Long Term Stability and Impact of Sulfur in Liquid Tin Anode SOFC (LTA-SOFC)

Fuel Cell Seminar 2011
Orlando, FL

November 3rd, 2011

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CellTech Power
Fuel Cells For Real Fuels

3 Generations of LTA-SOFC Development

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1998 — 2000 — 2002

First Coal

Gen 1: "Bubbling Anode"

48 cell stack

2004

Gen 2: "Internal separator"

30 Cell Stack

2 kW NG System

2006

Gen 3.0: "Reverse Anode"

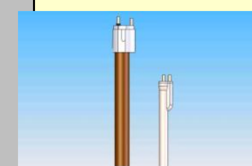
DARPA DSO

Direct Plastic Stack Test

2008

Gen 3.1: Direct JP-8

DARPA DSO
ARL
CERDEC



2009 - 2011

Gen 3.2: Direct JP-8

Advanced Cell

ONR

125W stack

ARL

Battery Charger

CERDEC

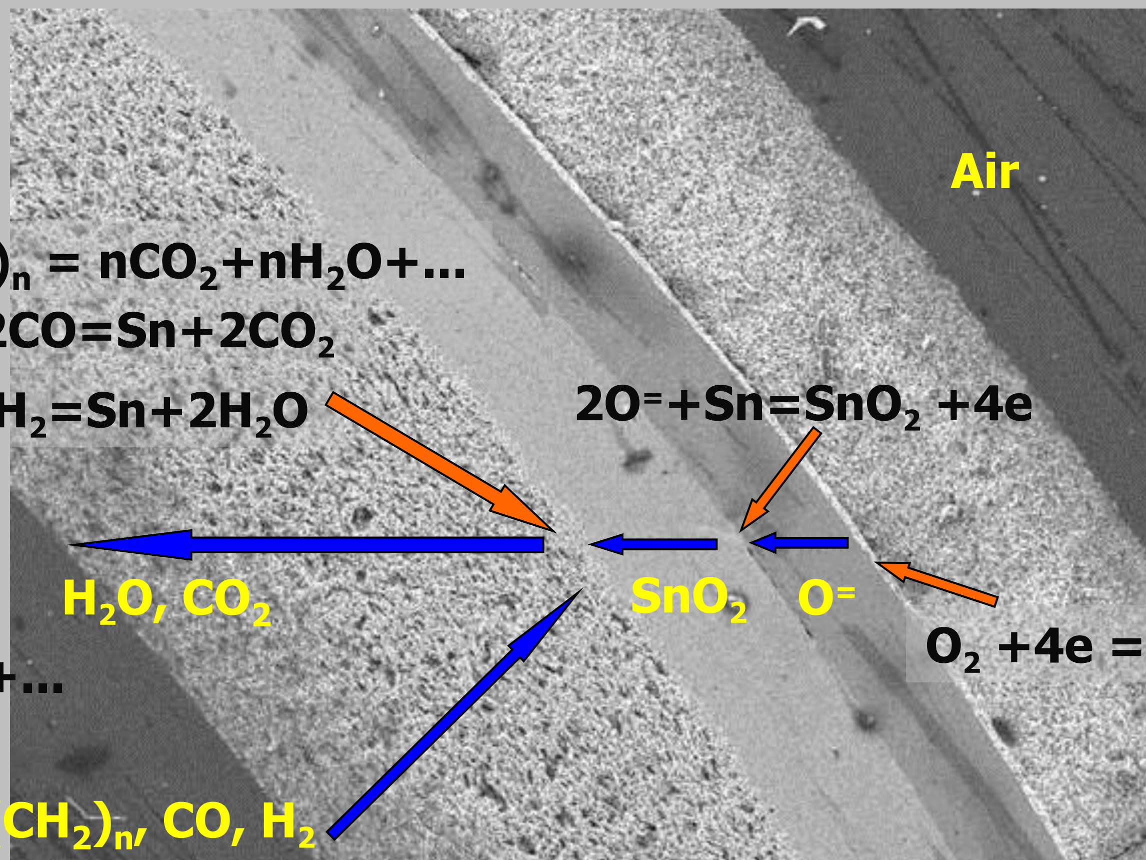
Direct Coal

NETL

Direct Biomas

NSF

Liquid Tin Anode SOFC Characterization: Direct Conversion of fuels



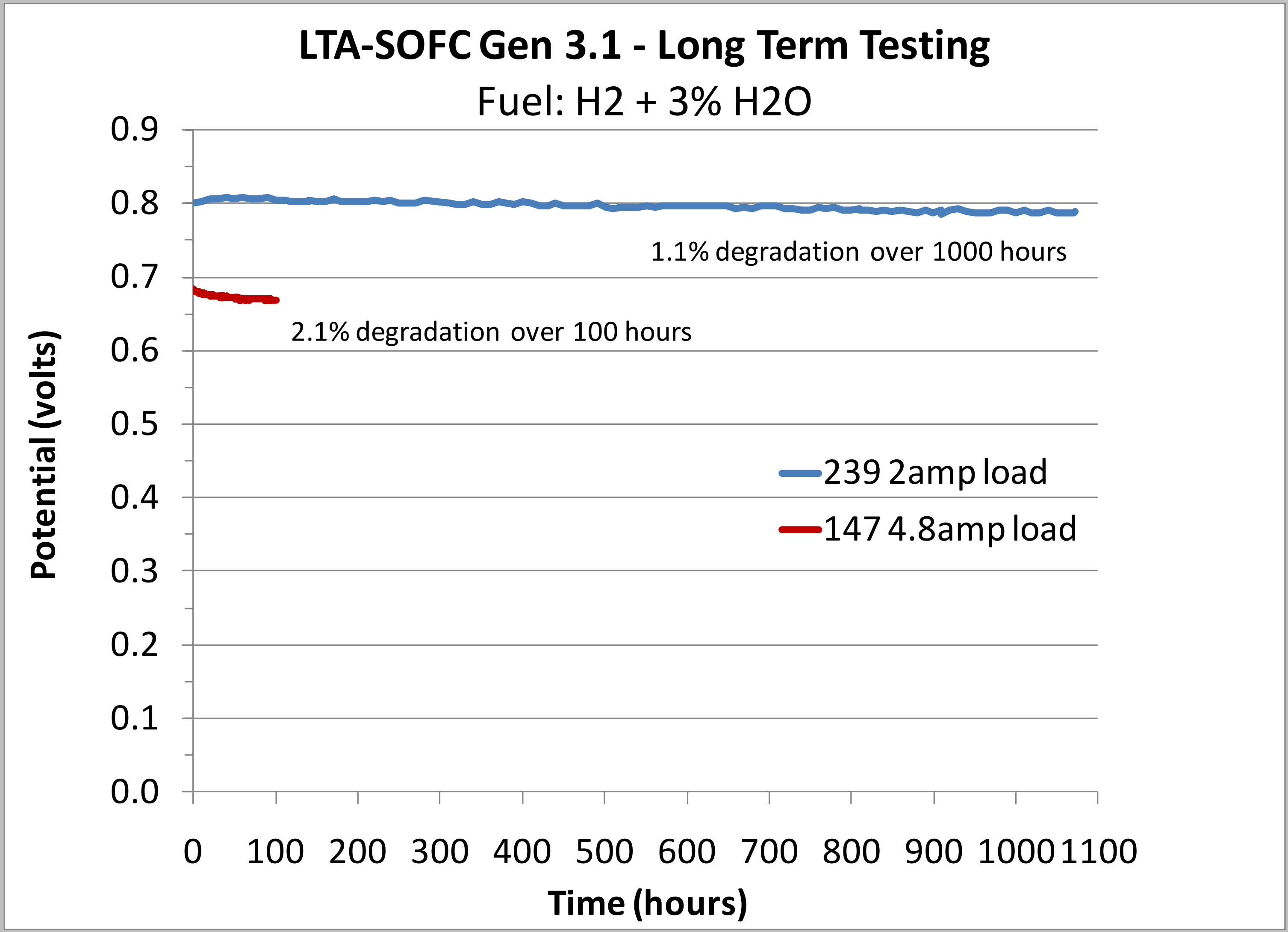
Hydrocarbons:

