PEM Stationary Power Plant

2011 DOE TOPIC ONE

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UTC Power
A United Technologies Company

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Project ID # FC101

OVERVIEW

Timeline

Project start date: Jan 2004
Project end date: Dec 2012
Percent complete: 70%

Barriers

Cost
- $3000/kW installed

Durability
- Lifetime: 50 khrs

Performance
- Electrical Efficiency: 45%

Budget

Total project funding: $21.8M
- DOE share: $11.6M
- Cost share: $10.2M

Funding received in FY11: $0K

Planned funding for FY12: $650K

Partners

No Partners

RELEVANCE

Objectives

DOE Barriers	Project Goals
A. Cost	Investigate feasibility and value proposition of a 150 kW High Temperature (HT) Proton Exchange Membrane (PEM) stationary fuel cell operating on Natural Gas (NG) reformate
B. Durability	Project durability and reliability of PEM fuel cell components
C. Performance	Preliminary systems analysis of PEM power plant capable of achieving >45% electrical efficiency Demonstrate advanced fuel processing breadboard system capable of delivering H_2 rich low CO (<10 ppm) reactant stream to PEM stack

APPROACH

Milestones

Date	Description	% complete*
12/31/2011	Investigate feasibility and value proposition of a 150kW PEM stationary fuel cell operating on natural gas reformate	100%
08/01/2012	Methanation catalyst screening and down-selection (Criteria: maintain CO content of ≤10 ppm for 250-500hrs depending on the catalyst)	10%
09/01/2012	Full size single tube reformer test stand upgrade	15%
11/01/2012	Complete advanced reformer catalyst verification test	0%
12/01/2012	Complete system feasibility analysis & heat-mass balance	0%
12/31/2012	100 hr durability testing for advanced reformer and methanation reactor	0%
12/31/2012	Complete single cell Membrane Electrode Assembly (MEA) durability testing of 1000hrs under accelerated conditions	0%

* Completion status is as of 03/16/2012

TECHNICAL ACCOMPLISHMENTS

Background

Reforming process requires steam

	Steam	40% (Baseline)	42%	45%
Low Temperature (LT) PEM	Burner or heater	N/A	2.0	4.0
~90C PEM	Vapor recompression	1.0	1.4	2.9
~115C PEM	'Free'	0.8	1.0	1.5

Results are shown as relative # of cells to baseline

90ºC PEM with vapor recompression capable of meeting power plant requirements

Leverages cost benefits of PEM cell stacks for transportation

TECHNICAL ACCOMPLISHMENTS

Steam Delivery Options

	Concept	Result
1	Cell Stack Assembly (CSA) provides a low-pressure, 2-phase water/steam mix directly from the coolers. Pump the steam to the Fuel Processor System (FPS)	Chosen for further study
2	CSA provides 1-phase water from the coolers, which is flashed to provide steam. Pump the steam to the FPS	Chosen for further study
3	Pressurize liquid water, heat to create steam, and send to the FPS	Insufficient heat available from the FPS to both create the steam and maintain FPS efficiency
4	Use anode recycle (requires a pump or compressor), several variants	Adds considerable system complexity, while still requiring a pumping device.

TECHNICAL ACCOMPLISHMENTS

Operating conditions

Feasibility study performed under the following conditions

Coolant			Cathode				Anode						
T_{in}	T_{out}	Flow	T_{out}	P_{out}	Util	O_2	T_{out}	P_{out}	Util	H_2	CO_2	CO	O_2
^{o}C	^{o}C	cc/min	^{o}C	kPag	%	%	^{o}C	kPag	%	%	%	%	%
60	90	315	80	50	60	21	60	50	80	79.8	20	0.001	0.2

1% air bleed at 1.2 A/cm2

Reformer steam/carbon ratio = 2.75-3.25

Overall water self-sufficiency (no external water required for operation)

