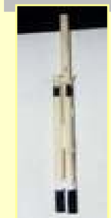
Novel Fuel Cells for Coal Based Systems

SECA
Pittsburg
July 27-29, 2010

Thomas Tao, presenter, CellTech Power

3 Generations of LTA-SOFC Development

1998 | 2000 | 2002 | 2004 | 2006 | 2008 | 2009 - 2010



First Coal

Gen 1: "Bubbling Anode"

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48 cell stack

30 Cell Stack

2 kW NG System

Gen 2: "Internal separator"

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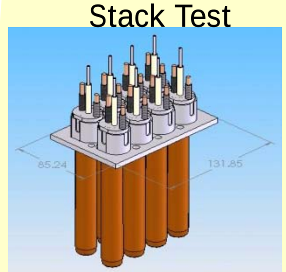
Gen 3.0: "Reverse Anode"

DARPA DSO

Direct Plastic Stack Test



Gen 3.1: Direct JP-8

DARPA DSO

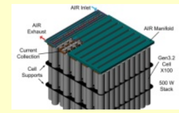
ARL

CERDEC

Gen 3.2 &: Stack

ONR

ARL



Direct coal & biomass

DOE, EPRI

NETL

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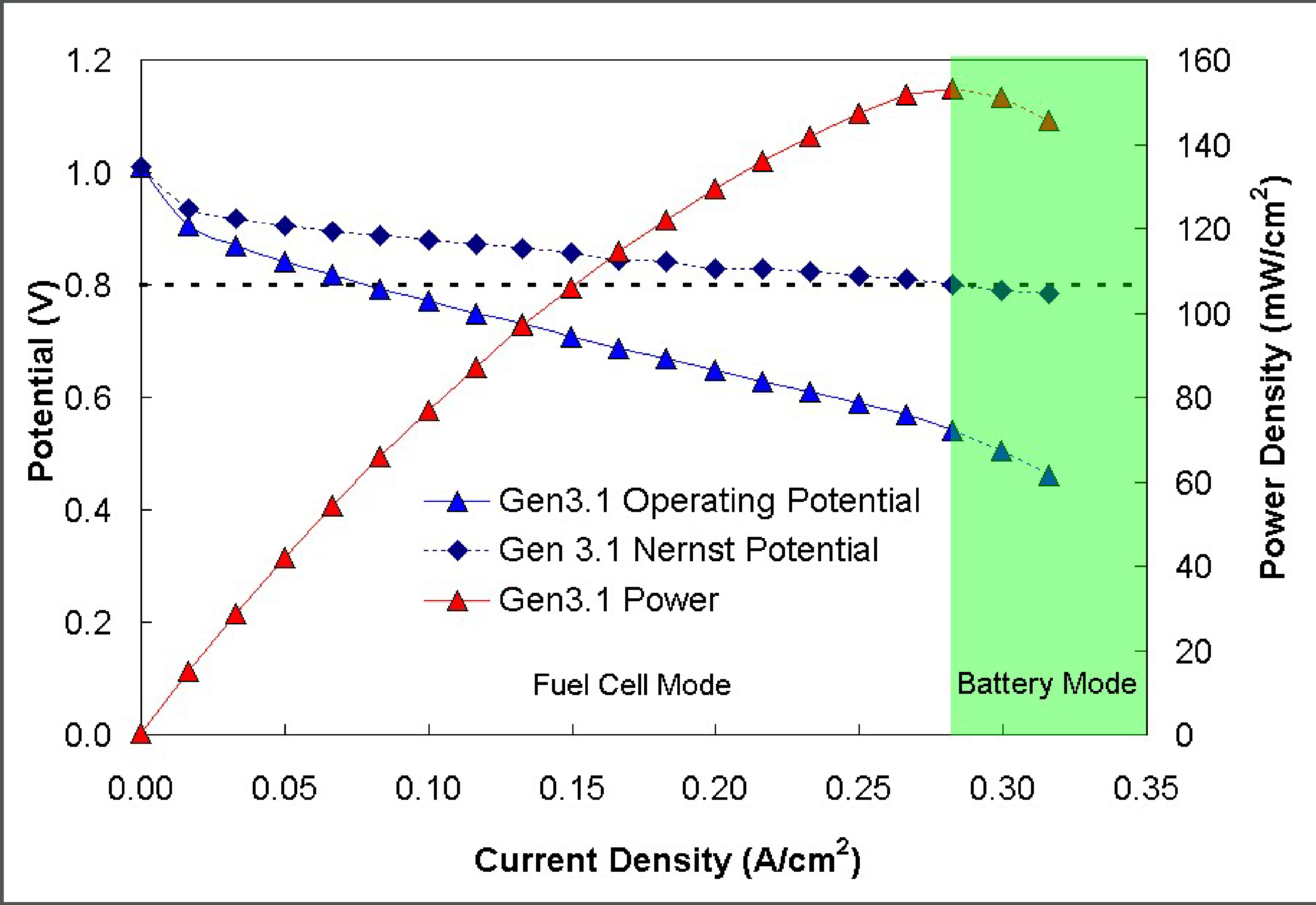
LTA-SOFC: Characteristics