$(CH_2)_n = nC+nH_2+...$

$C+H_2O=CO+H_2$

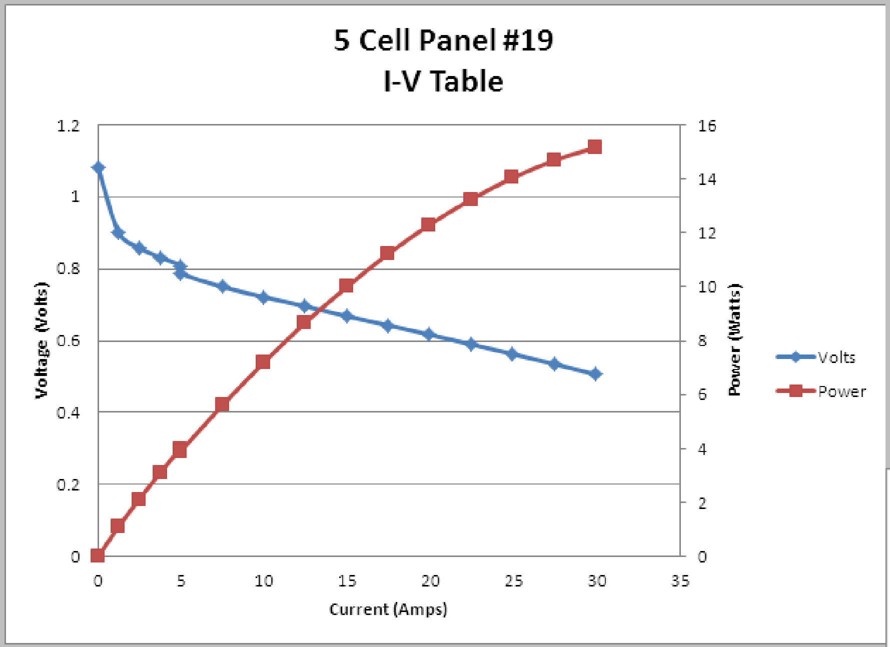
$C+CO_2=2CO$

LTA-SOFC Current Status: Longevity and Degradation

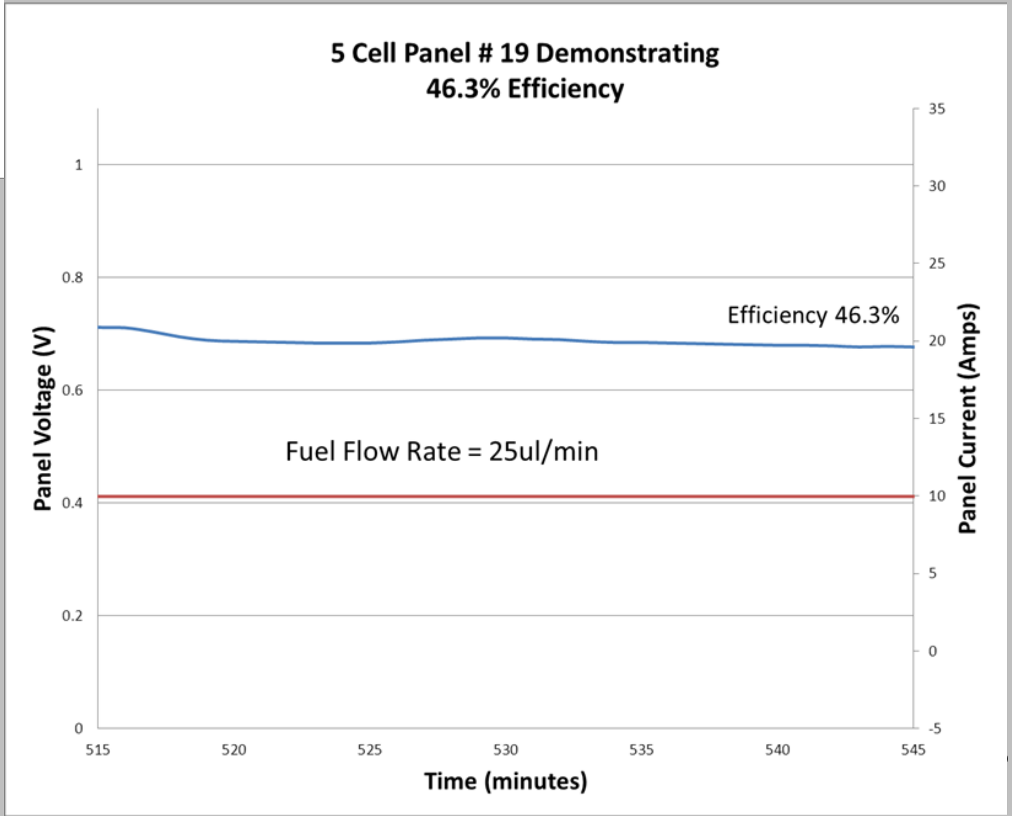


1.1% voltage degradation over 1,000 hours

LTA-SOFC Current Status – Direct JP-8 conversion in 5-cell stack

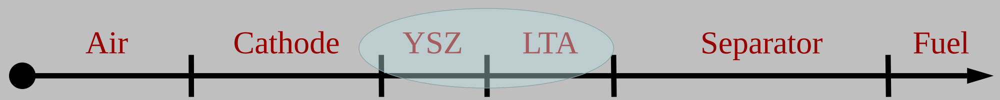


Successfully demonstrated
direct JP-8 conversion in 5-cell stack
with fuel efficiency of 46%;
25-cell stack/system is in the making



LTA-SOFC Long Term Stability

Characteristics related to Liquid Tin Anode:

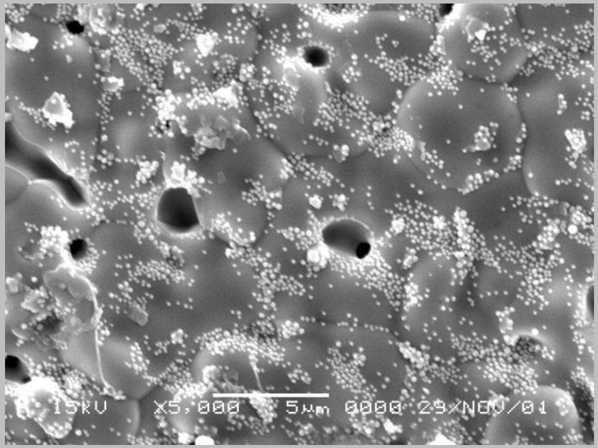


Domain of YSZ Electrolyte – Tin interface

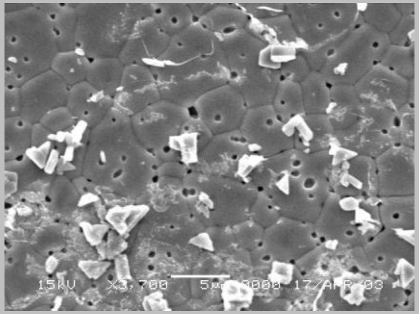
Issue / mechanism	**Tech approach to resolve**	**DecisionPoint/Status**
Tin oxide formation	Control of operation	Adequate for portable power
Gas bubble	To be studied	Do not understand – important for stationary power
Impurities including from fuels	In process	18 elements are under study