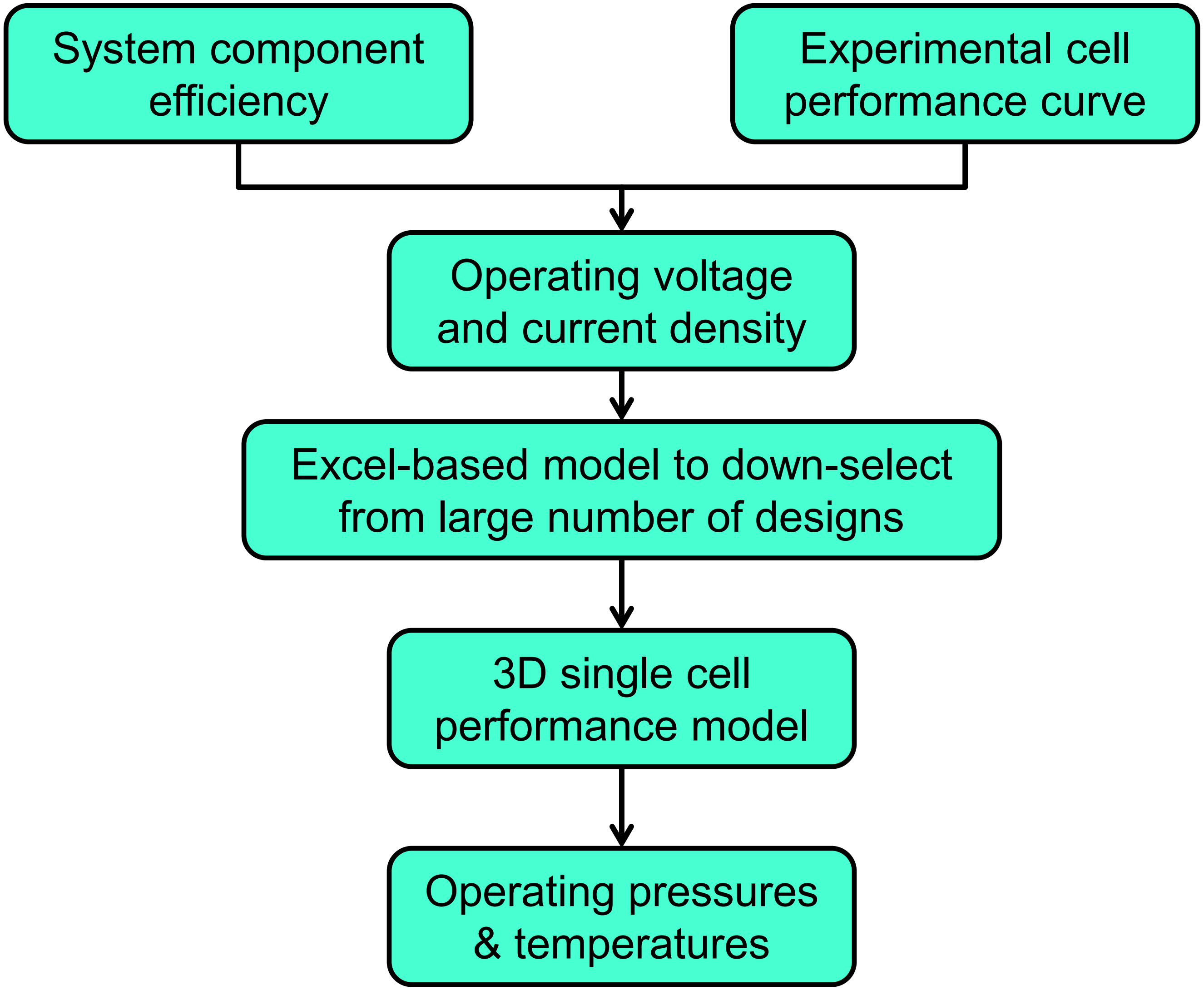
Anode exhaust used to supply heat to reformer