Voltage Threshold 0.78V @1,000°C, Hydrogen, Gen 3.1 LTA-SOFC

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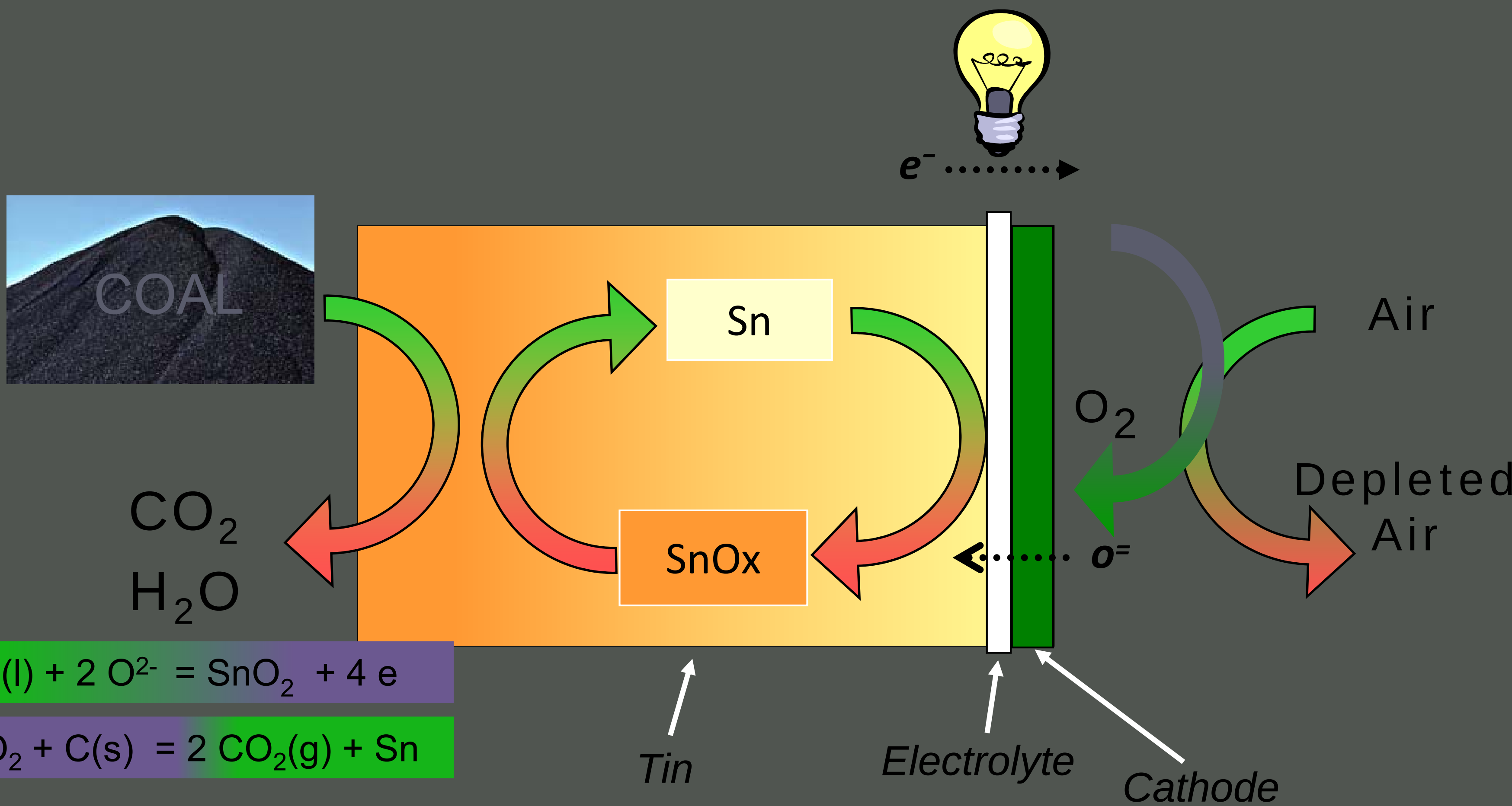
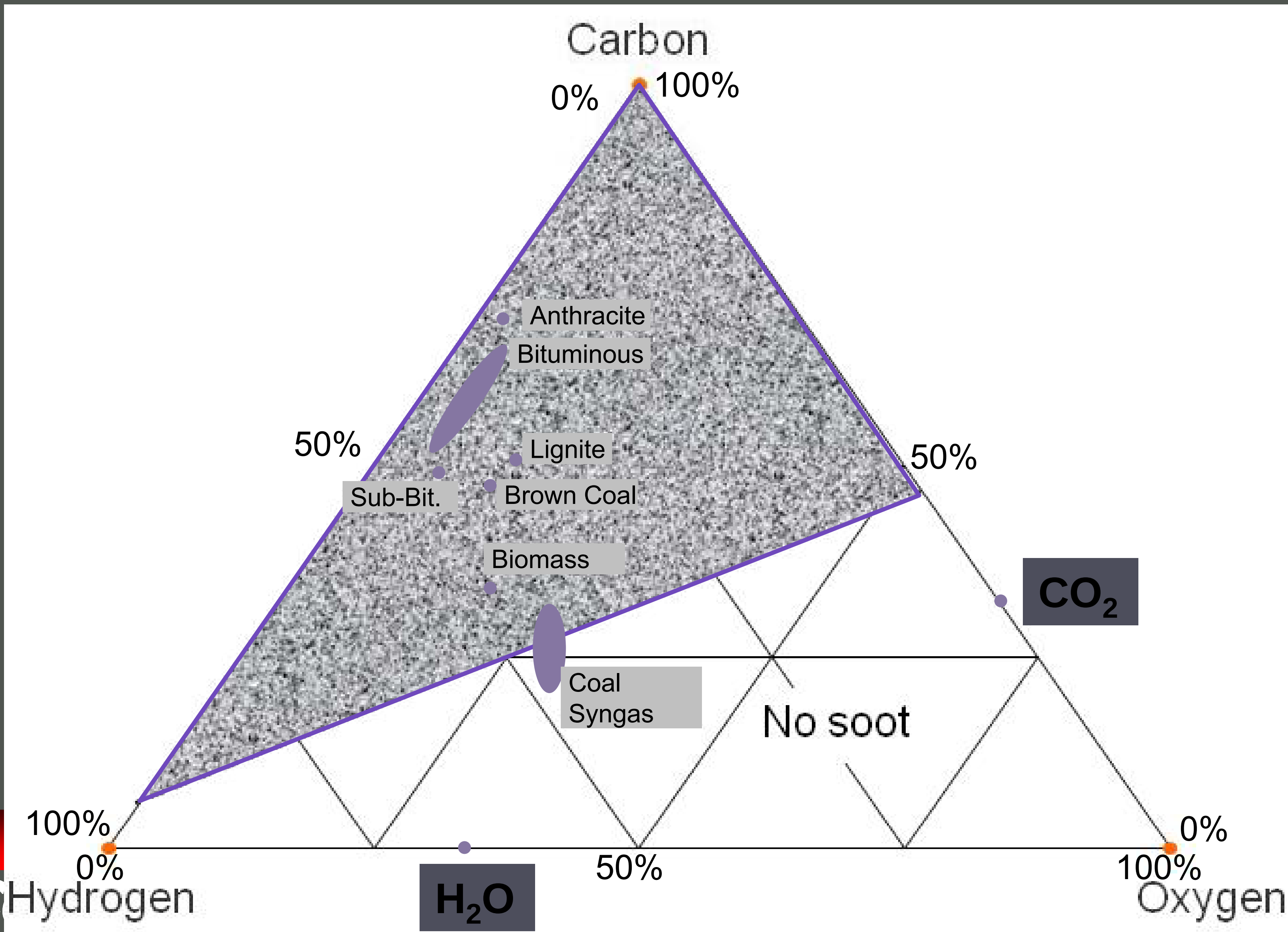
Direct Coal Power Using Liquid Tin Anode SOFC



$Sn(l) + 2\ O^{2-} = SnO_2 + 4\ e$

$SnO_2 + C(s) = 2\ CO_2(g) + Sn$

All Forms of Coal Will Make Soot – damage to Ni anode SOFC



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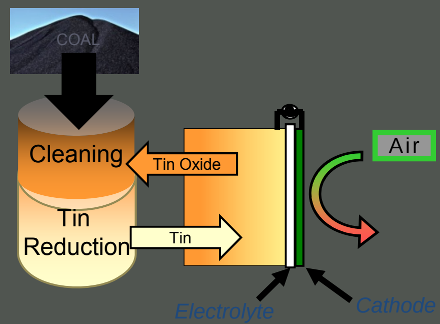
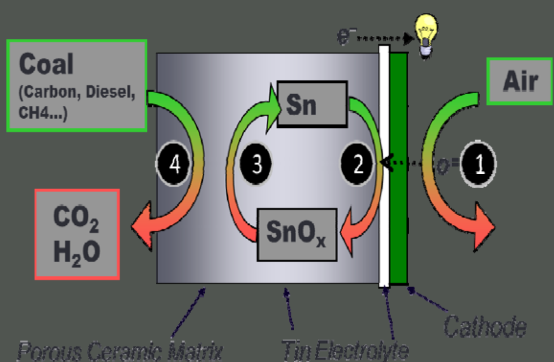
Liquid Tin Anode Fuel Cell Direct Coal – 3 Alternative Configurations

Electrochemical Looping

Based on Coal-Tin Reactor
DE-NT0004111, DE-ER85006

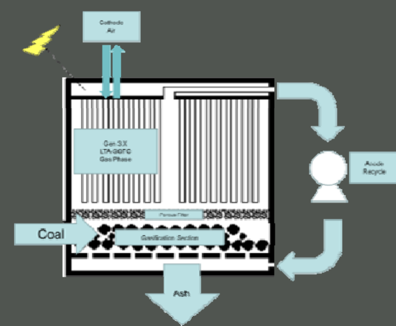


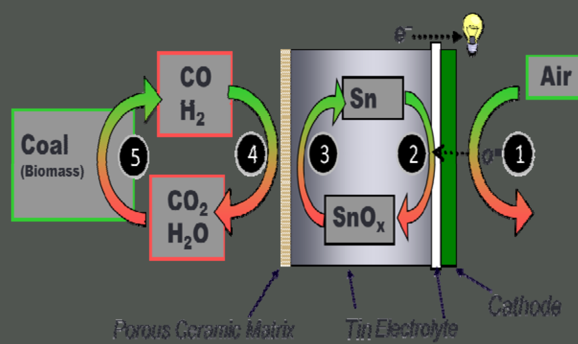


1. Oxygen ions extracted from air by cathode and cross the electrolyte
2. Ions react with tin, releasing electrons and forming tin oxide
3. Tin oxide is independently reduced back to tin by reaction with fuel
4. Fuel directly contacts tin