LTA-SOFC: Tin Oxide Formation and Impact on Degradation

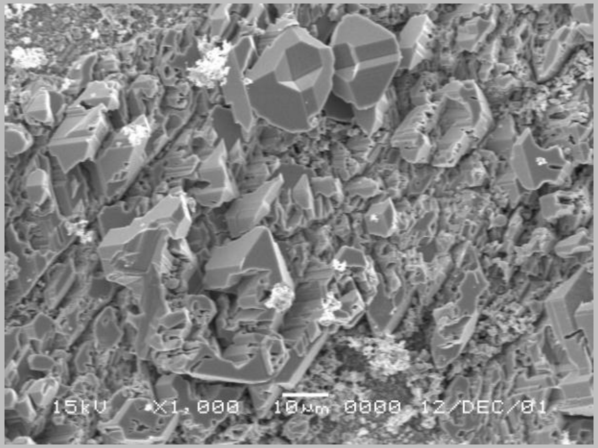
Section I Section II Section III



$Sn + O_2 = SnO_2$ OCV 0.78V at 1,000C



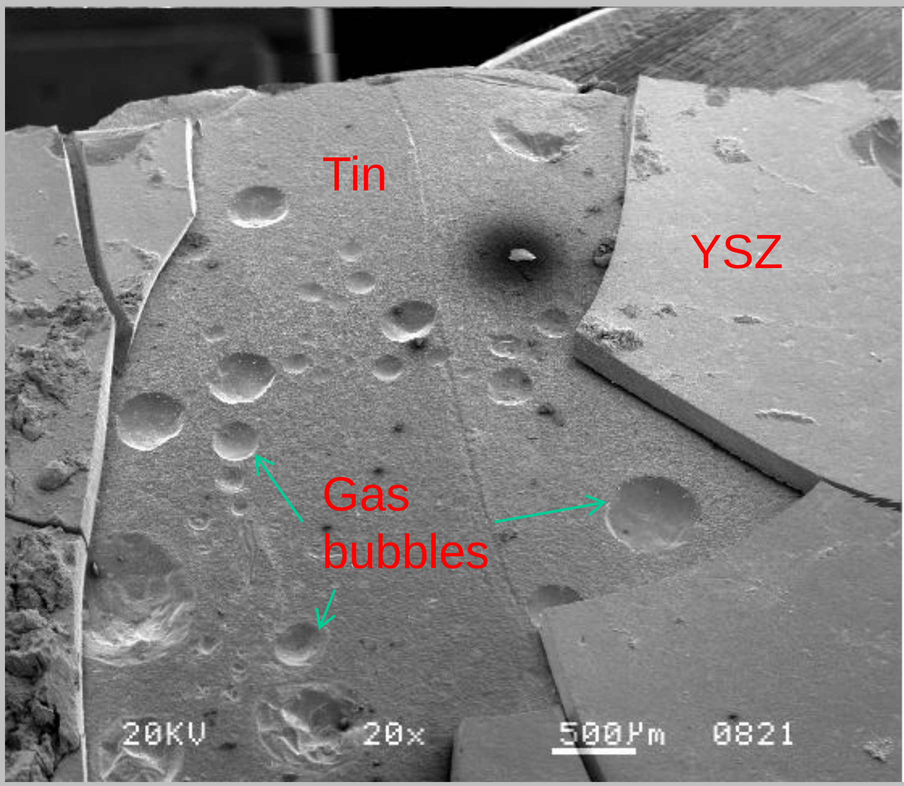
Tin droplets on electrolyte: Normal operation

