 1500 watt output by simply replacing the Bundles.
- Parallelization - Multiple power generators can be linked to increase the output
- Minimal Maintenance - the only parts requiring regular maintenance checkups are the air and fuel filters.

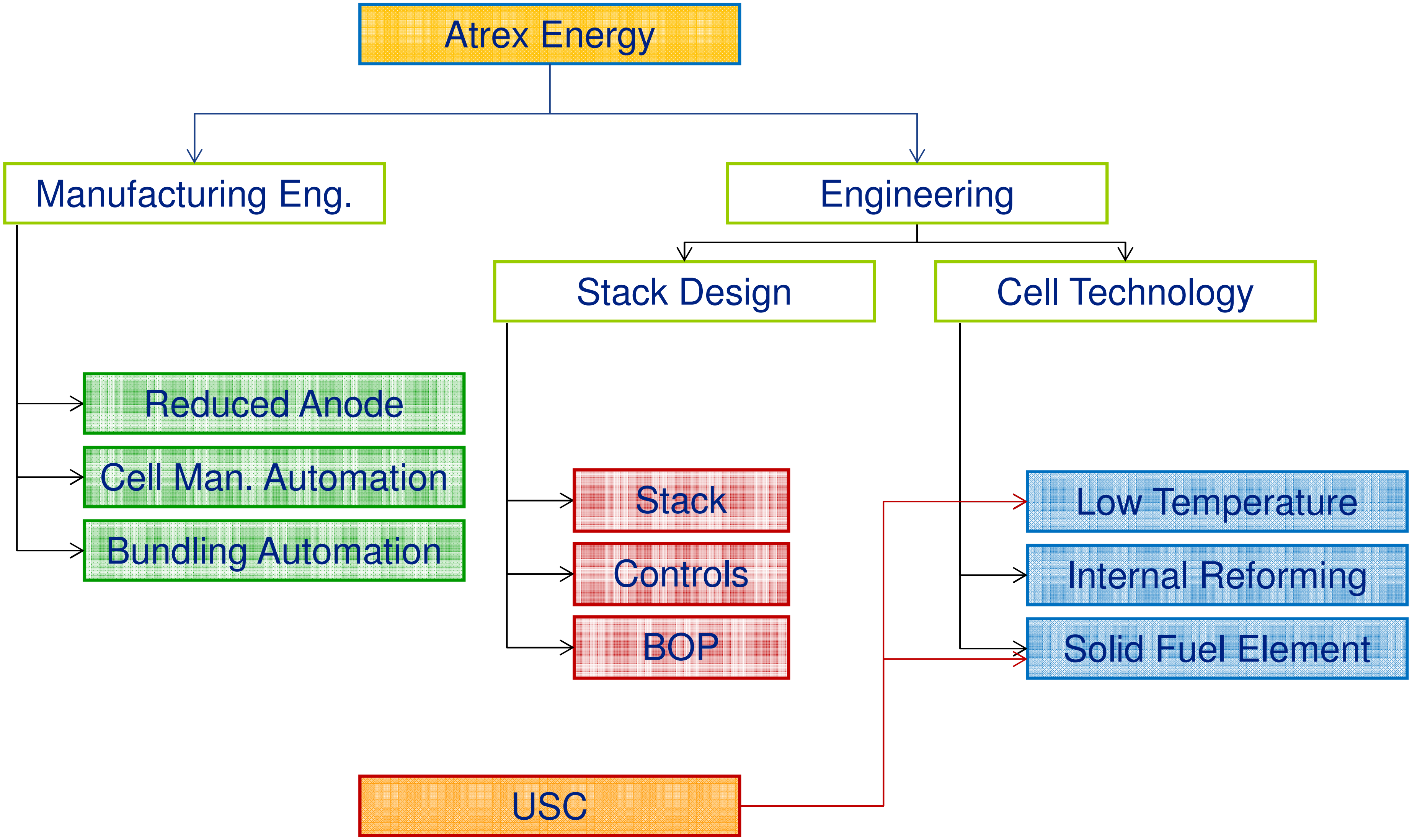
Project Objective

- **Commercial lessons are clear. Widespread market acceptance requires low cost and reliability**
- **Ultimate project aim is for a <u>low cost</u> fuel cell system through improved technology and production automation**
  - Reduction in materials costs (lower temperature operation, thin cells)
  - Reduction in labor cost (production automation)
  - Reduced ROI (increased efficiency through internal reforming)
  - Increase in reliability (inexpensive solid fuel element for overload protection)
- **Month long demonstration of a low cost, low degradation natural gas fueled 5kW system by September 2018**

