Direct Coal Conversion in Liquid Tin Anode SOFC

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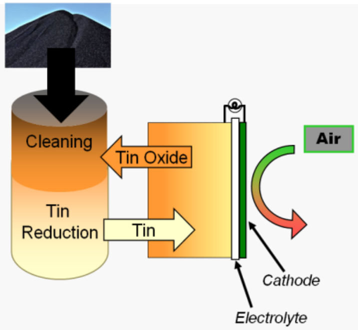
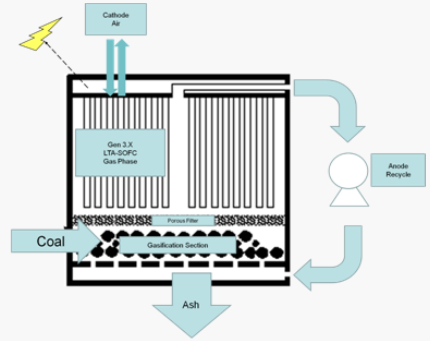
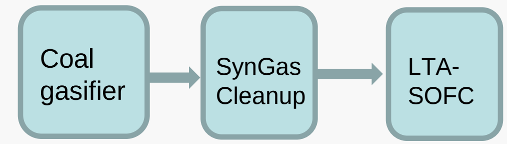
Concepts of Coal Conversion To Electricity in LTA-SOFC

Concepts of coal conversion in LTA-SOFC

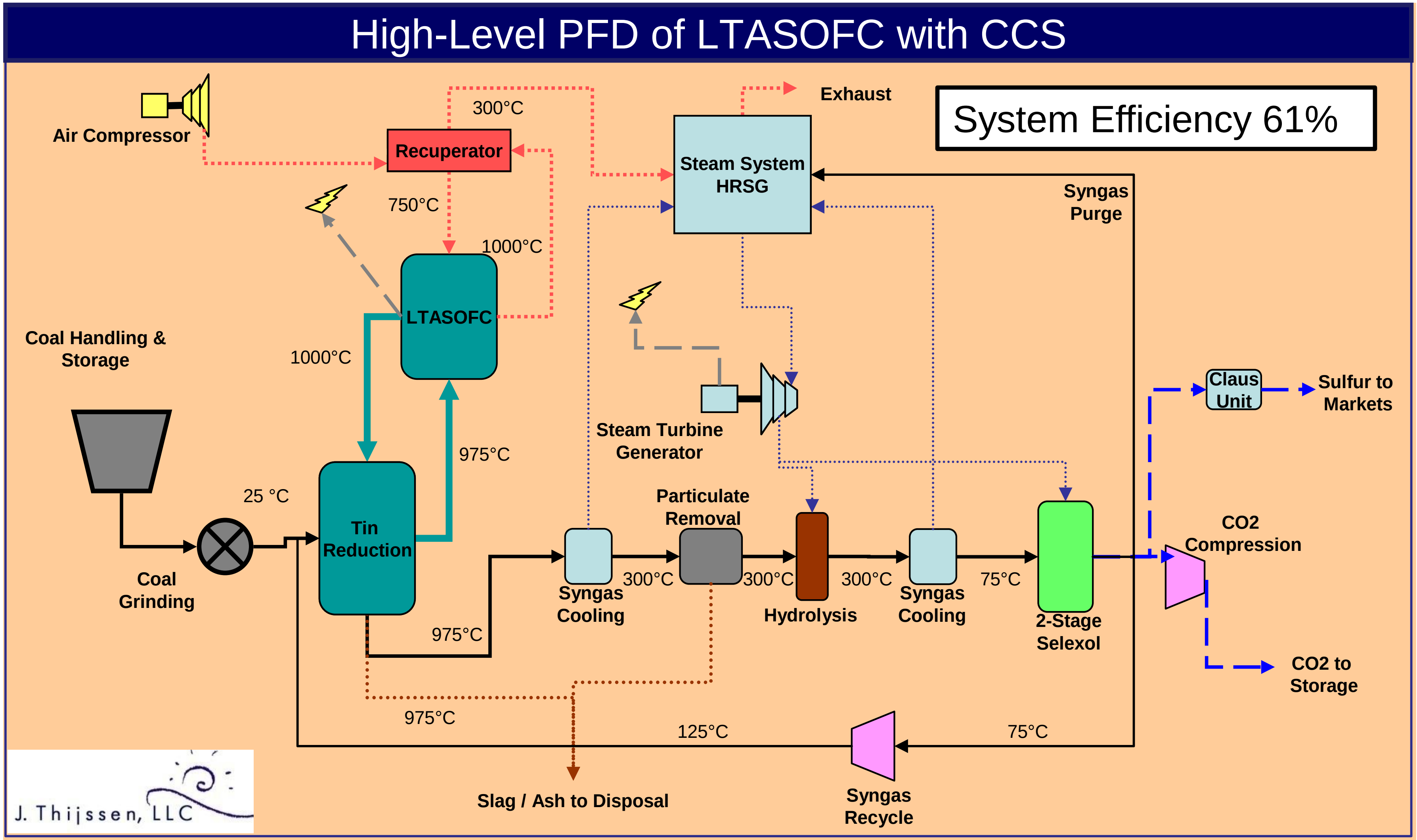






Feature	Tin/Coal Reactor (TCR) Concept	Insitu Gasifier Concept	Outside Gasifier Concept
Anode O_2 transport	Carried by circulating tin in form of SnO_x. High temp tin circulation required.	Diffuses through stationary tin layer.	Diffuses through stationary tin layer.
Fuel contact with anode	Direct contact – coal and contaminants are immersed in tin.	Indirect via gasified products. Coal and contaminants interact with tin surface.	Indirect via SynGas. Coal contaminants removed from SynGas.
Power range	1 MW and above based on scalability of Tin/Coal Reactor.	5 Watts and above based on size of individual cell.	5 Watts and above based on size of individual cell.
Solid waste (ash and slag)	Gravimetrically separated in tin reactor.	Solid waste products are separated from tin anode by porous layer, may be entrained in anode exhaust.	Solid waste separated in SynGas production from coal
Gas waste	Produced in TCR, easy to separate.	Produced at exterior of cell.	Produced at exterior of cell.
Current Collection	Conductive tin anode connects cells in parallel. Current break is required to avoid excessively high currents.	Cell anodes are electrically isolated. One anode current collector required for each cell.	Cell anodes are electrically isolated. One anode current collector required for each cell.
Cell Construction	Cathode electrolyte assembly.	Cathode electrolyte assembly with external tin layer held in place by porous element.	Cathode electrolyte assembly with external tin layer held in place by porous element.
Fuel Utilization	Solid fuel remains in liquid tin until completely consumed	Gasified coal mixes with exhaust gas, requiring more sophisticated separation tech.	Requires external gasification of coal. Lowest utilization and efficiency expected
Scalability	Tin Reactor design effective only above 1 MW.	Scalable from sub-kW to MW	Scalable fro sub-kW to MW