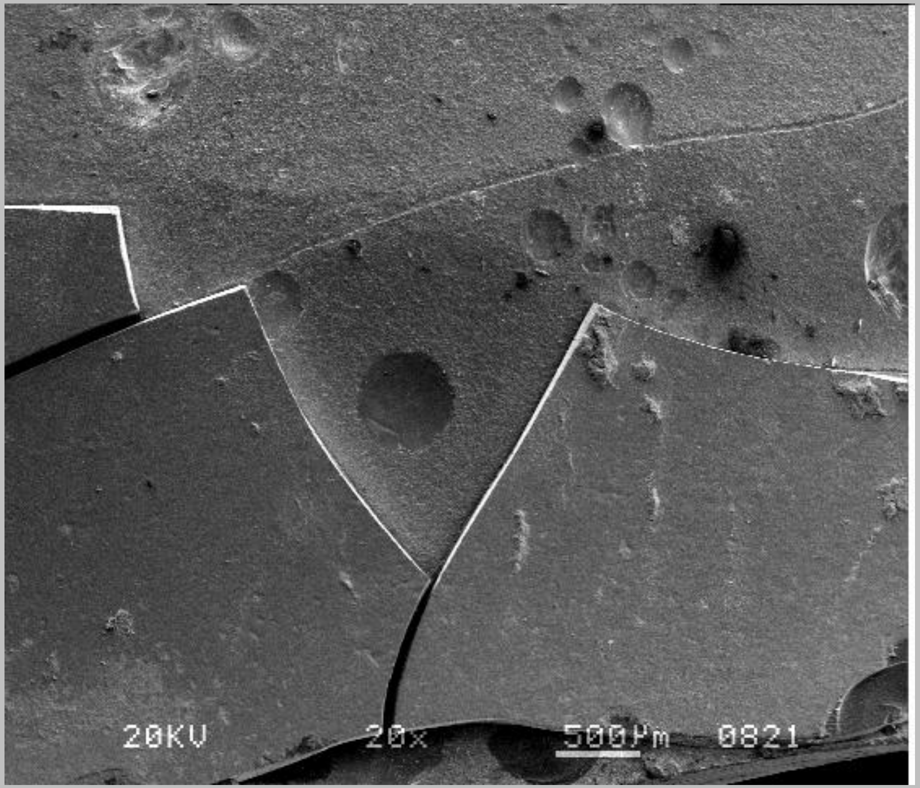


Tin oxide spikes

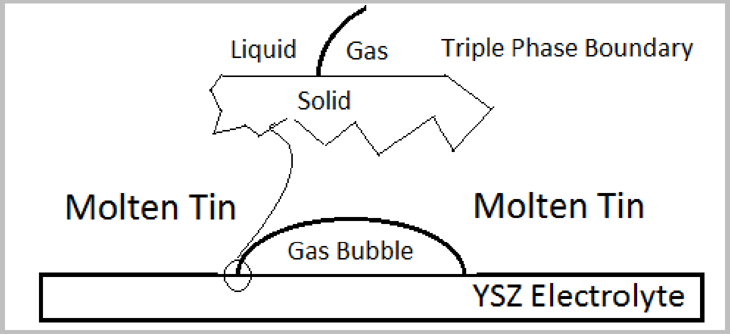
Tin oxide layer

Impact of Gas Bubbles on Degradation - Tin-Electrolyte Contact Area

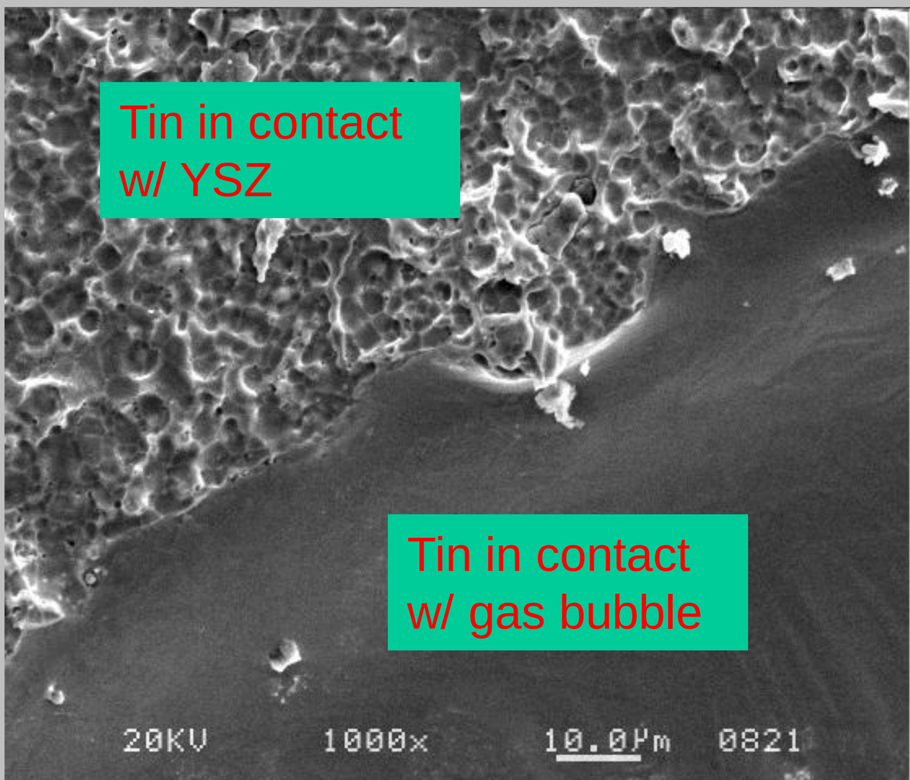


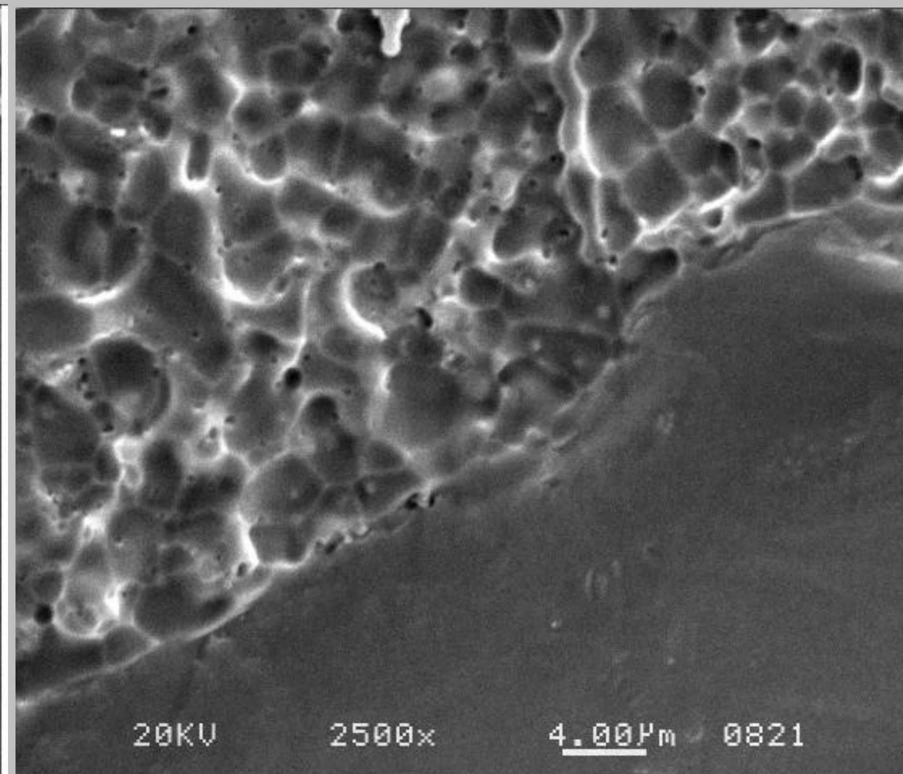


Gas bubbles trapped between tin and electrolyte
Nature of gas bubbles unknown
Up to 30% electrolyte area covered
Triple Phase Boundary (TPB) - Degradation