Overall system electrical efficiency of 40%

Higher efficiencies can be traded for cost by adding additional cells

TECHNICAL ACCOMPLISHMENTS

CSA Feasibility Analysis Strategy



System component efficiency

Experimental cell performance curve

Operating voltage and current density

Excel-based model to down-select from large number of designs

3D single cell performance model

Operating pressures & temperatures

TECHNICAL ACCOMPLISHMENTS

CSA 3D Performance Model

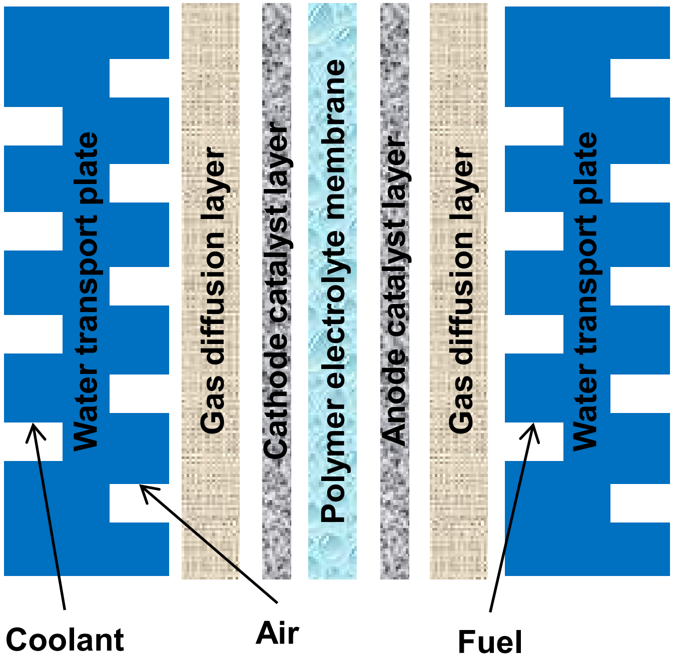
Fuel cell modeled as an assembly of different layers

Gas phase transport in each layer modeled via diffusion with porous media effects incorporated if required

Heat transport via conduction, convection and diffusion incorporated

Darcy's law used to model water transport in different layers

Hydrogen oxidation reaction and oxygen reduction reaction captured via Butler-Volmer kinetics



Schematic of through-plane Unitized Electrode Assembly (UEA) configuration used in 3D performance model

TECHNICAL ACCOMPLISHMENTS

Concepts Analyzed

Concept	Description
Concept 1	Ambient operation with steam generation outside CSA
Concept 2	Ambient operation with steam generation within CSA
Concept 3	Pressurized operation with steam generation within CSA

TECHNICAL ACCOMPLISHMENTS

CSA Analysis — Summary & Challenges

Concept	Avg cell temp (°C)	Hot spot temp (°C)	Cathode				Anode			
			Inlet		Exit		Inlet		Exit	
			Temp (°C)	Press (kPag)	Temp (°C)	Press (kPag)	Temp (°C)	Press (kPag)	Temp (°C)	Press (kPag)
Concept 1	75.9	84.1	37.0	13.3	68.2	0.0	71.0	7.3	60.7	0.0
Concept 2	78.1	82.6	37.0	13.3	79.3	0.0	71.0	7.3	77.4	0.0
Concept 3	83.7	88.9	37.0	56.3	78.8	50.0	71.0	52.3	76.9	50.0

Concept	Flow rate per cooler (g/s)	Product water per cooler (g/s)	Coolant			
			Inlet		Exit	
			Temp (°C)	Press (kPag)	Temp (°C)	Press (kPag)
Concept 1	1.9	3.71e-3	47.0	-12.0	82.0	-6.5
Concept 2	0.7	-5.49e-2	67.0	-54.0	80.0	-48.5
Concept 3	0.9	-9.45e-3	47.0	-41.2	86.0	-35.7

>80°C ok for use with vapor recompression

Needs to be at least 100°C to be favorable

TECHNICAL ACCOMPLISHMENTS

CSA Analysis — Summary & Challenges

Higher operating temperatures can assist with steam production

Standard flow configuration limits cell temperature below 90ºC even under pressurized conditions

Gas and coolant flow configuration can be altered to increase operating temperature

Difficult to generate steam within the CSA without High Temperature Membranes (HTMs)

Steam generation within CSA poses several risks —

- Gas ingestion in water transport plate
- Steam pockets in flow field leading to coolant flow maldistribution