Direct coal conversion in LTA-SOFC: Tin Coal Reactor Concept



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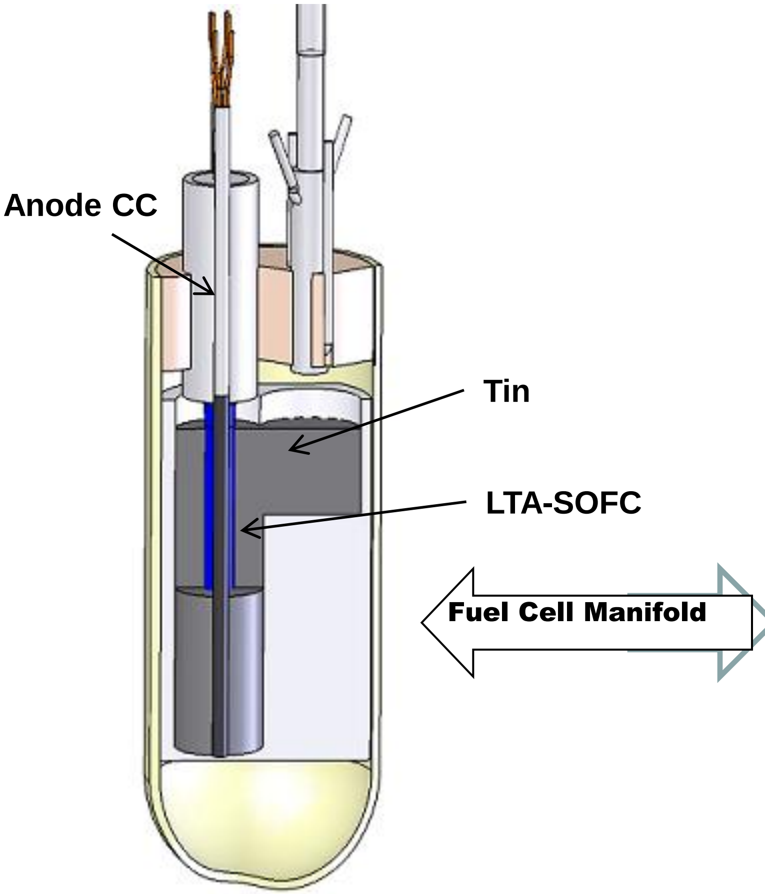
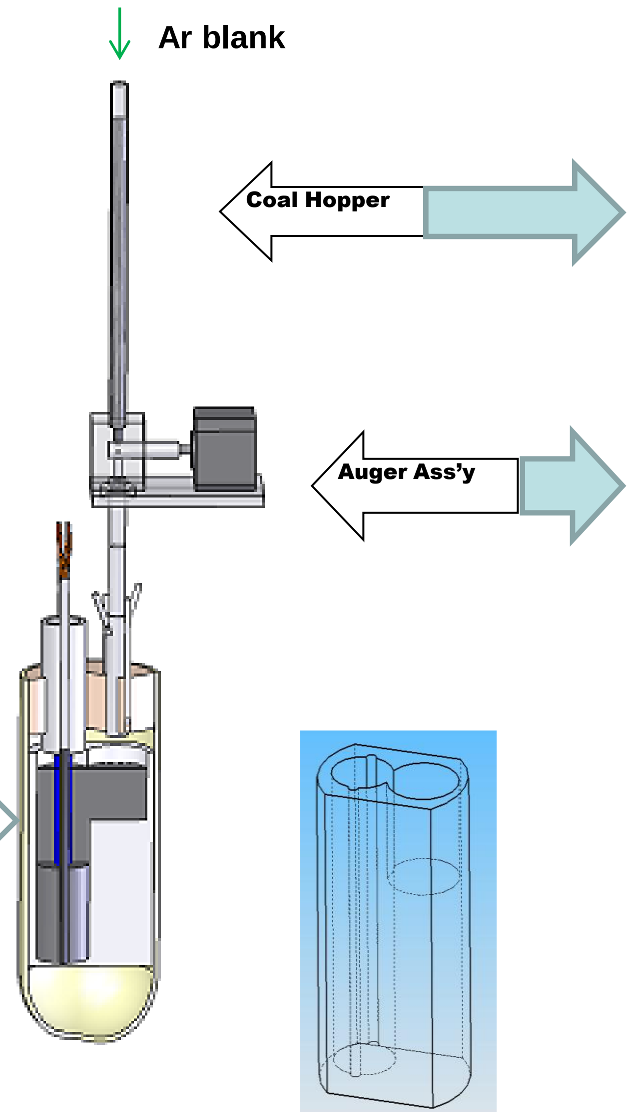
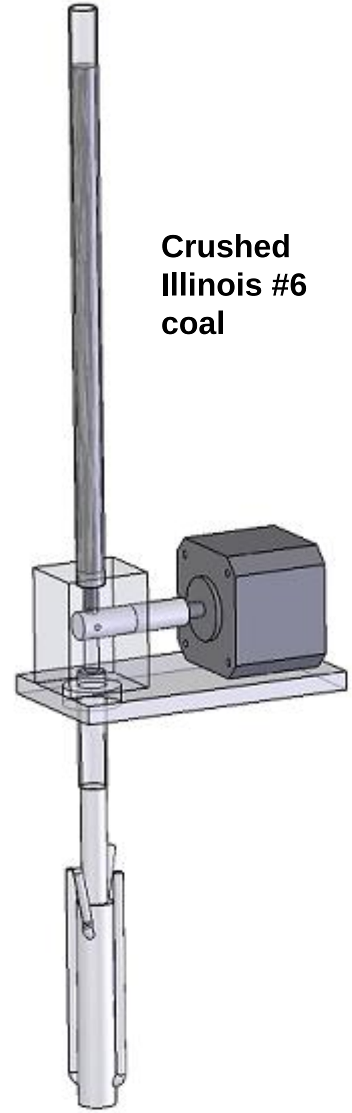
Direct coal conversion in LTA-SOFC: Tin Bath Experiment