Insitu Gasifier

Based on Portable Power Cell
DE-ER95350S10

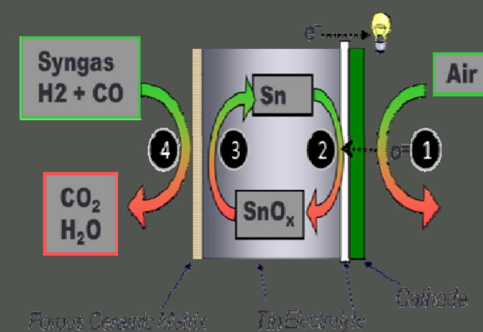




1. Oxygen ions extracted from air by cathode and cross the electrolyte
2. Ions react with tin, releasing electrons and forming tin oxide
3. Tin oxide is independently reduced back to tin by reaction with fuel
4. Tin-fuel interaction can occur inside tin or across a porous ceramic membrane
5. Coal or other solid fuel is gasified insitu by the cell reaction products

External Gasifier

Based on Portable Power Cell



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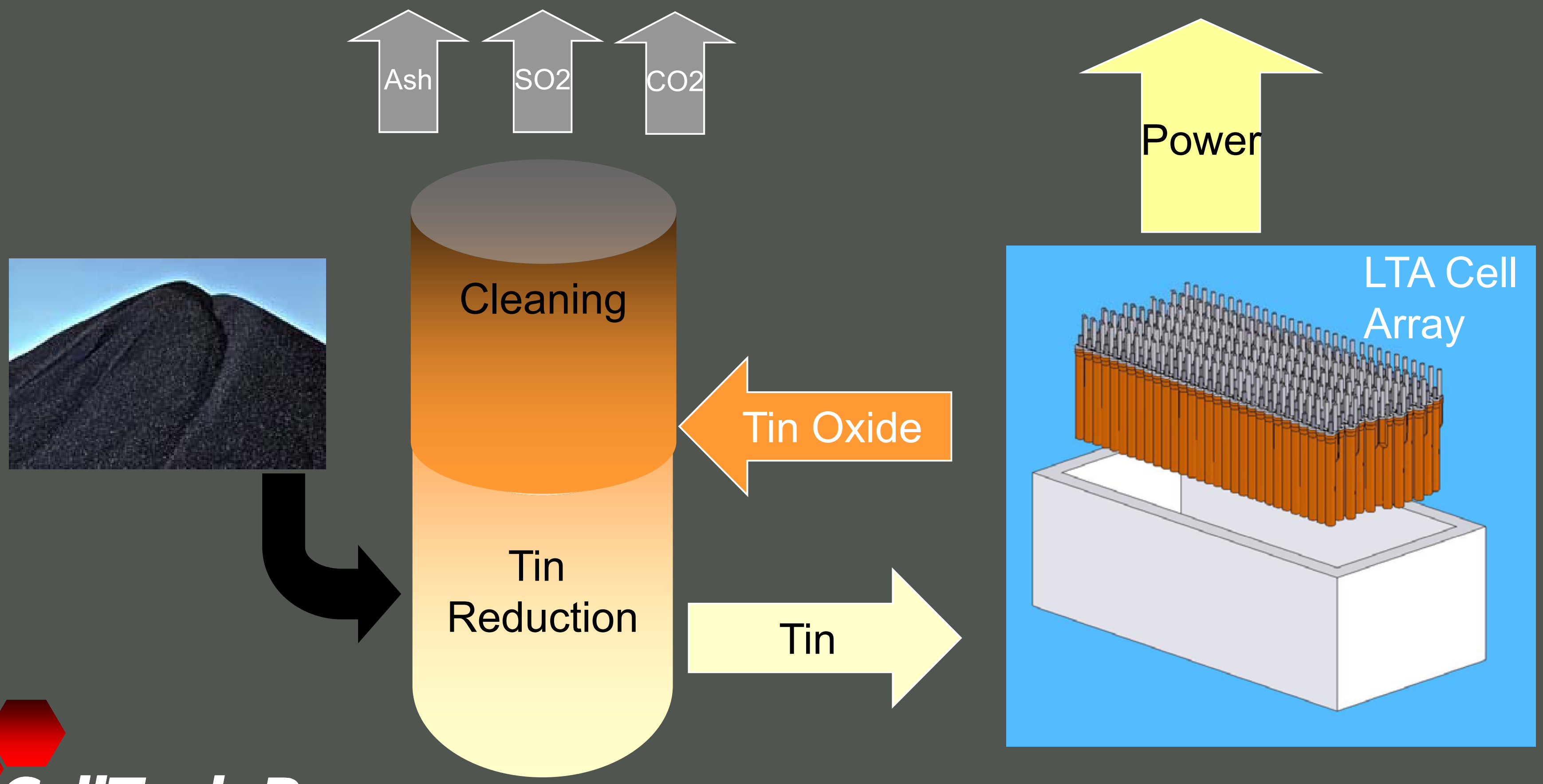
LTA- SOFC Electrochemical Looping - Tin Bath Concept for MW coal plant

- Separates fuel cleaning and reaction gases from Power Production module.
- Direct Coal-biomass feed into anode
- Tubular configuration without ceramic porous separator
- Carbon dioxide sequestration



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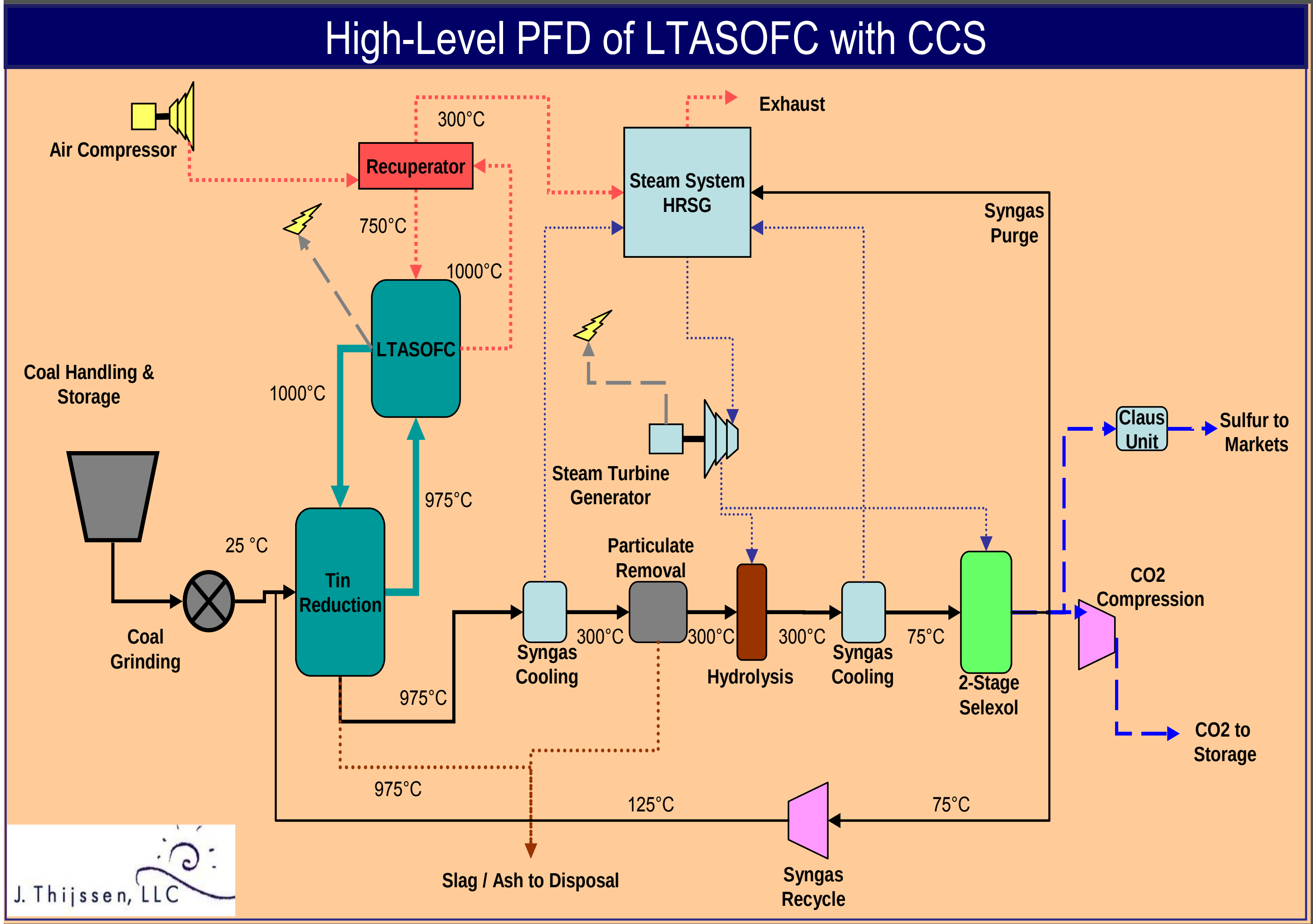
LTA-SOFC Coal Tin Bath Power Plant Concept