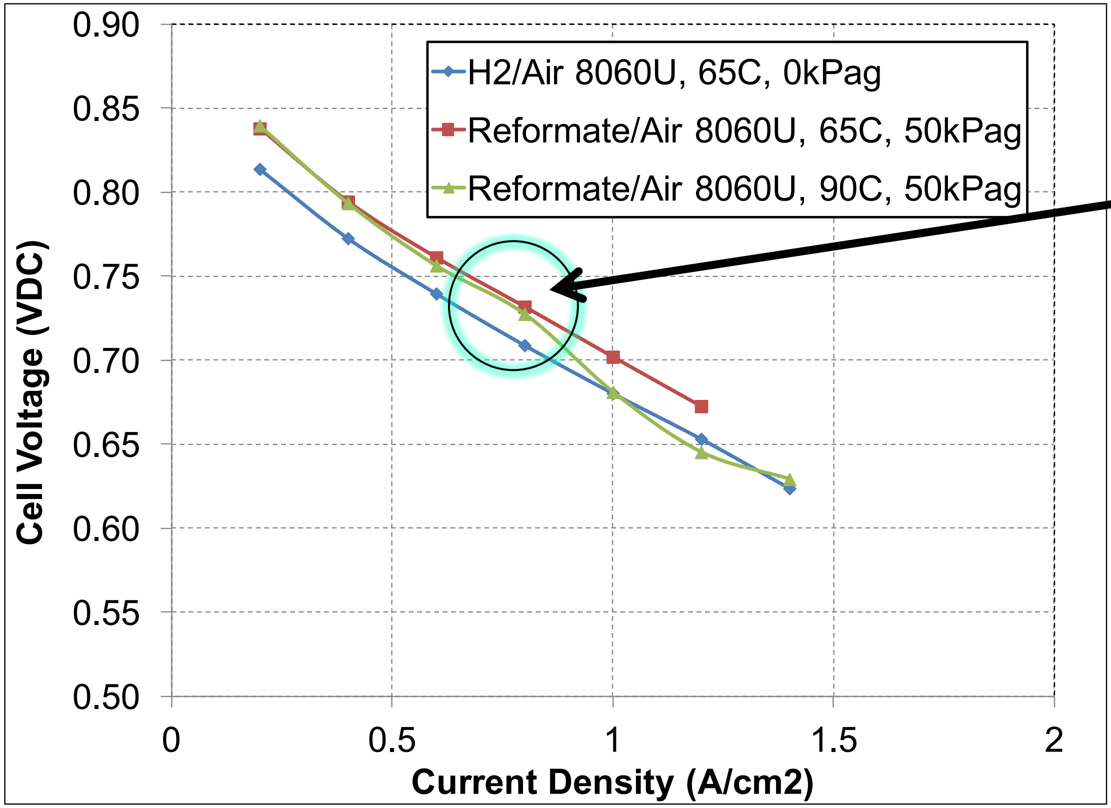
TECHNICAL ACCOMPLISHMENTS

BOL Performance Curve

BOL H_2/Air performance used as baseline

Performance with reformate higher due to increased pressure

90ºC performance similar to 65ºC



Similar performance at both temperatures at operating point

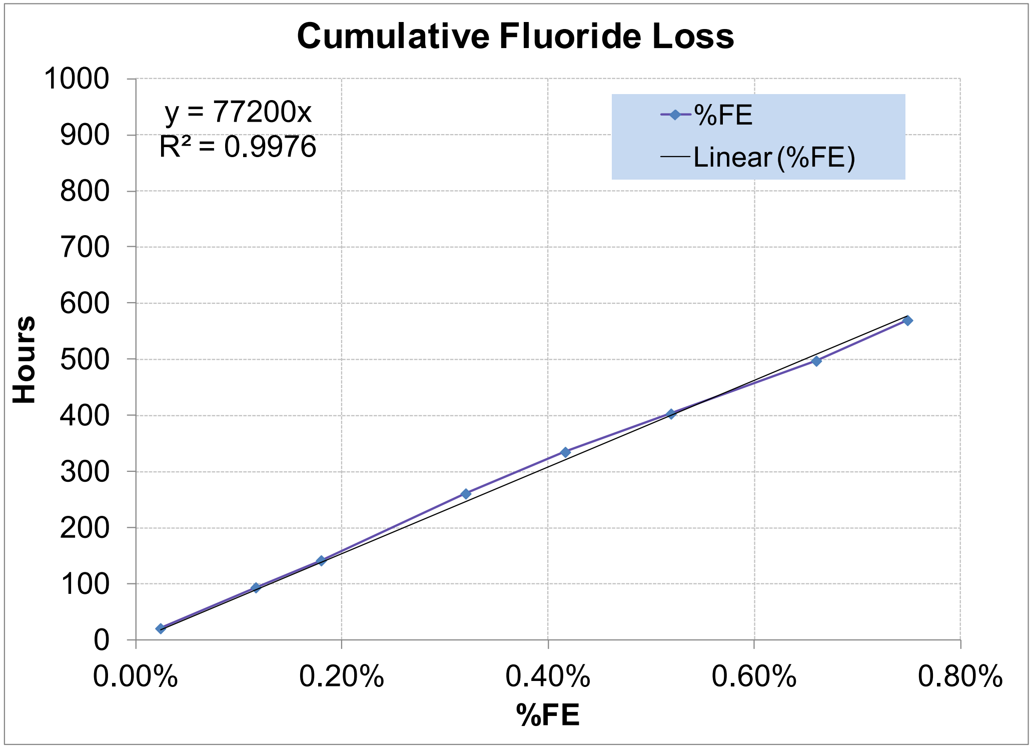
TECHNICAL ACCOMPLISHMENTS

Membrane Lifetime Projection

Fluoride emissions measured in reactant condensates & coolant