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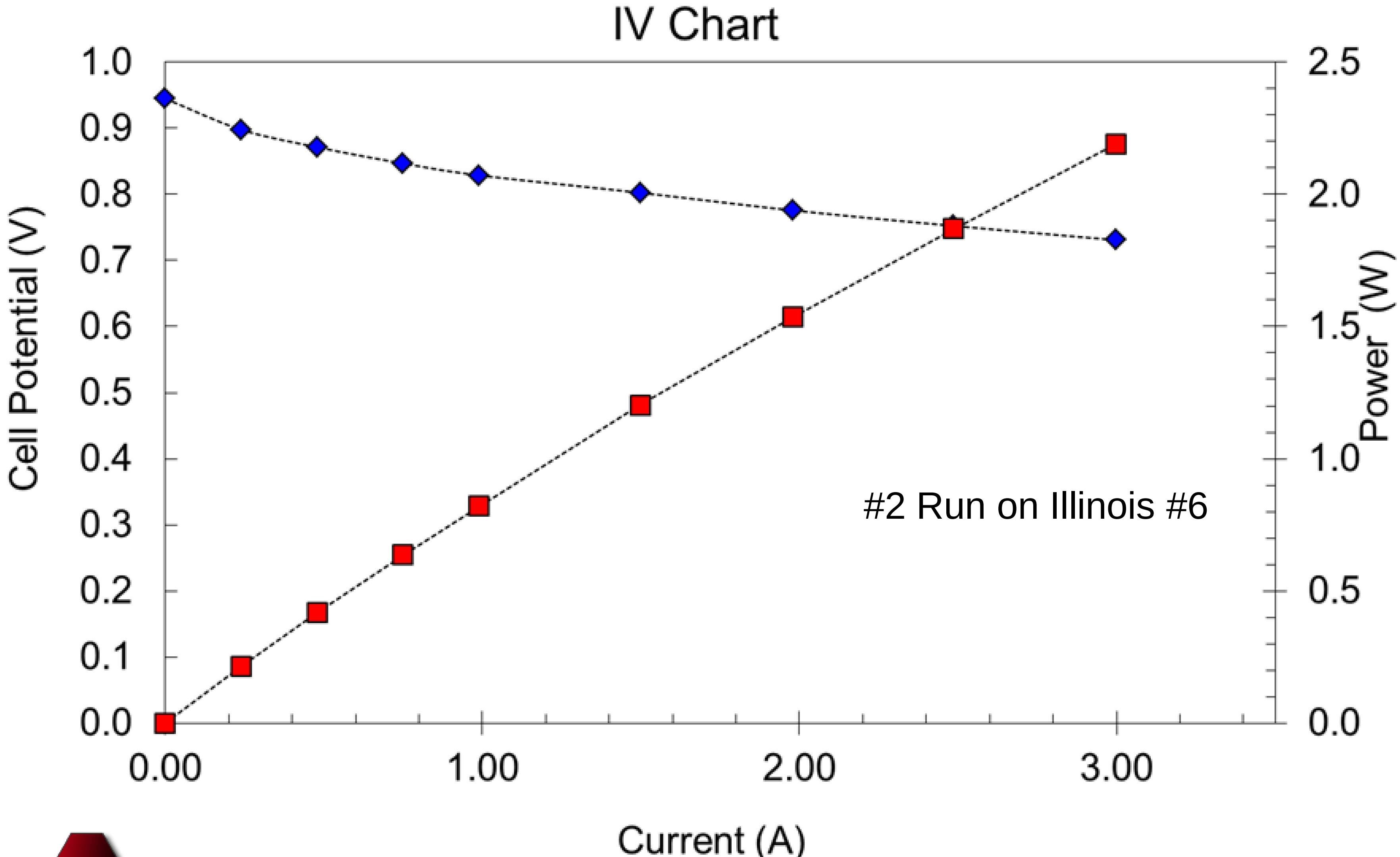
Direct Illinois #6 Coal Conversion in LTA-SOFC : Tin Bath

Experimental Procedure:

- Pre charge 200 grams of tin
- Heat cell under H2 gas to 450 degrees C
- Charge additional 300 grams of tin
- Heat cell under H2 gas to 1000 degrees C
- Shut off H2 and start feeding coal (no leak data obtained)
- Perform IV table (2.5 Amps max stable output)
- Load Cell and monitor ZLV

Average Power	**0.96**	**Watts**
Runtime at load	1400	Minutes
Total Coal Input (Illinois #6)	20.359	grams
Average Flow Rate	18.36	mg/min
LHV Illinois #6	28453	J/g

Direct Coal Conversion in LTA-SOFC



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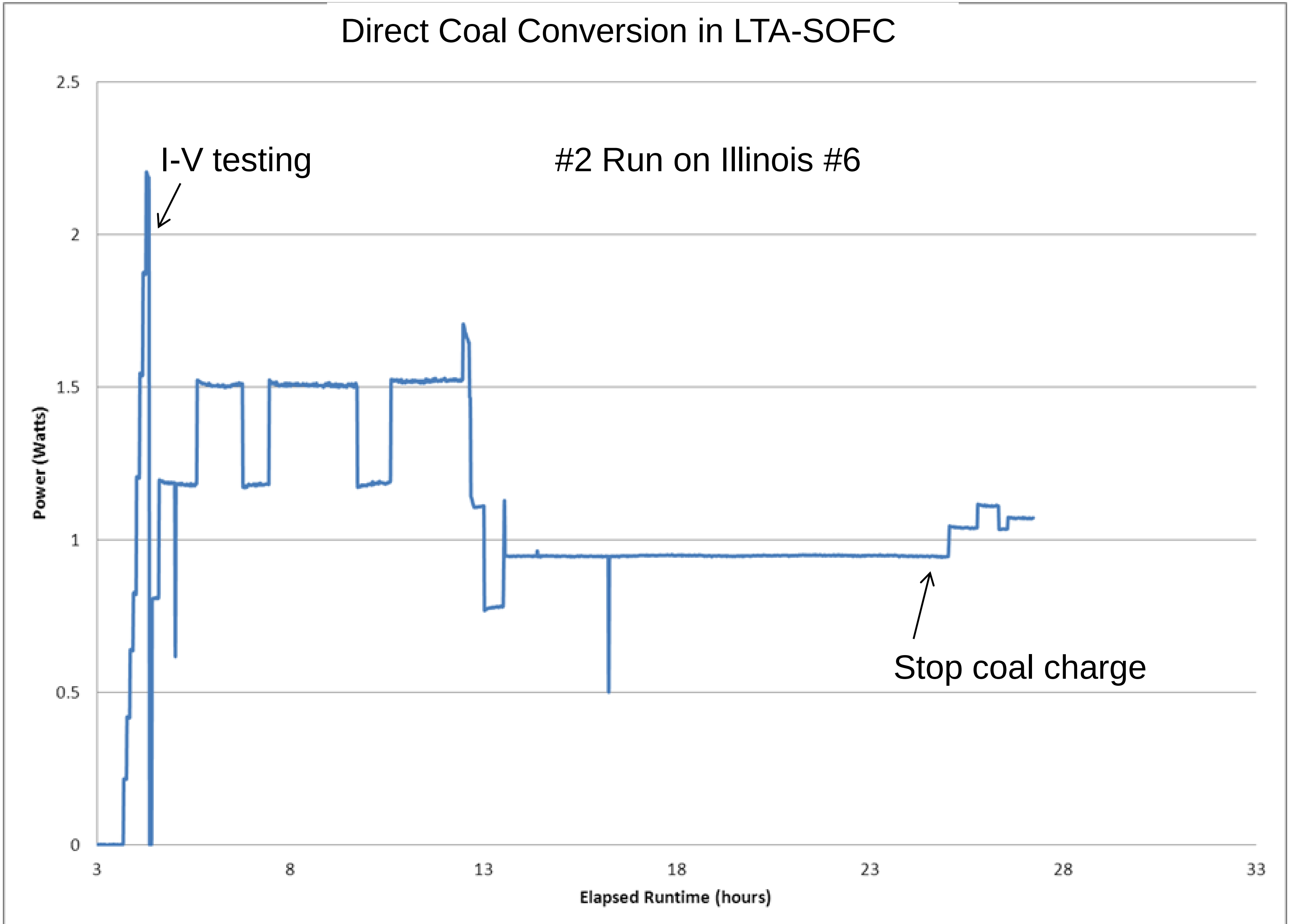
Direct Coal Conversion in LTA-SOFC
I-V testing
#2 Run on Illinois #6
Stop coal charge
Power (Watts)
2.5
2
1.5
1
0.5
0
3
8
13
18
23
28
33
Elapsed Runtime (hours)