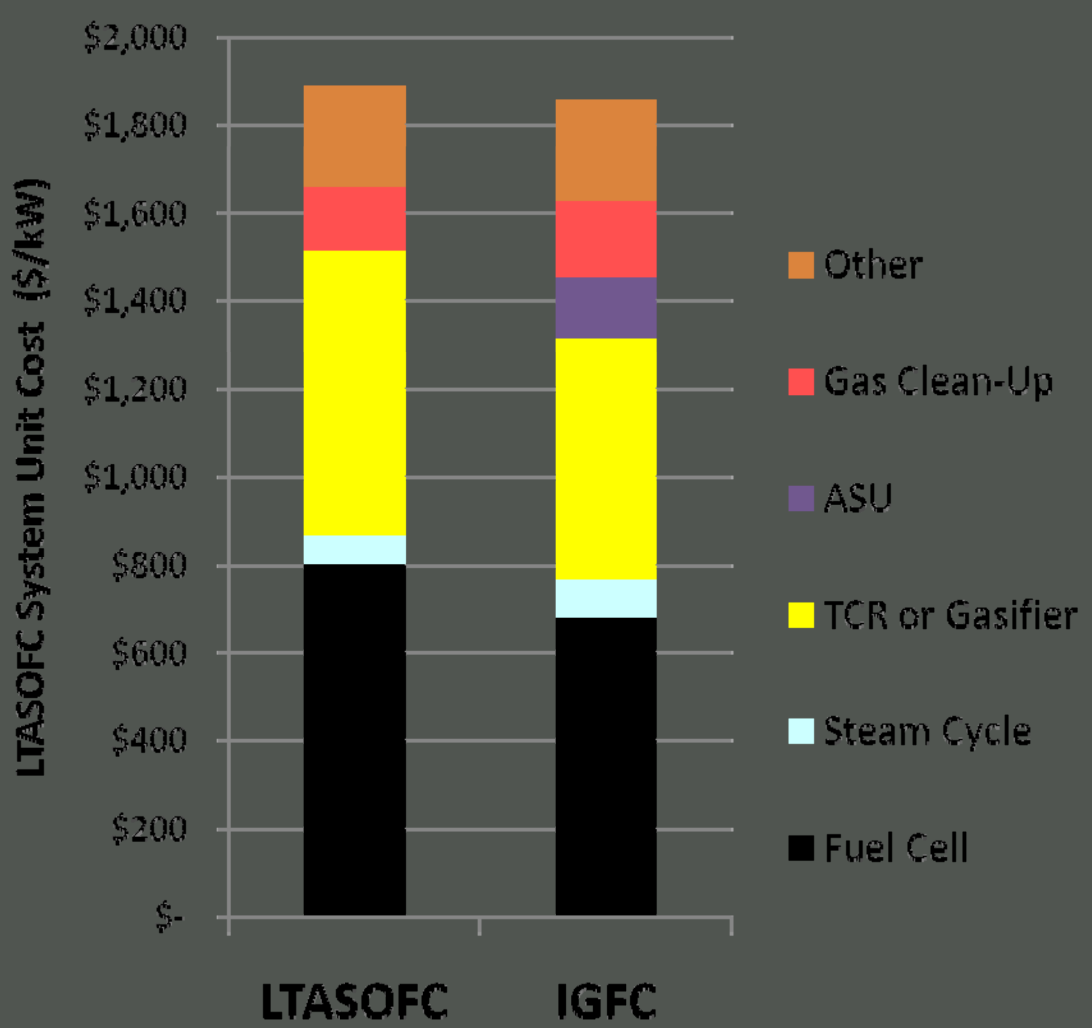
Most thoroughly analyzed concept to-date

- 63% System efficiency with CO2 capture and compression
- System CAPEX: $1400 – 2400/kW (similar to IGCF)
- Near 100% CO2 capture

- Tin provides separation of ash/impurities
- Requires development of Tin Coal Reactor similar to liquid metal gasifiers
- High tin recirculation rate required to meet O2 transport requirements.
- Tin anode requires electric current break

LTA-SOFC Coal Tin Bath System Cost Estimate

Preliminary System Cost Structure (2007 $)