Membrane lifetime projected assuming 30% total thickness loss at failure and an 18 micron 1100 EW membrane

Estimated life ~23khrs


Cumulative Fluoride Loss

Projected life for next generation membranes range between 44 khrs to 220 khrs at similar operating temperatures

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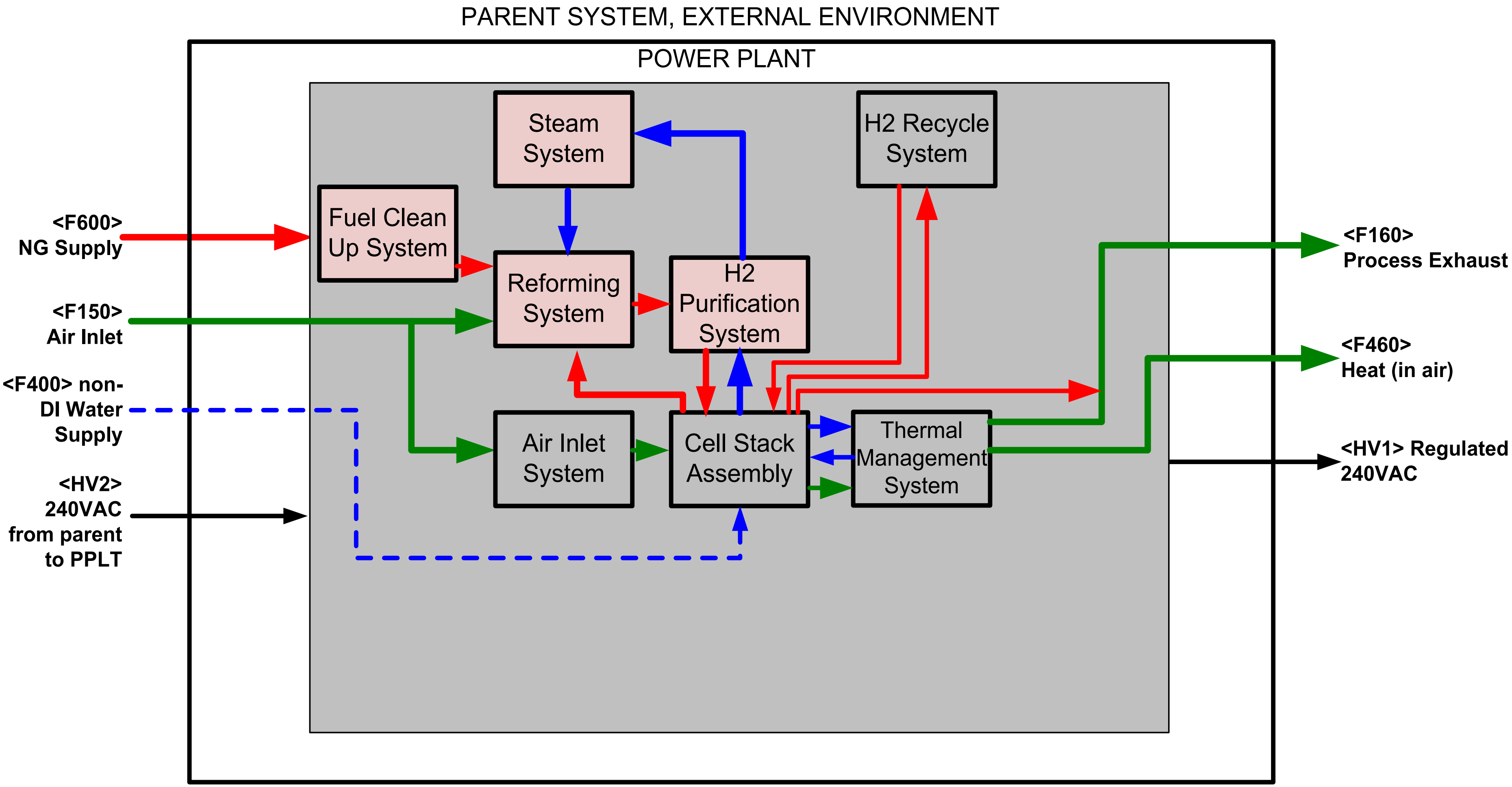
TECHNICAL ACCOMPLISHMENTS