Post mortem of direct coal testing:

Remaining ash from Illinois #6 coal

Element	Tin	Ash
	[ppm wt]	[ppm wt]
C	-	Matrix
Na	< 0.01	~ 0.14 wt%
Mg	< 0.01	840
Al	< 0.05	~ 1.9 wt%
Si	0.02	~ 7.3 wt%
P	< 0.01	240
S	-	-
Cl	-	-
K	< 0.01	~ 0.15 wt%
Ca	0.01	~ 0.27 wt%
Ti	< 0.005	~ 0.6 wt%
Cr	< 0.005	55
Mn	< 0.005	44
Fe	410	~ 2.5 wt%
Ni	0.75	230
Sr	< 0.005	170
Sn	Matrix	~ 0.6 wt%
In	-	Binder
Ba	< 0.05	-

GDMS analysis:
(1) 0.6wt% Sn in ash
(2) In tin only Fe, Ni and trace Ca, Si detected

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Coal reduction of tin oxide:

Ranking of soluble elements in molten tin based on their Gibbs free energy (Nernst Potential)

Only those elements in coal with Nernst Potential less than 0.9 V were found in consolidated tin

Element	S5 Concentration (ppm wt)	Oxide, valance at highest or stable	Nernst Potential @1,000C	Coulombic Energy CE
Ag	1.1	1	-0.24	0.16
Se	< 0.01	6	-0.2	2.57
Rh	< 0.005	3	0.06	0.81
As	8.8	5	0.34	1.96
Cu	29	1	0.39	0.23
Bi	13	3	0.4	0.52
Pb	150	2	0.49	0.3
Te	< 0.1	2	0.56	
Ni	2.9	2	0.65	0.52
Sb	400	3	0.66	0.71
Cd	< 0.05	2	0.67	0.38
Co	0.28	2	0.75	0.55
S	23	4	0.75	1.95
Sn	Matrix	4	0.82	1.04
Fe	51	3	0.85	0.98
Ge	< 0.01	4	0.87	1.36
In	58	3	0.89	0.67
W	< 0.01	6	0.9	1.8
Mo	< 0.01	4	0.93	1.11
P	< 0.01	5	0.93	2.37
K	< 0.01	1	1.01	0.13
Cr	< 0.005	4	1.07	1.31
V	< 0.001	5	1.07	1.67
Mn	< 0.005	3	1.09	0.93
Zn	< 0.01	2	1.1	0.49
Ga	< 0.005	3	1.16	0.87
Na	< 0.01	1	1.27	0.18
Nb	< 0.005	5	1.4	1.41
Ta	< 5	5	1.55	1.41
U	< 0.005	6	1.55	1.48
Si	< 0.01	4	1.77	1.8
Ti	< 0.005	4	1.85	1.18
Al	< 0.05	3	2.2	1
Zr	< 0.005	4	2.22	1
Li	< 0.005	1	2.23	0.24
Mg	< 0.01	2	2.39	0.47
Sr	< 0.005	2	2.4	0.31
Be	< 0.005	2	2.51	0.8
Ca	< 0.01	2	2.6	0.36
Sc	< 0.001	3	2.65	0.72
Y	< 0.005	3	2.66	[illegible]
Tl	0.04	3	<0.9	0.61

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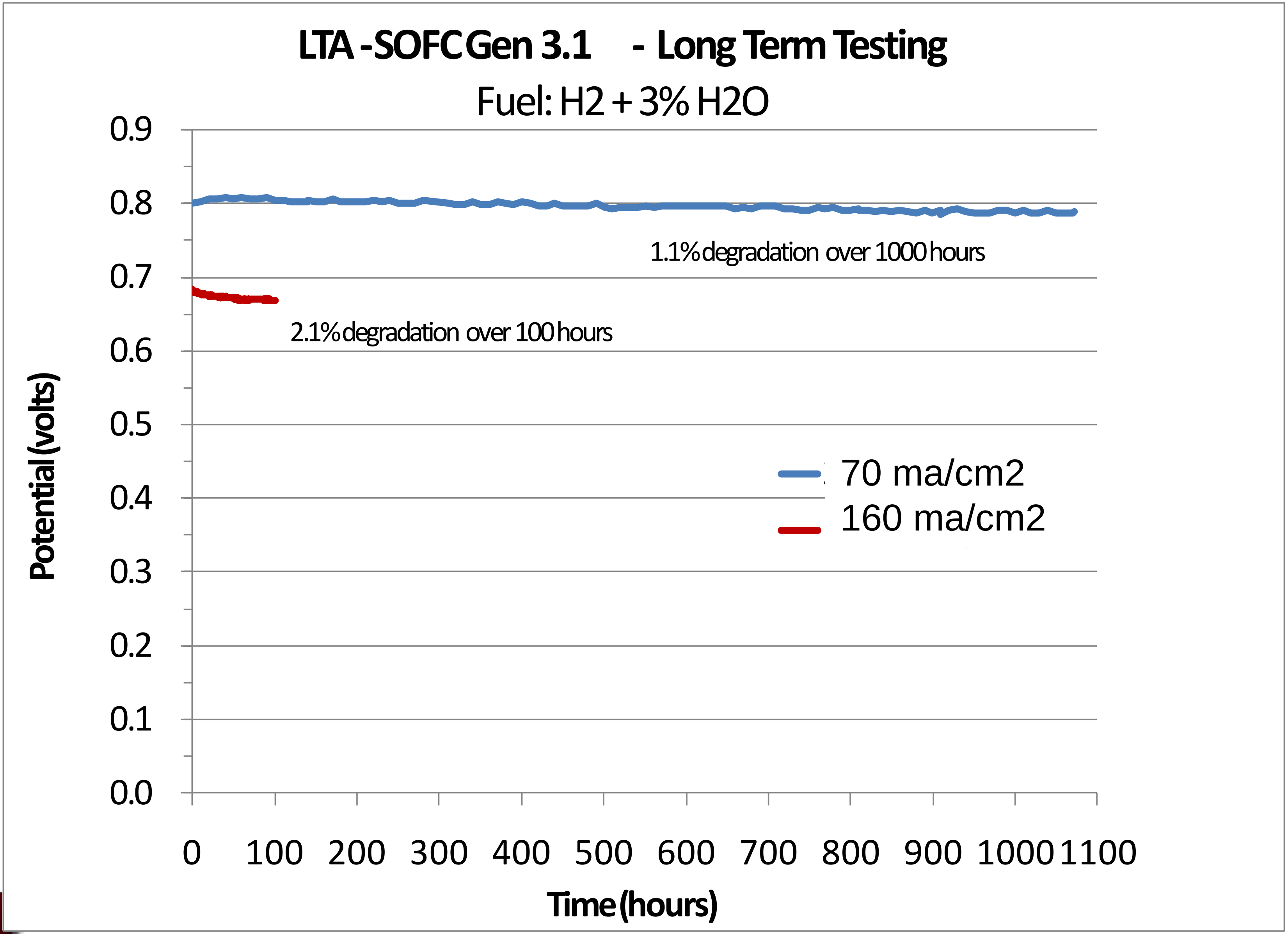
Matrix of Potential Coal Impurity Impact