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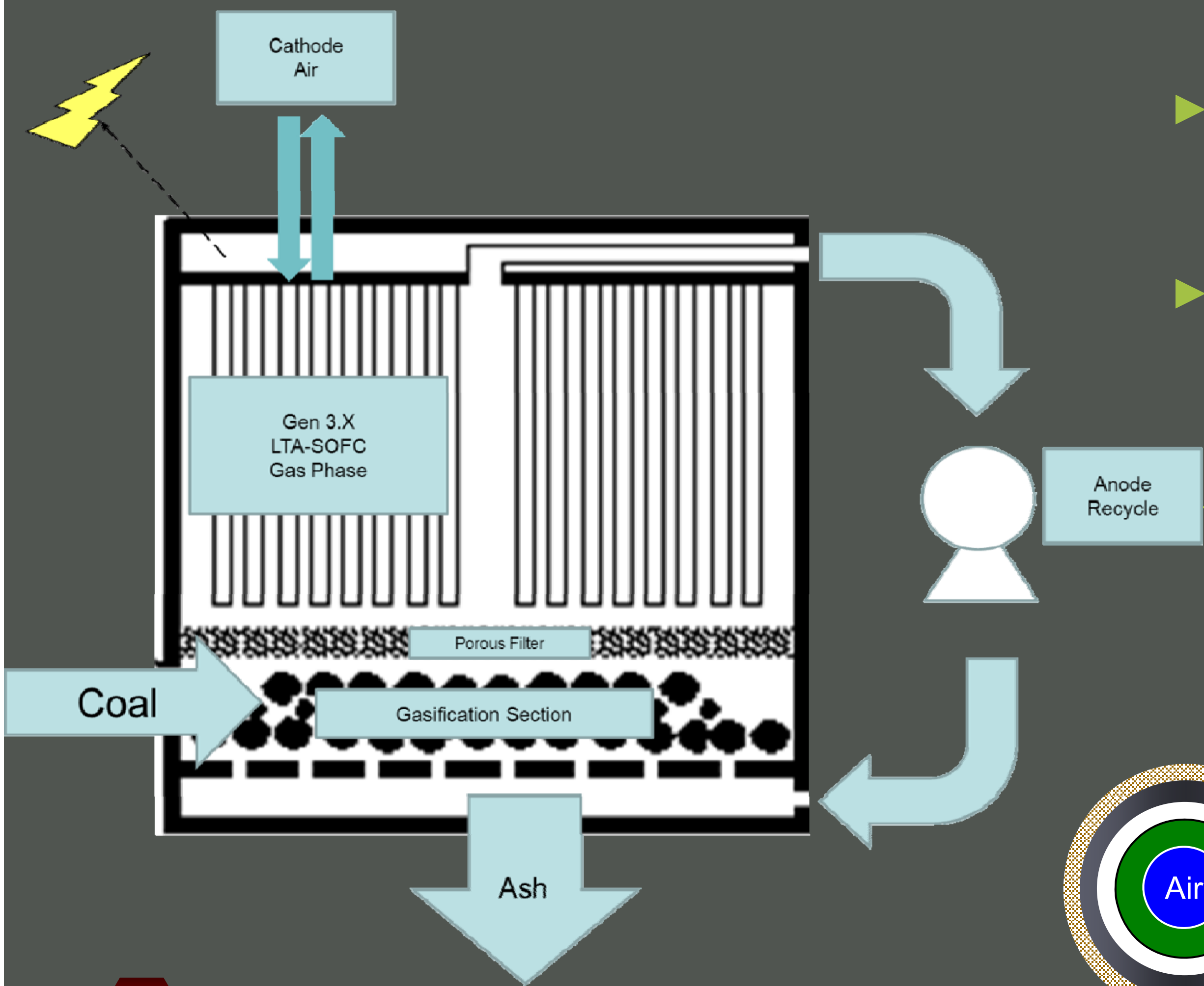
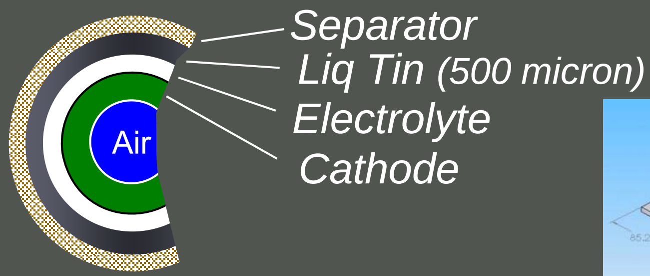
J. Thijssen, LLC

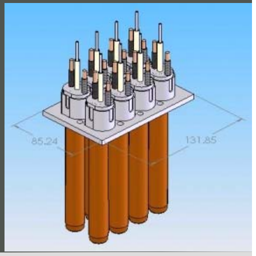
LTA-SOFC In-situ Gasification Concept



- Tubular same as current Gen 3 cells
- Tin anode contained by porous ceramic separator and electrolyte

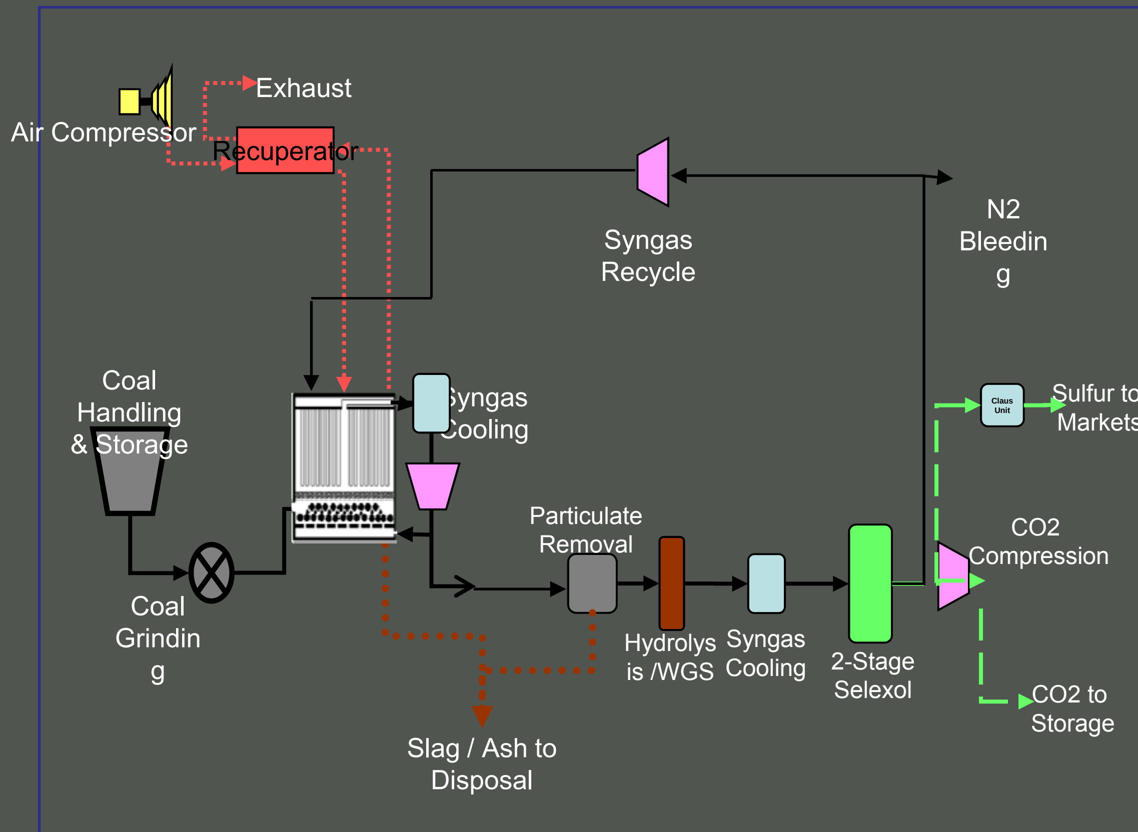
Direct Fuel Conversion through internal gasification