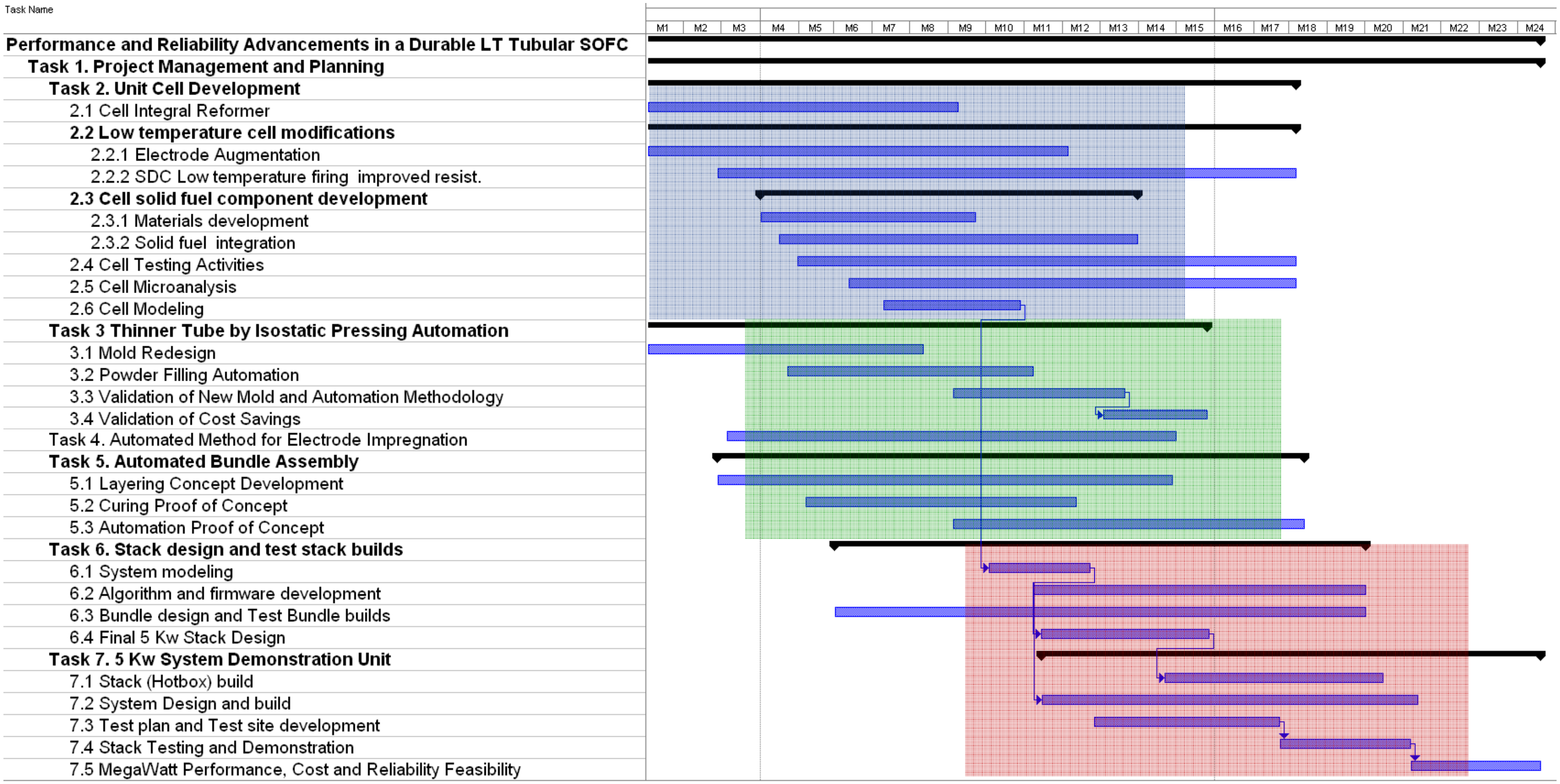
Technological Approach to Low Cost Reliable SOFC Systems