Spiked element 4,000 ppm	Remaining contaminant level at OCV=1.1V ICP-OES (ppm)	100 hr electro-chemical testing @ 0.16 A/cm² (hrs)	100 hr electro-chemical testing @ 0.16 A/cm² (% degradation)
Pure tin		100	2
As	2535	47.6	29
V	10	65	10
Mo	9	65	30
Mn	2405	10	100
Cr	1098	23.5	100
U			
Nb	115	100	34
Se	45	100	3
Ta	8	100	5
W	60	100	8
I, Br	N/A		
Cl	N/A – 500	100	6.5
Si	5	22.8	13
S	8	70.7	6
P	203		



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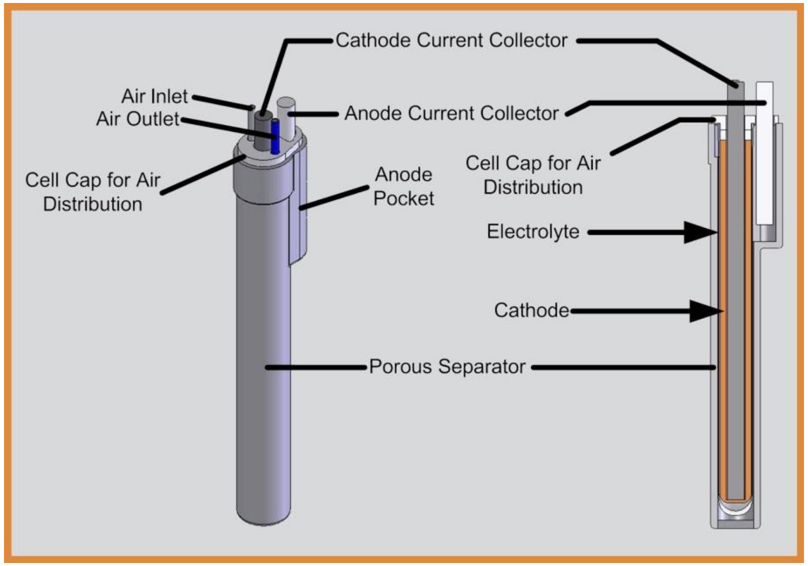
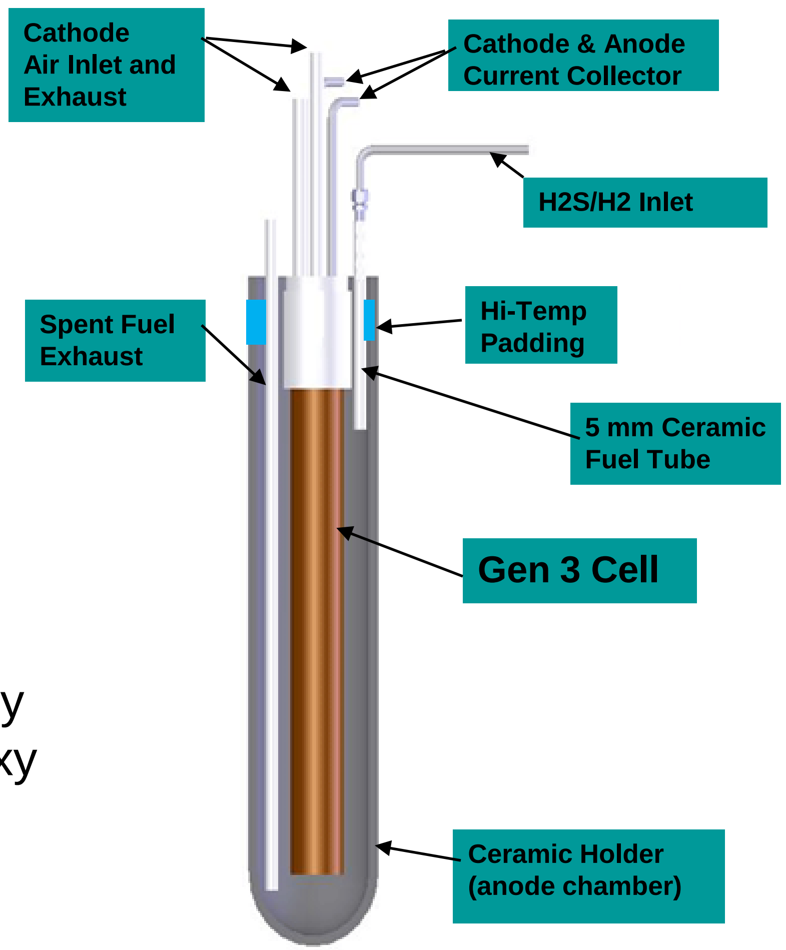
Sulfur Impact on LTA-SOFC