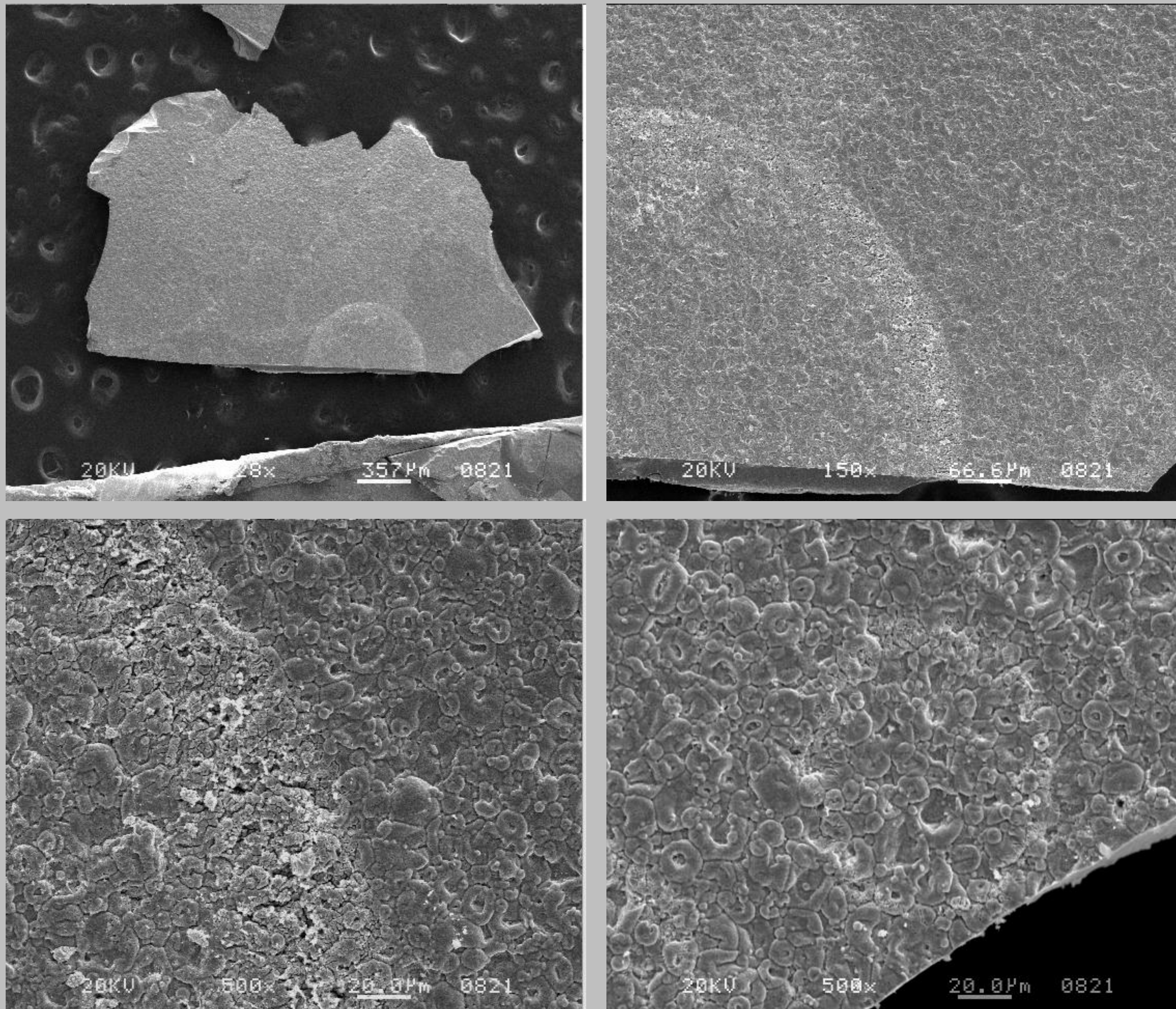
Tin Surface in Contact with Electrolyte



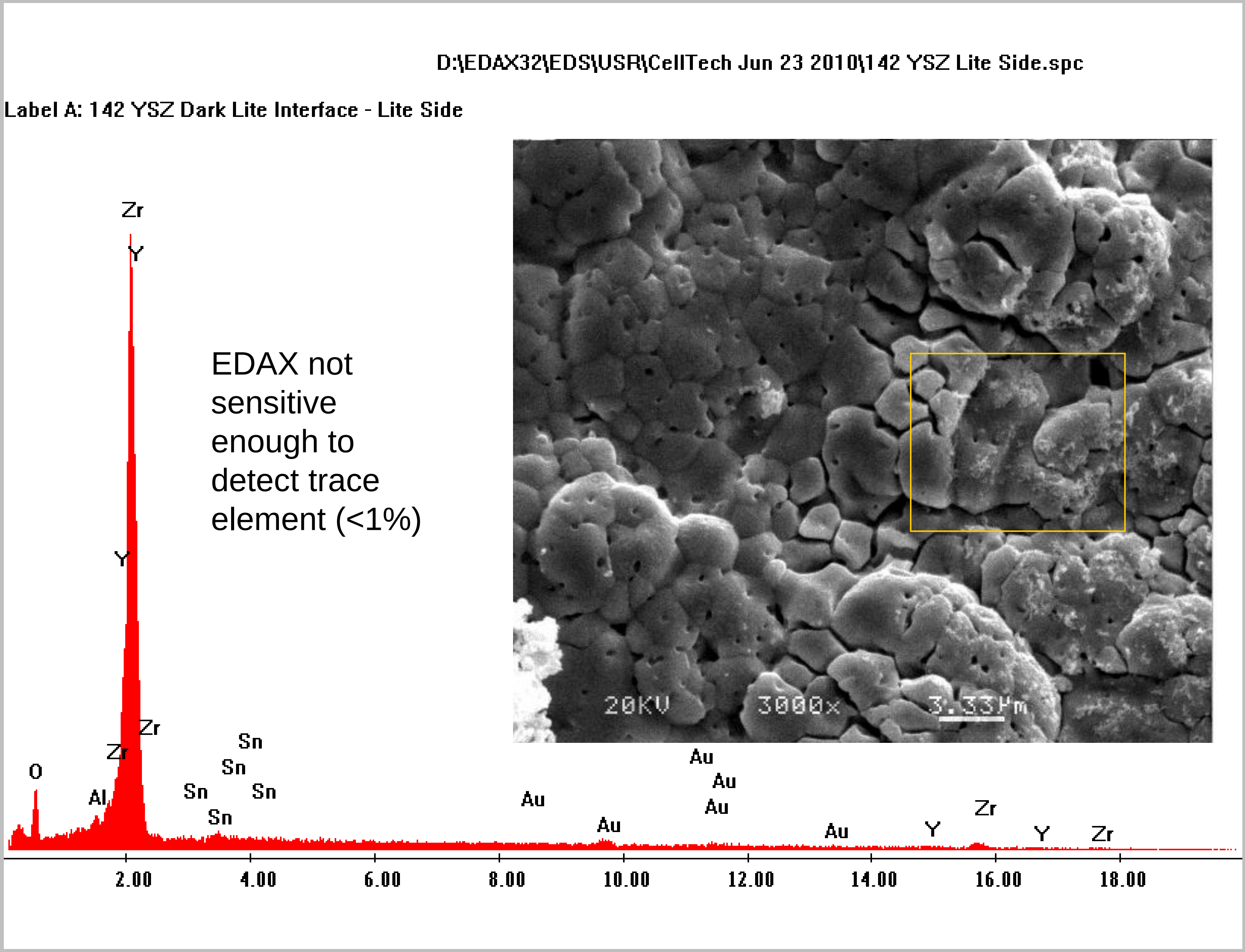


Tin-YSZ contact area: YSZ grain structure – its mirror image imbedded in tin
Tin-Gas bubble contact area: smooth, featureless

Electrolyte surface in contact with tin



TPB grain damage