LTA-SOFC In-situ Gasification Concept

High Level of PFD of Insitu Gasifier

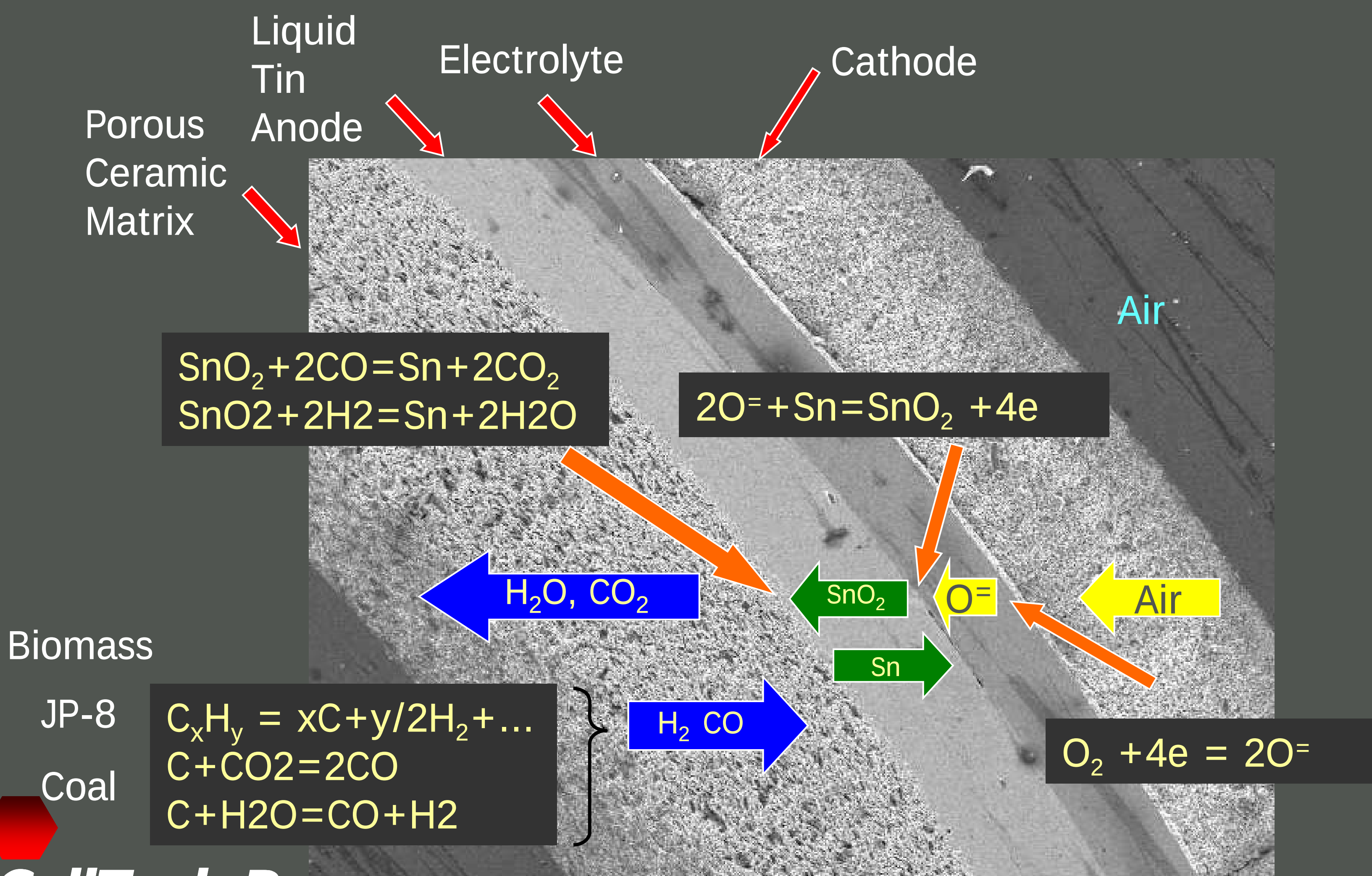


Uses cells with porous separator like existing CellTech Gen 3

- No direct contact between tin anode and solid fuel.
- Gasification is driven by CO_2 and H_20 produced by cells (no Oxy plant required).
- Isolated anodes allow cell voltage build up.
- Ash, tar and carbon clogging of separator could be an issue.
- Volatile metal oxides in coal impact on cells unknown.
- Could test concept with Gen 3.1 cells and lab gasifier.
- Cathode air flow may increase to remove cell heat load.

LTA-SOFC Gen 3 for direct coal

Gasification cell using porous separator



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LTA-SOFC External Gasification Concept

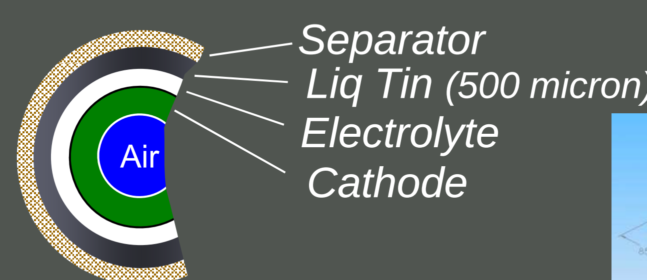
- Tubular same as current Gen 3 cells
- Tin anode contained by porous ceramic separator and electrolyte
- Direct Fuel Conversion through internal gasification

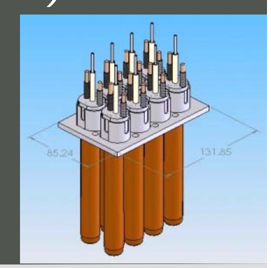
Uses cells with porous separator like existing CellTech Gen 3

•Compatible with existing gasifiers

•Reduced gas clean-up (Sulfur, CO)

•Lowest efficiency





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Issues related to coal impurity

- Impact on liquid tin anode
- Impact on electrolyte
- Impact on other cell components

Fuel Impurity
Impact on Liquid Tin Anode

- Molten tin fluid state: Structure or surface cannot be damaged by contamination
- Gravimetric separation of ash from molten tin
- Addition of tin during plant operation is feasible and loss of tin not an issue

tin compounds of sulfur and halogens, volatile
tin monoxide, volatile
residual tin in ash

→ Evaluating fuel impurity impact on tin is a lesser issue

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Coal Impurity Impact on Electrolyte

- Yttria stabilized zirconia and phase destruction
- Modeling for zirconia phase stability
- Predictor for harmful elements and their list

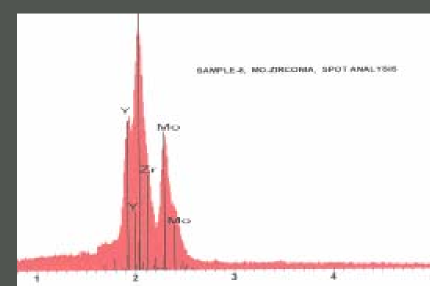
Impurity Impact on Electrolyte

Yttria stabilized zirconia and phase destruction

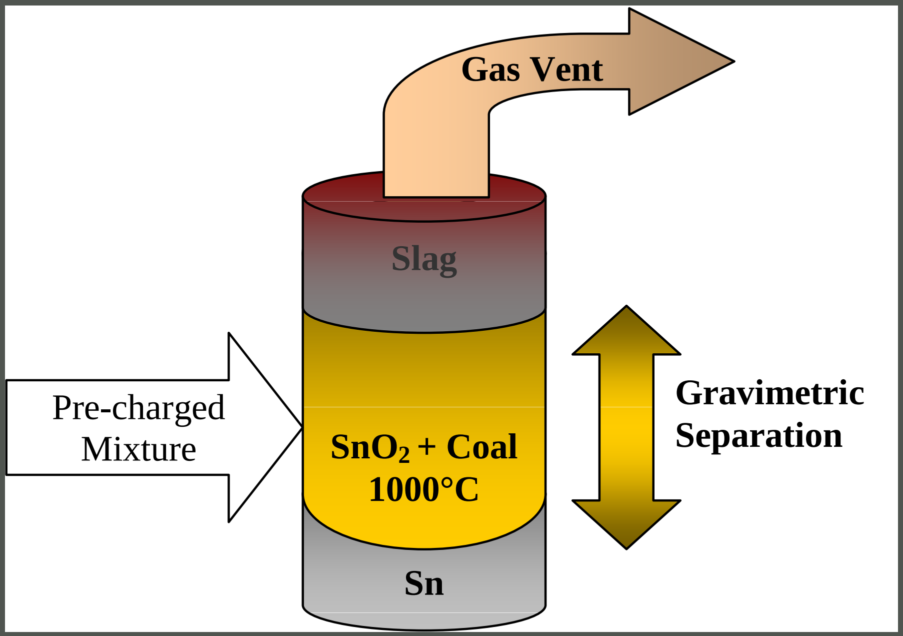
- **Yttria stabilized zirconia**
  - **Tetragonal – low yttria, partially stabilized**
  - **Cubic – high yttria, fully stabilized**
- **Phase destruction**
  - **Yttrium was displaced by higher CE elements and migrated to grain boundary**

Exposed to Mo oxides, YSZ cracked

SEM/EDAX Indicating yttria migrating to grain boundary



SnO_2 reduction by coal - setup



Experimental concept for the chemical reactor that operates at 1000°C to separate the pre-charged mixture of coal and tin dioxide into tin and slag with a vented gas.