Gen 3.1 LTA-SOFC
#1 H2S 2,134 ppmv MaineOxy
#2 H2S 36,900ppmv MaineOxy

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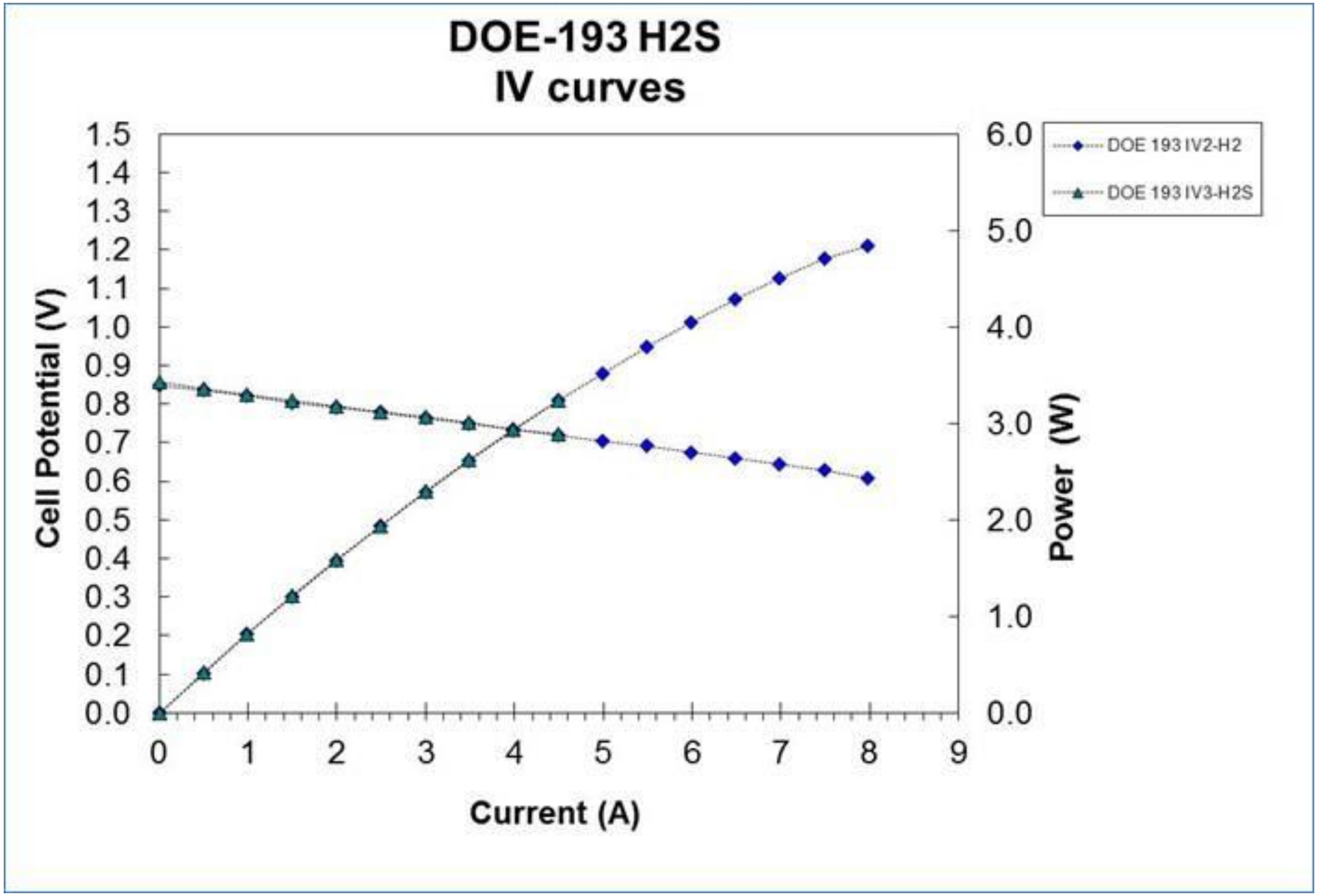
H2S/H2 as fuel in Gen 3 LTA-SOFC



H2S 2,134 ppmv (4.8wt%) as comparison with hydrogen

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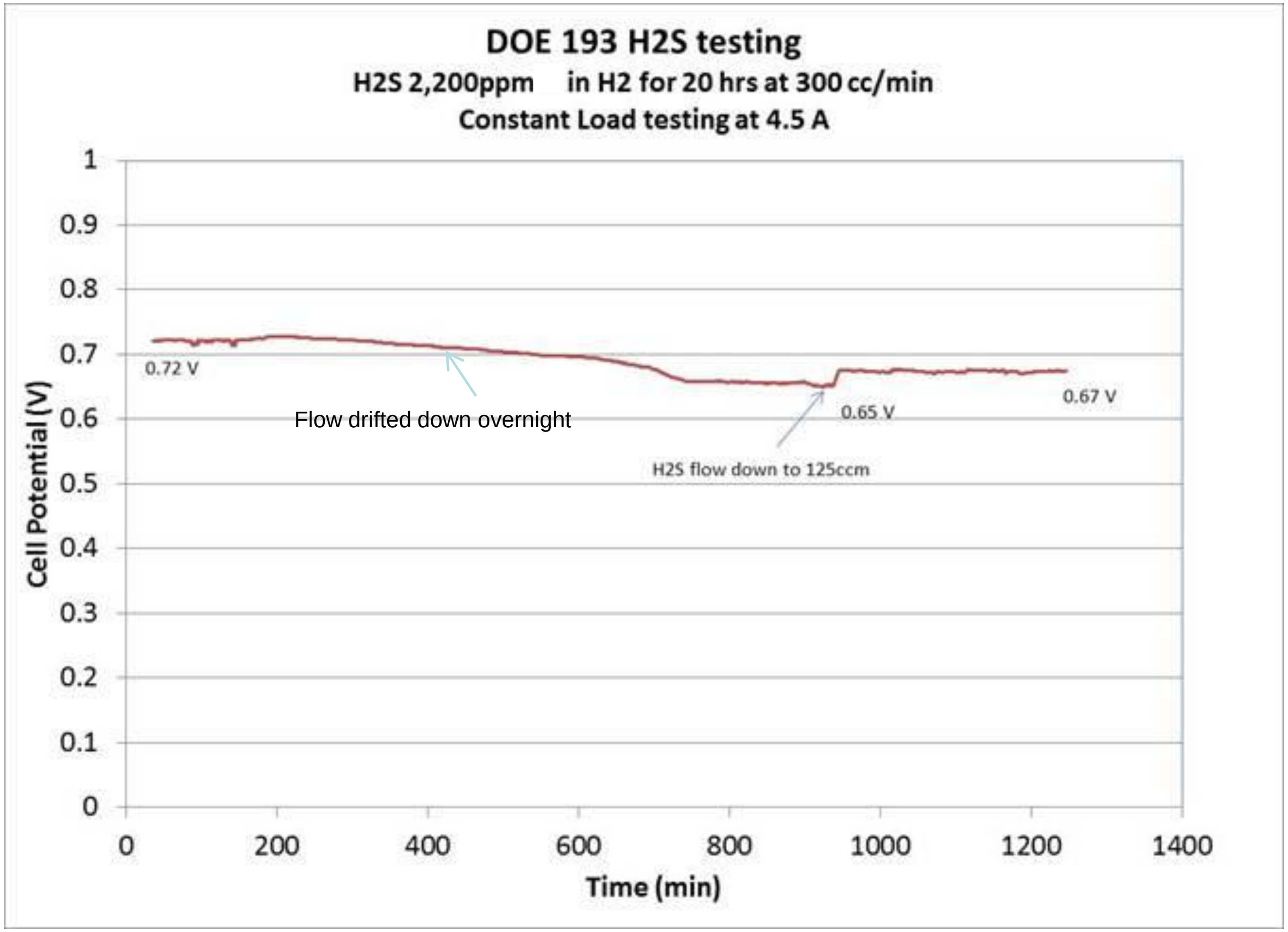
H2S (4.8wt%) in H2 as fuel in Gen 3 LTA-SOFC