EDAX not sensitive enough to detect trace element (<1%)

Sulfur Impact on LTA-SOFC

Estimation of sulfur rate for Illinois #6 coal

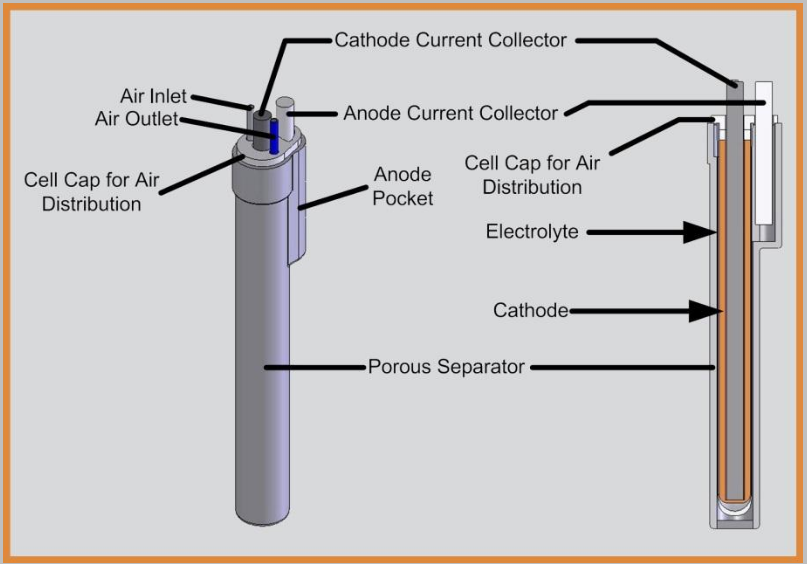
- **Power output per cell: 3 watt**
- **Coal rate @60% Eff: 0.63 g/hr**
- **Sulfur (5wt% of coal): 31.6 mg/hr**

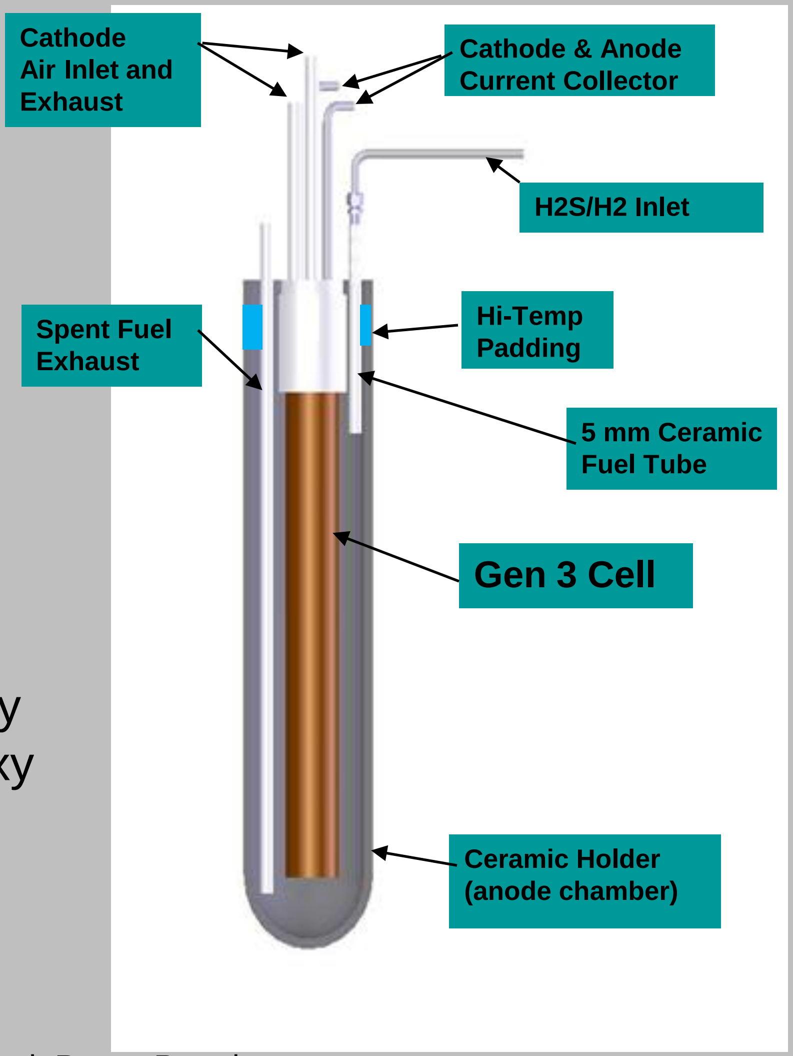
Simulated gas: H_2S in H_2 (from MaineOxy)