Coal contaminants with potential to harm ZrO2 based electrolyte: Arsenic, Chromium, Molybdenum, Manganese, Uranium, Niobium, Selenium, Vanadium, Tantalum, Tellurium and Tungsten

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	0.6
Tl	0.04	3	<0.9	0.61

Impurities found in Sn from SnO2 reduction by coal (US Wyoming)

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 tin (sample S5)

Potential Coal Contaminant Solubility in Tin
at condition of tin-coal reactor

Spiked Element	Initial amount (ppm wt)	ICP-OES Results (ppm wt)	Pure Sn GDMS results (ppm wt)
Cr	4000	1098	2.7
V	4000	10	< 0.001
Mo	4000	9	< 0.01
Nb	4000	115	< 0.005
As	4000	2535	1
Mn	4000	2405	0.2
W	4000	60	< 0.01
Ta	4000	8	< 5
Se	4000	44.7	< 0.01
Cl	4000		< 0.01
S	4000	8	0.07
P	4000	203	0.08
Si	4000	5	< 0.01
Br	4000		< 0.05
I	4000		< 0.05

Solubility Experiment: tin spiked, 1,000C, 1% H2O in H2, 5 hours, cooled

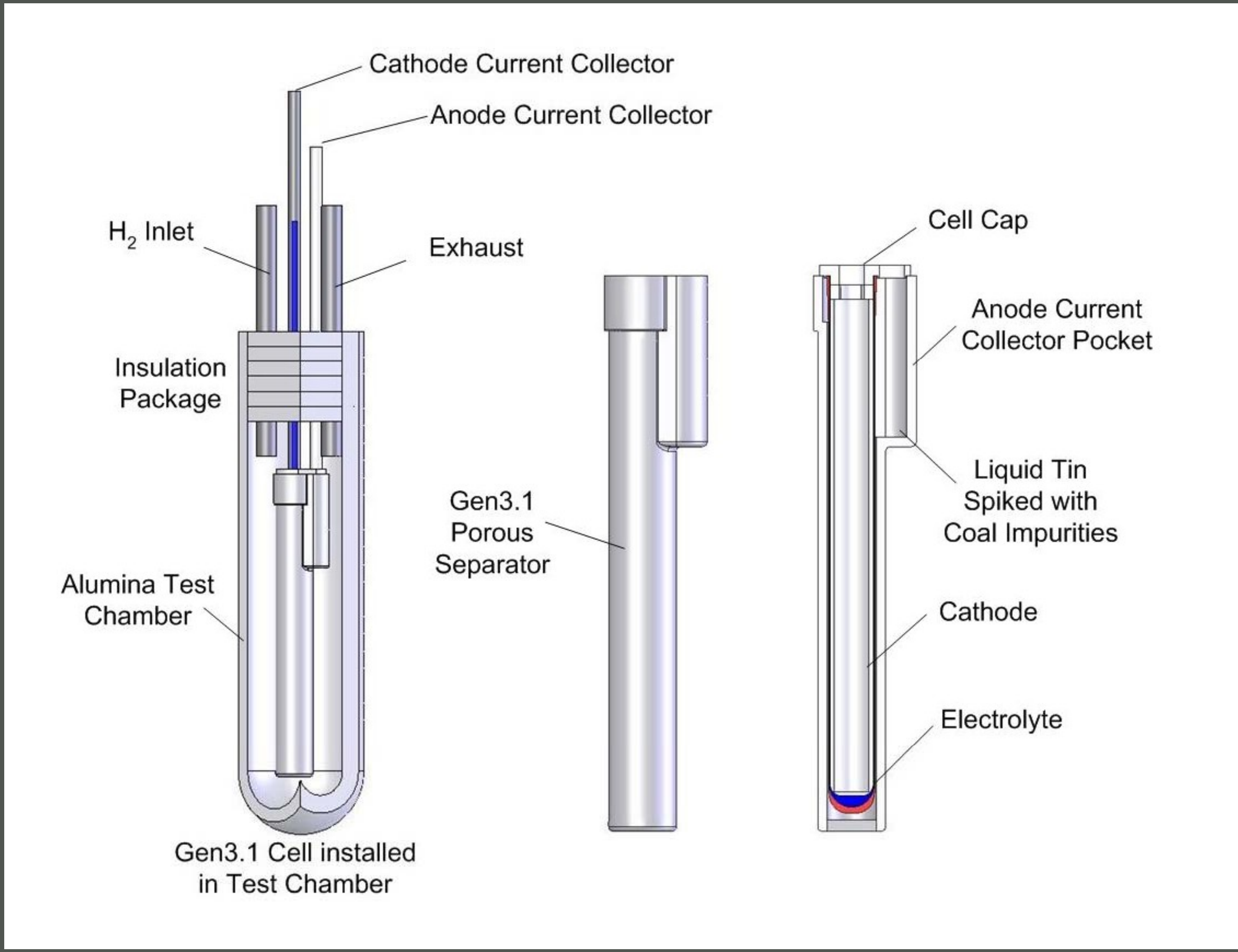
ICP-OES analysis results: including both dissolved and entrained

Results imply the maximum possible solubility of impurity in tin at coal-tin reactor condition

Electrochemical testing - setup

Setup:
Gen 3.1 cell
Hydrogen as fuel

Tin spiked with potential coal contaminants such as V, As, Ta, Ti, Mo, Nb, P, Cl, Si, Na and Cr, etc.



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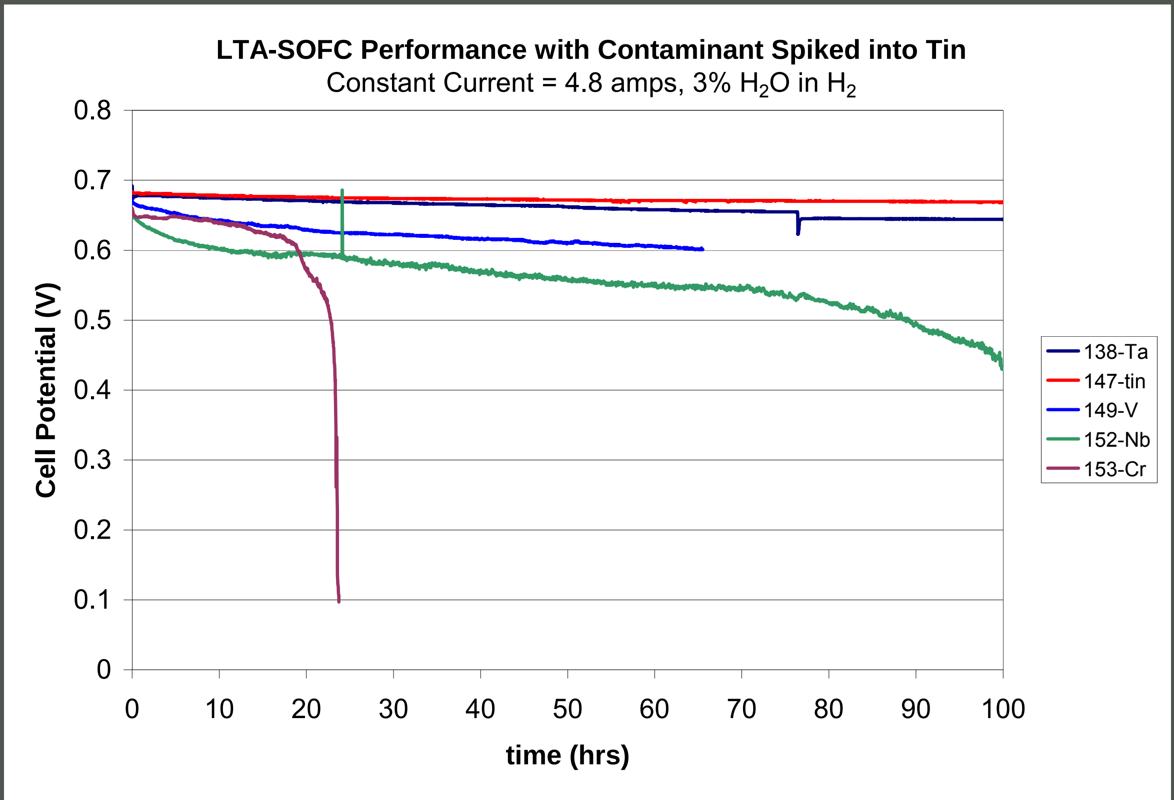
Potential Coal Contaminant Impact on LTA-SOFC