Last 5 hours no degradation observed

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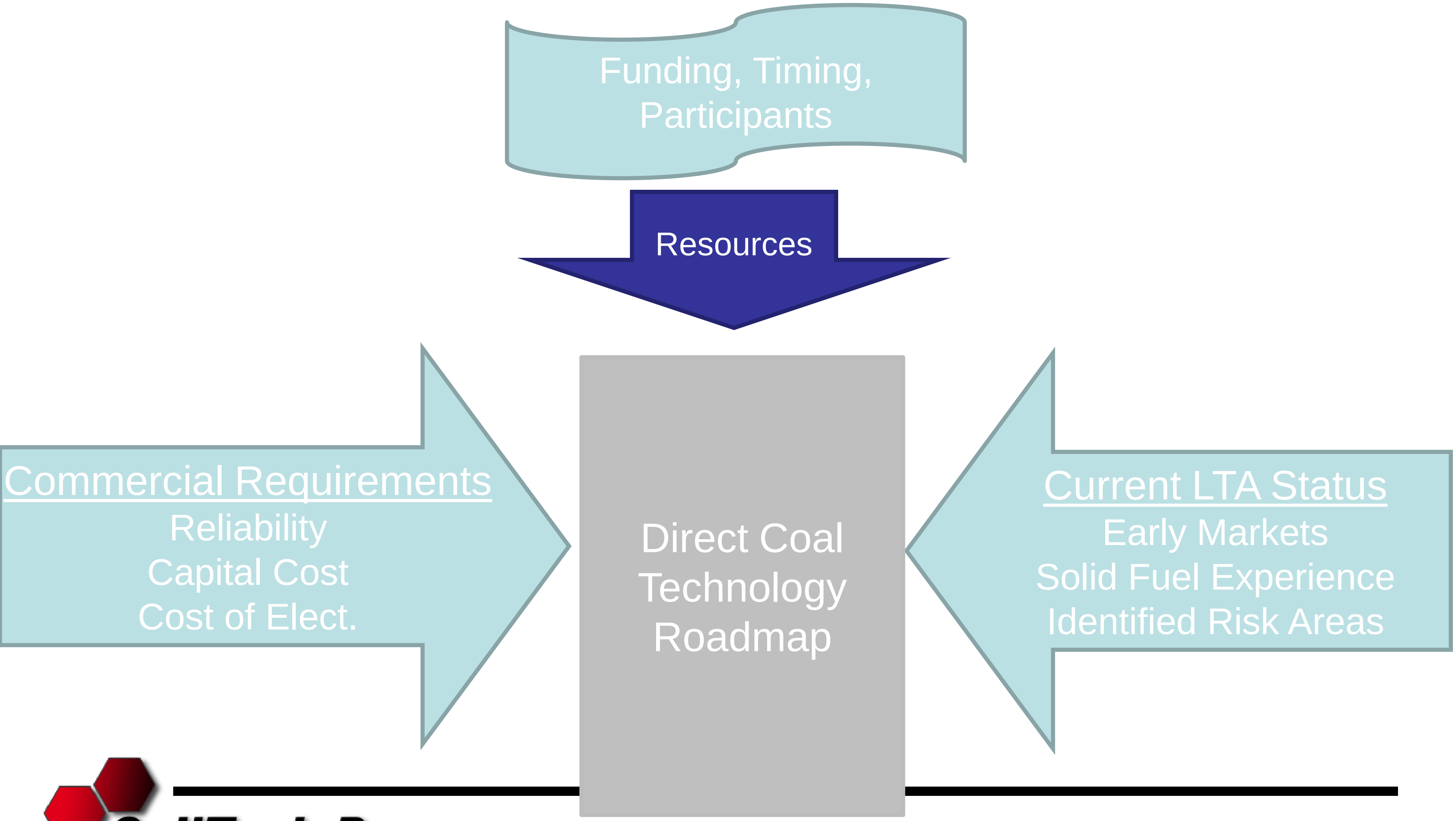
Key Issues And Future Programs



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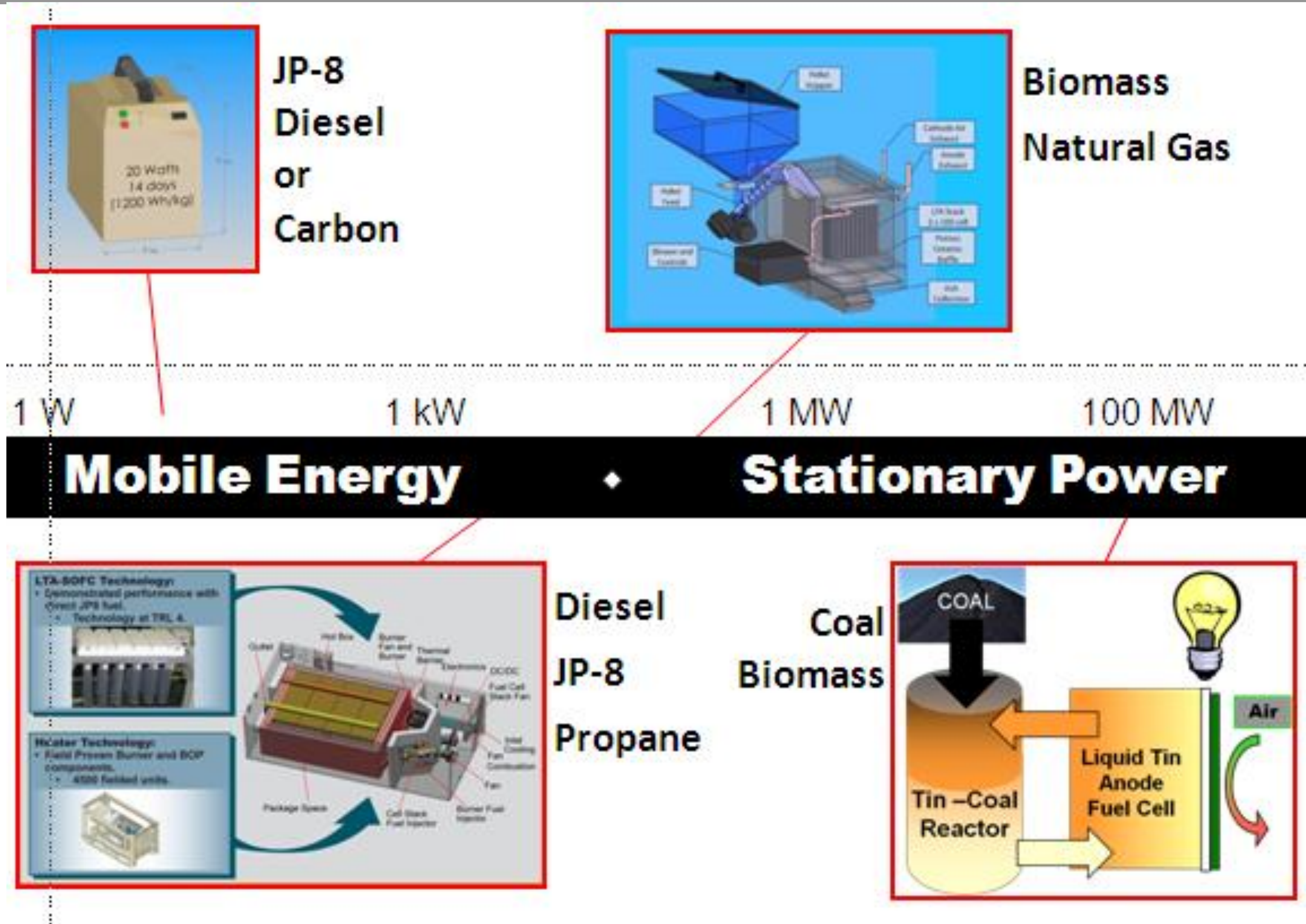
Solutions for Mobile and Stationary Markets