No.	Innovation	Degradation	Reliability	Efficiency	Cost	Risk
1	Integral solid fuel element	✓	✓			Med.
2	Passivated catalytic injector		✓	✓		Med.
3	Low Temp Electrode impregnations	✓		✓		Low
4	Automated bundle assembly		✓		✓	High
5	LT Sintering aids for ceria layer		✓		✓	Med.
6	Pressing automation				✓	Med.
7	Automated electrode impregnation		✓		✓	Med.

Project Structure: Company wide effort



Schedule (October2016–September 2018)



Project Milestones 1

Milestone No (SOPO Task No.)	Milestone Description	Completion Risk	Planned Completion
1 (2.1/2.4) ☑	Long term cell test started for low O/C and low temperature (650°C)	Low	12/31/2016
2 (2.3.2)	Preliminary Iron or other solid fuel bed insert	Moderate	12/31/2016
3 (2.3/2.4)	Long term cell test started for fuel bed and low temperature (650°C)	Low	3/1/2017
4 (7.3)	1st Bundle test of 2 of 3 innovations	Low	3/31/2017
5 (7.3)	2nd Bundle test of 2 of 3 innovations	Low	5/31/2017
6 (7.3)	3nd Bundle test of 2 of 3 innovations	Low	7/31/2017
7 (2.2.1)	USC: Mass-loading-performance relationship for impregnations	Low	9/1/2017

Project Milestones 2

Milestone No (SOPO Task No.)	**Milestone Description**	**Completion Risk**	**Planned Completion**
8 (3.0/2.4)	**Thin wall cell on test**	Low	9/1/2017
9 (7.3)	**4th Bundle test: Thin wall cells**	Moderate	1/1/2018
10 (7.4)	**Robotic bundle assembly test**	Moderate	2/28/2018
11 (5.0)	**Final stack design 5kW**	Low	3/31/2018
12 (2.3.1)	**USC: Developed the final makeup for an optimized chemical bed**	Moderate	3/31/2018
13 (2.2.2)	**USC: Recipe for sintering aid for low-temperature CeO2 barrier layer**	Moderate	3/31/2018
14 (8.3)	**Test plan**	Low	5/1/2018
15 (8.4)	**5kW demonstration start**	Moderate	8/1/2018

Cell Performance Improvement

- Intermediate temperature operation
  - Cell performance improvement at intermediate temperature by electrode engineering
  - Long term cell test to verify degradation
- Low O/C CPOX fuel operation
  - Develop catalyst for low O/C operation with improved efficiency and without carbon formation
- Overloading protection
  - Develop solid fuel process recipe
  - Demonstrate overloading protection by solid fuel element

Cost Reduction - Automation

- Will review Tubular Cell Manufacturing Methods
  - Focus on thin wall cells
  - Isostatic Tube Pressing or other technique
- Robotic Stack Assembly
  - Concepts still need to be developed
- 5kW Concept
  - Twin replaceable bundles
  - Parts close to certified product line

Current Progress

- **Program Management**
  - DOE contract has been signed
  - Sub contract and NDA with USC imminent: expected to be signed this week
  - Human resources at USC and Atrex have been directed. Technical teams and meeting schedules have been organized
- **Technical**
  - Demonstration of Low O/C CPOX in cell at 650^{o}C completed
  - Pressing of solid fuel beds for actual cell completed; overloading protection demonstrated