Percent Voltage Drop at end of Test			
Element	ppm	Time (hrs)	%
-----------		100	2.1
Ta	8	100	3.2
V	10	66	9.6
Nb	115	100	34.4
Cr	1098	24	12.9

Testing conditions:

Gen 3.1 LTA-SOFC cells

Tin individually spiked to the maximum possible concentration

Constant current 4.8 amp @ 3% H2O in H2

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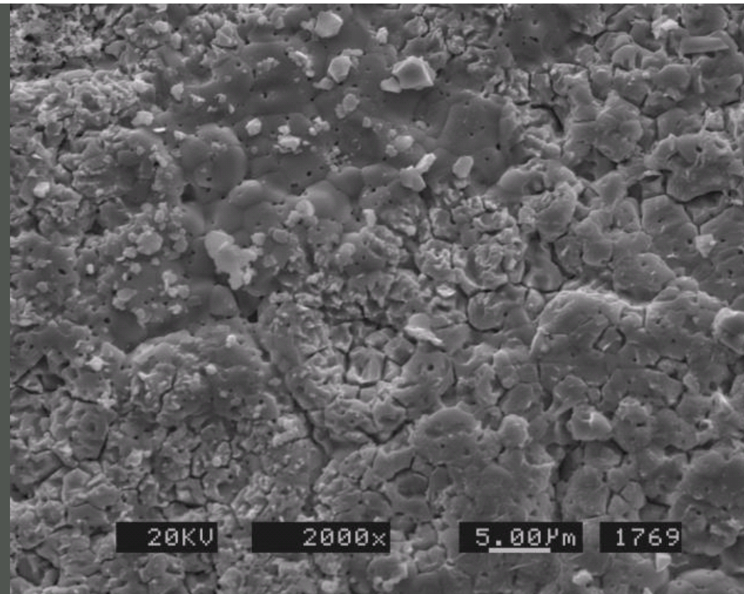
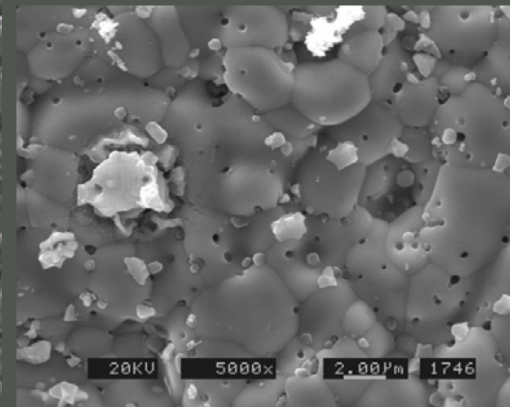
LTA-SOFC Gen 3.1 cell collectively spiked with V, As, Nb, Mo and Cr to 1,500ppm

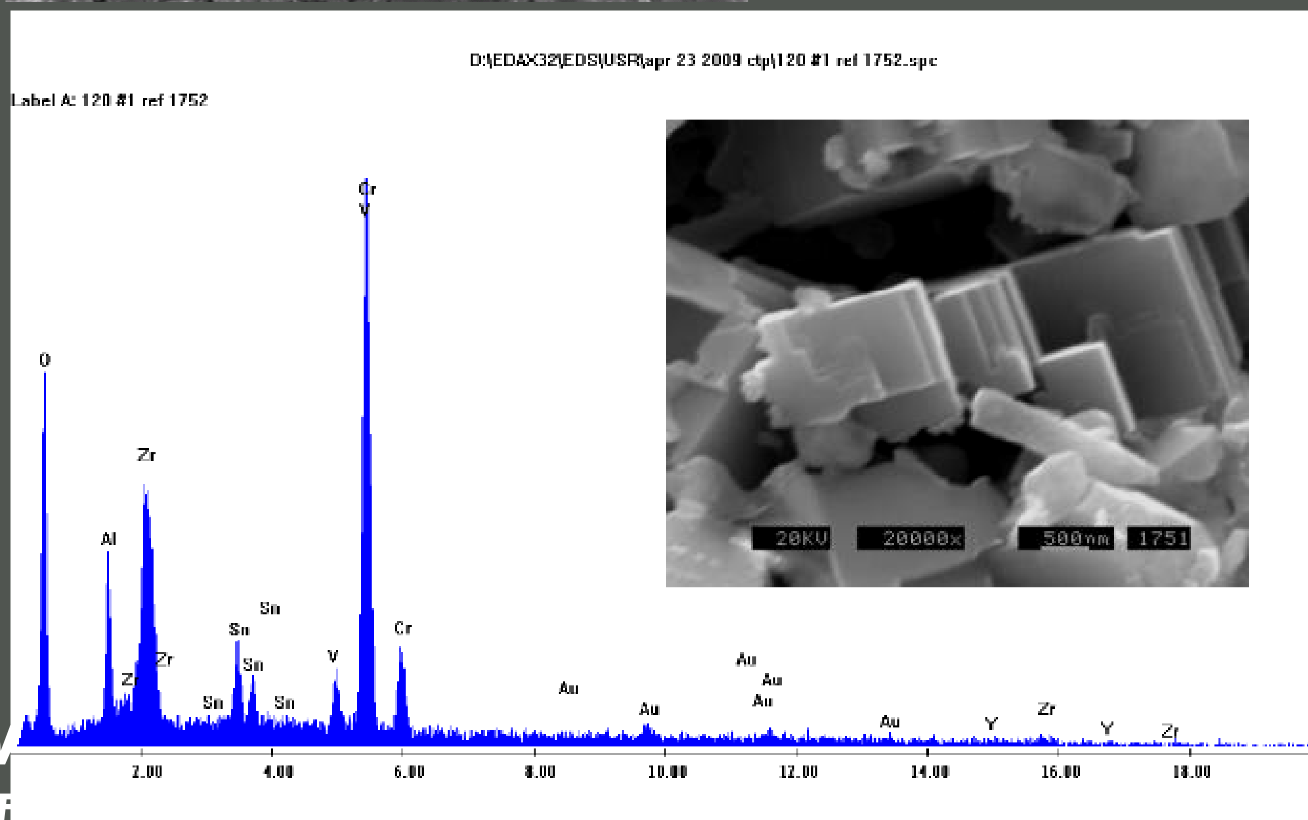
Post Mortem analysis:

Electrolyte damage found

Oxide crystals of Cr, V found on YSZ surface







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Summary

Demonstration of Feasibility of Liquid Tin Anode SOFC as Direct Coal Conversion Fuel Cell

- Three liquid tin anode configuration concepts for direct coal conversion
- Fuel impurities cause degradation / damage to electrochemical component
- Tin's potential as a media for removing or reducing fuel contaminants including from coal, biomass and diesel
- Ongoing projects in progress to address individual contaminant and coal ash

Acknowledgements

For Direct Coal/Biomass Conversion:

DOE NETL DE-FG02-08ER85006, Dr. Joe Stoffa
DOE NETL DE-PS26-07NT43208, Dr. Joe Stoffa
NSF IIP-1013755, Dr. Anthony Walters
EPRI EP-P29519/C13921, Mr. Dan Rastler

For direct logistic fuel, diesel & waste conversion:

DOD DARPA-DSO Contract W911QY-04-2-003, Dr. Rosemary Szostak
DOD DARPA-DSO/ARMY Contract W911NF-07-C-0032, Dr. Valerie Browning
DOD ONR Contract N00014-08-C-0164 , Mr. Cliff Anderson
DOD ARL/CERDEC Contract W911NF-08-1-0115 , Dr. Rob Mantz
DOD ONR contract N00014-08-1-0962, Dr. Michele Anderson
DOD ARL contract W911NF-08-C-0075, Dr. Dick Paur
DOD ARL, contract W911NF-09-C-0165, Dr. Rob Mantz

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