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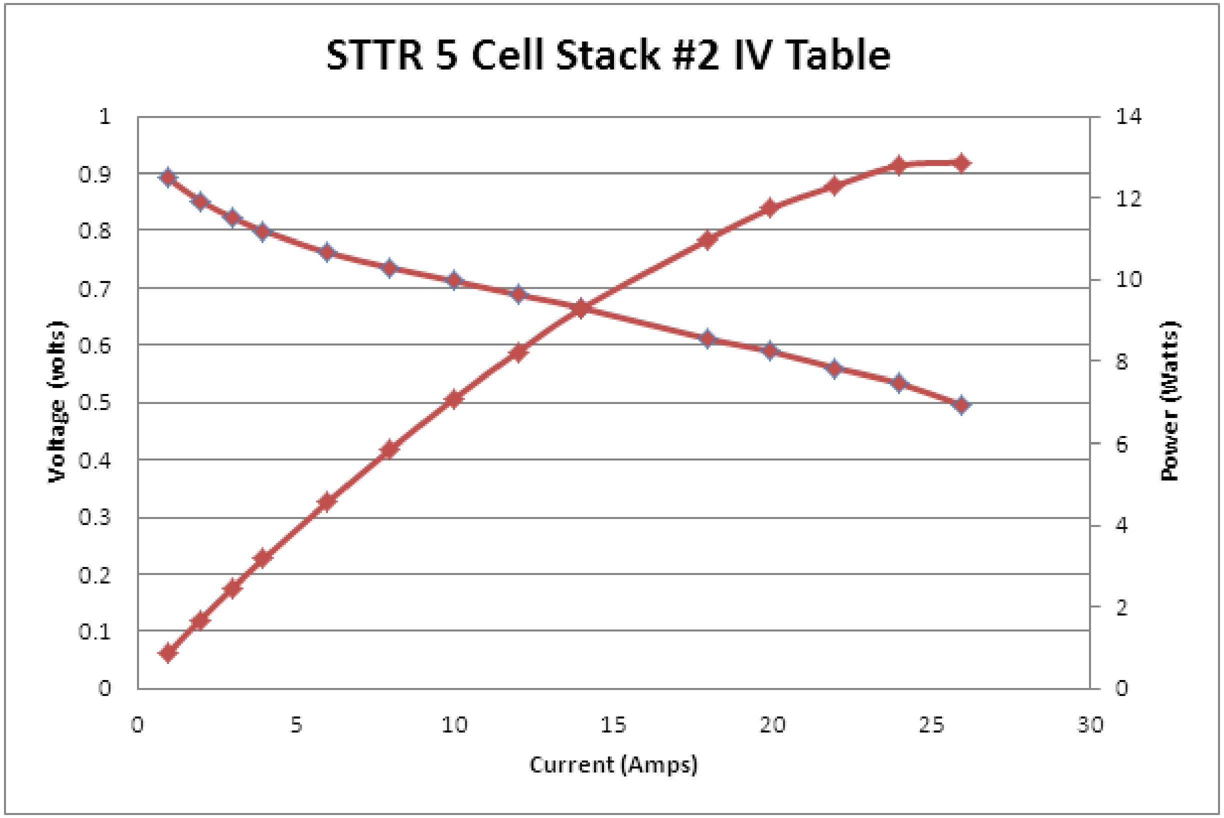
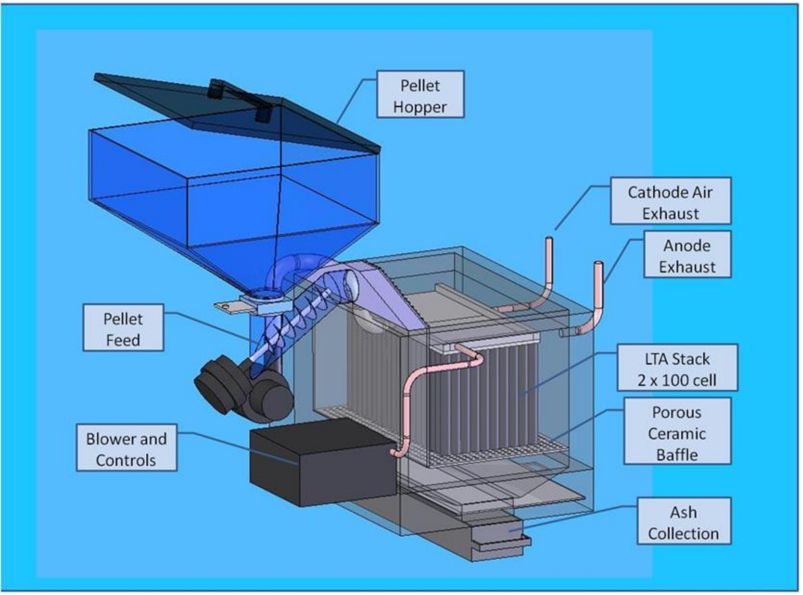
Direct JP-8 LTA-SOFC Stack Testing



Direct Biomass Conversion Using LTA-SOFC



Direct Wood Pellet Conversion

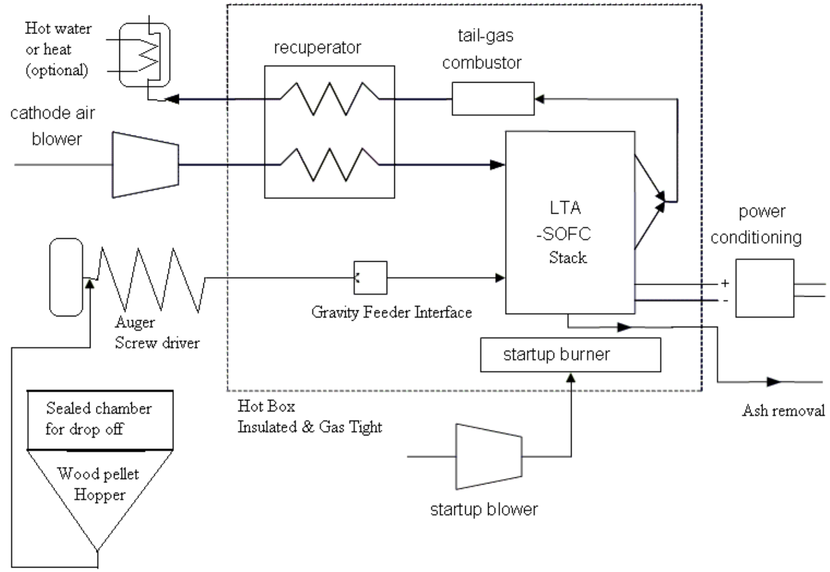
NSF SBIR: Direct biomass to electricity

Uses Gen 3.1 cell architecture

Factors effecting efficiency and performance

Applicable to recycle & waste-energy

Leads to kW and MW scale biomass systems



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