Program Risk- Technical

Description of Risk	Probab ility	Impact	Overall Degree of Risk	Risk management and mitigation strategy
Technical Risk				
Cell performance does not achieve goals at low temperature	Low	High	**Moderate**	Cell testing has already shown that concentration polarization accounts for a significant loss. Two tasks (low O/C) and thinner anode support tubes will counteract performance loss due to the temperature
Long term stability of nano-scale impregnations	Low	Moderate	**Moderate**	•Cell testing will start very early in this project so that modifications can be tested often and as necessary • Recipes from other collaborations can be brought into the project if USC is unsuccessful
Solid fuel component carbon fouling	Low	Moderate	**Moderate**	•O/C will be modulated with current density and the solid fuel positioned in the cell region of highest FU so that the water is protective. • The fuel element can be modified to include a gasification catalyst *e.g.* ceria much like the anode
Isostatic pressed cells cannot be automatically manufactured on schedule	Moderate	Moderate	**Moderate**	•Cells will be manually formed from the mold if automation is not possible •If yield is too poor at least single cell tests and 20 cell bundle tests will be completed with these manually fabricated cells in order to attain the necessary data for projections
Carbon formation in injectors at low O/C	Moderate	High	**High**	Low O/C reforming has been proven viable but carbon fouling is sensitive to metal surface and catalyst preparation. • Several routes for passivation exist. For cost we will screen aluminization, use of alumina forming stainless steels, and only if necessary alumina forming nickel alloys. •As a last resort if unsuccessful, integral autothermal reforming (condensed water recycle) could be employed, but at the cost of BOP complexity
Robotic assembly of stacks	High	Low	**Moderate**	•Concept for robotic assembly will be started early in the project •A go no-go evaluation will occur early in the project to so that unnecessary capital investment in robotics does not take place •The 5kW demonstration, nor any of the performance and degradation metrics depend on the robotic assembly

Program Risk- Resources and Management

Description of Risk	Probability	Impact	Overall Degree of Risk	Risk management and mitigation strategy
Resource Risk				
Acumentrics personnel diverted to other projects	Low	High	**Moderate**	• The topic of SOFC commercialization through innovation is in line with our mission. The manufacturing tasks selected for the project are from an internal review for mass production • The PIs for the project have been selected from the management and executive level and will re-address resources as needed.
Staff Attrition	Moderate	Moderate	**Moderate**	•In the event that staff leave Atrex or USC, resources from within the company will be reallocated and new personnel will be hired as soon as possible. •Acumentrics' plan in general is to maintain a redundancy of expertise to avoid such problems
Insufficient funding	Low	Moderate	**Moderate**	•The tasks in this project can be highly leveraged against current awards or external research contracts if supplementary funds are required to complete a task
Management Risks				
Poor management	Low	High	**Moderate**	The project will be reviewed by the Director of Engineering monthly. Insufficient progress will be escalated to the COO and weekly reviews will commence from that point
5kW demonstration schedule delays	Moderate	Low	**Moderate**	Atrex has amassed experience delivering on 3 and 10kW SOFC projects. Acumentrics will use all resources possible to stay on schedule, however delays outside Atrex' control will be reported to the DOE project manager

Funding Profile

	Fiscal year 1 (10/1/16-9/30/17)						
	Baseline Cost Plan				Cumulative Baseline Cost Plan		
	Federal Share	Non-Federal Share	TOTAL		Federal Share	Non-Federal Share	TOTAL
October	$81602	$20400	$102002		$81,602	$20,400	$102,002
November	$81602	$20400	$102002		$163,204	$40,800	$204,004
December	$81602	$20400	$102002		$244,806	$61,200	$306,006
January	$117177	$29294	$146471		$361,983	$90,494	$452,477
February	$117177	$29294	$146471		$479,160	$119,788	$598,948
March	$117177	$29294	$146471		$596,337	$149,082	$745,419
April	$117177	$29294	$146471		$713,514	$178,376	$891,890
May	$117177	$29294	$146471		$830,691	$207,670	$1,038,361
June	$90496	$22624	$113119		$921,187	$230,294	$1,151,480
July	$90496	$22624	$113119		$1,011,683	$252,918	$1,264,599
August	$90496	$22624	$113119		$1,102,179	$275,542	$1,377,718
September	$90496	$22624	$113119		$1,192,675	$298,166	$1,490,837
TOTAL	**$1,192,671**	**$298,167**	**$1,490,838**		**$1,192,671**	**$298,167**	**$1,490,838**

	Budget Period 1 10/01/16-09/30/17		Budget Period 2 10/01/17-03/30/18		Total Project	
	Gov't Share	Cost Share	Gov't Share	Cost Share	Government Share	Cost Share
Atrex Energy	$1,067,245	$266,811	1,138,996	$284,749	$2,206,241	$551,560
Univ.of South Carolina	$125,426	$31,357	$124,561	$31,140	$249,987	$62,497