Systems Schematic



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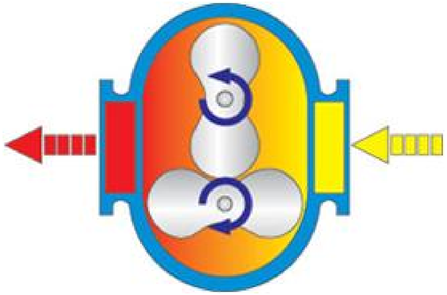
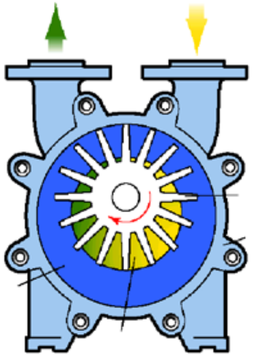
TECHNICAL ACCOMPLISHMENTS

Steam Compressors



Rotary lobe blowers

Capable of meeting flow and head requirements
Efficiency is good but not the best at our conditions
Not tolerant of liquid



Liquid ring compressors :

Minimal heat gain from compression due to heat transfer with liquid ring
Condensation is easily accommodated
Very low efficiency
Requires ancillary systems to manage water

Twin screw compressors

Superior efficiency at proposed operating conditions
History of application in steam compression
Readily available in **commercial product form**
Not tolerant of liquid

TECHNICAL ACCOMPLISHMENTS

Systems Analysis Strategy

Heat and mass balance confirmed using fundamental system equations

Pressures determined at all key system locations

CSA performance curve obtained consistent with the assumed conditions

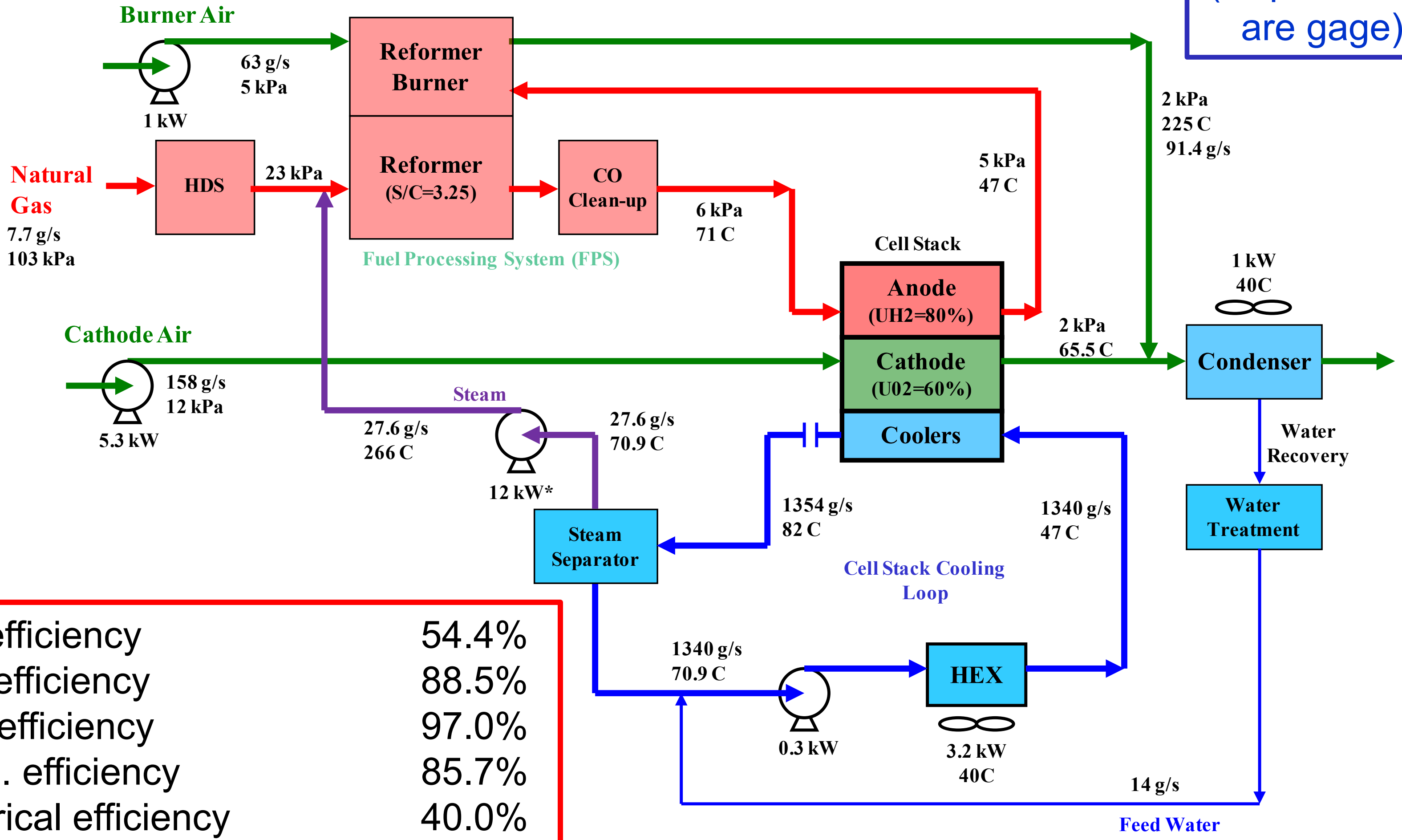
Parasite power audit conducted (to calculate mechanical efficiency)

Relative CSA area calculated consistent with the baseline 40% efficiency assumption

TECHNICAL ACCOMPLISHMENTS

Preliminary Baseline Configuration

(all pressures are gage)



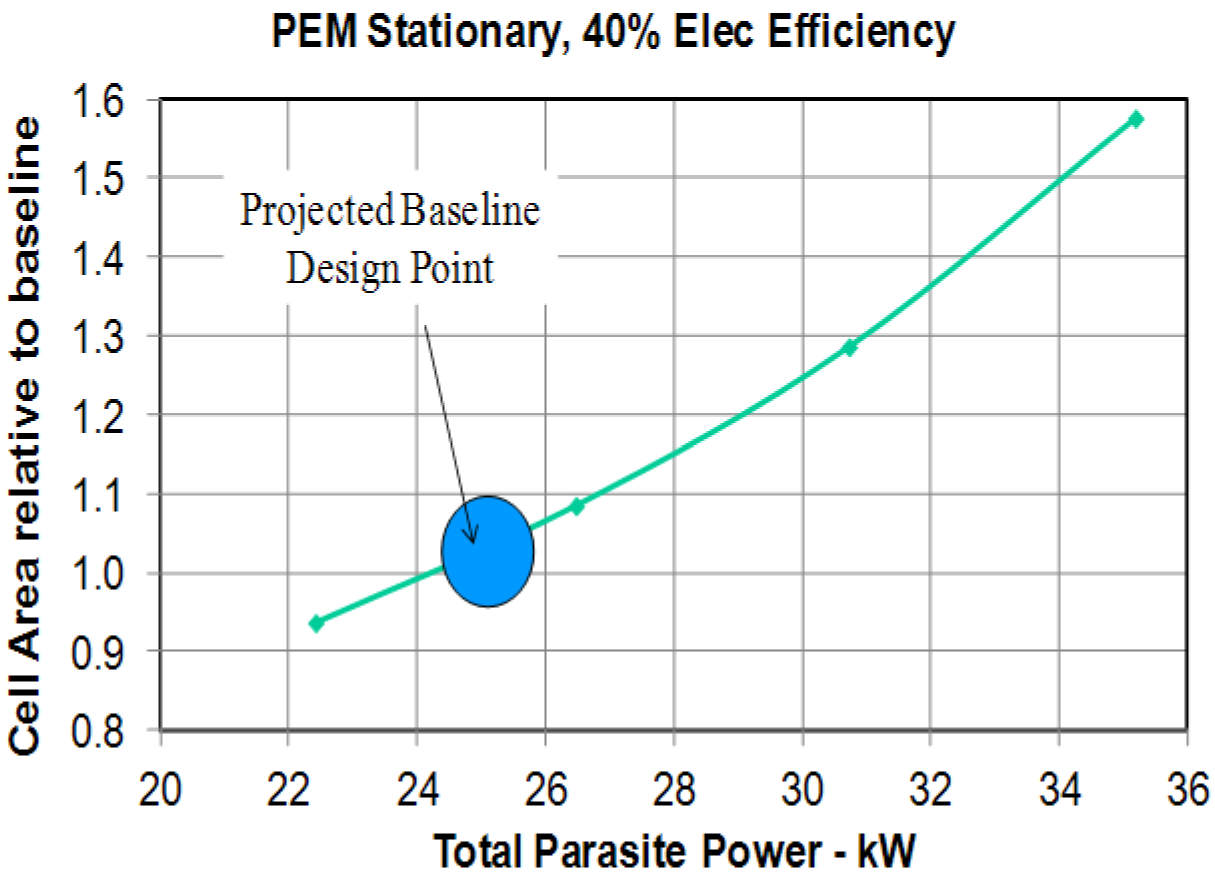
Cell efficiency	54.4%
FPS efficiency	88.5%
PCS efficiency	97.0%
Mech. efficiency	85.7%
Electrical efficiency	40.0%
Gross kW	180
Parasite power (kW)	25.0

Impact of S/C =2.75

+0.8 points OR 10% decrease in cells

TECHNICAL ACCOMPLISHMENTS

Impact of Parasitic Power



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FUTURE WORK

Advanced Fuel Processing System

Remove sulphur to <10 ppb

Pt group metals to generate ammonia free H2 rich stream

Reduce CO to < 10 ppm to meet PEM requirements

Methanator design to achieve CO < 10 ppm

Improved Reformer design —

- ✓ Improved heat transfer
- ✓ Improved kinetics
- ✓ Lower transport limitations

PROJECT SUMMARY

Relevance	Investigate feasibility and value proposition of a 150 kW high temperature stationary PEM fuel cell operating on natural gas reformate
Approach	Project durability and performance of stationary PEM fuel cell Complete system feasibility studies and mass-heat balance Design and demonstrate advanced fuel processing breadboard system capable of delivering H_2 rich low CO (<10 ppm) reactant stream to PEM stack
Technical accomplishments	Completed CSA and systems analysis to arrive at baseline power plant design Completed membrane durability testing to ensure that next generation membranes can meet durability requirements
Collaborations	None
Proposed future work	Design advanced fuel processing system with methanator to deliver H_2 rich low CO (< 10 ppm) stream to PEM stack Investigate durability of fuel cell components

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