H2S, ppmv	flow, cc/min	S, mg/hr
2,134	300	60
36,900	300	950

2,134 ppmv⇔ 36,000 ppmw ⇔ 3.6wt% H2S
36,900 ppmv ⇔ 50wt% H2S

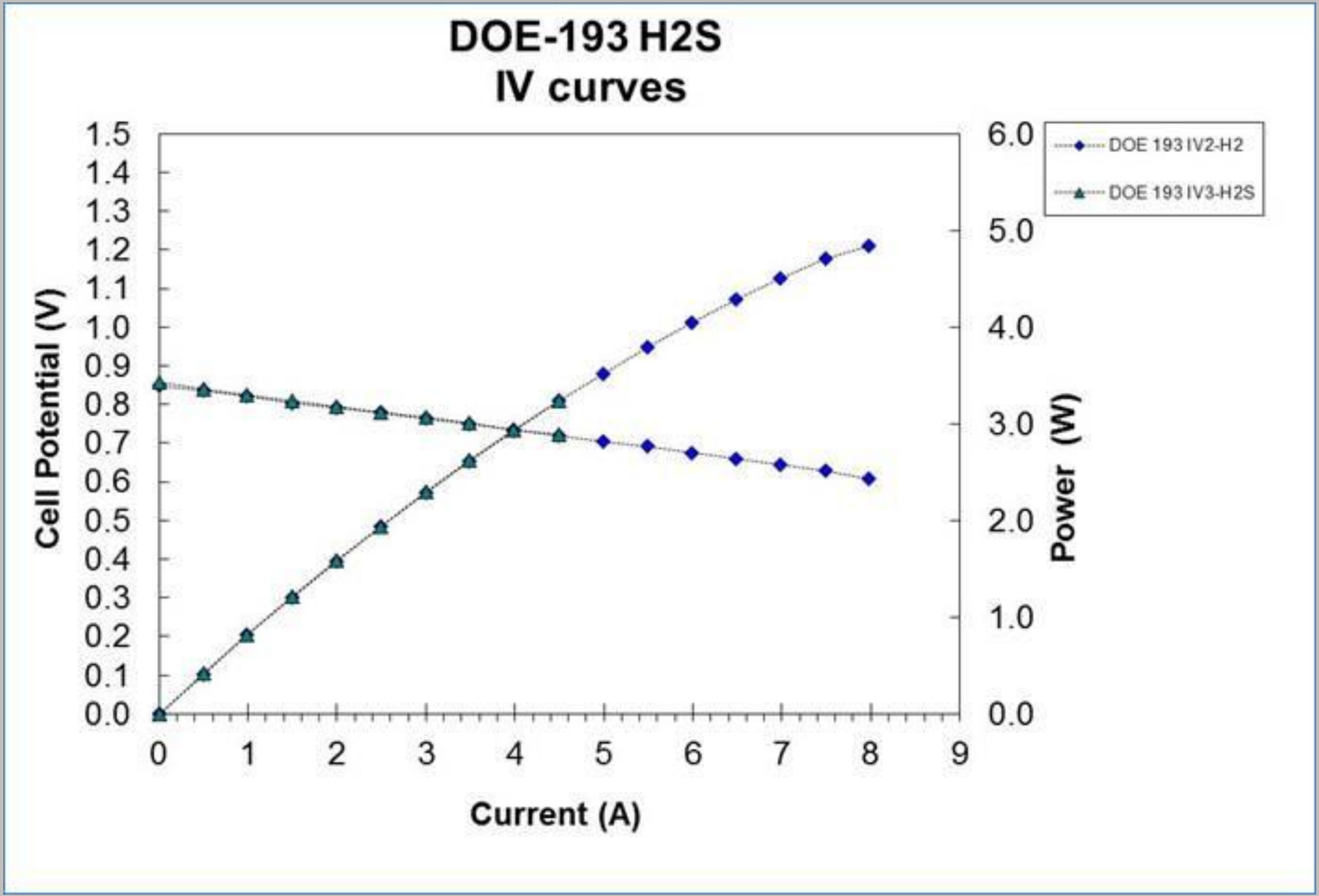
Sulfur Impact - H2S Simulated Gas Testing





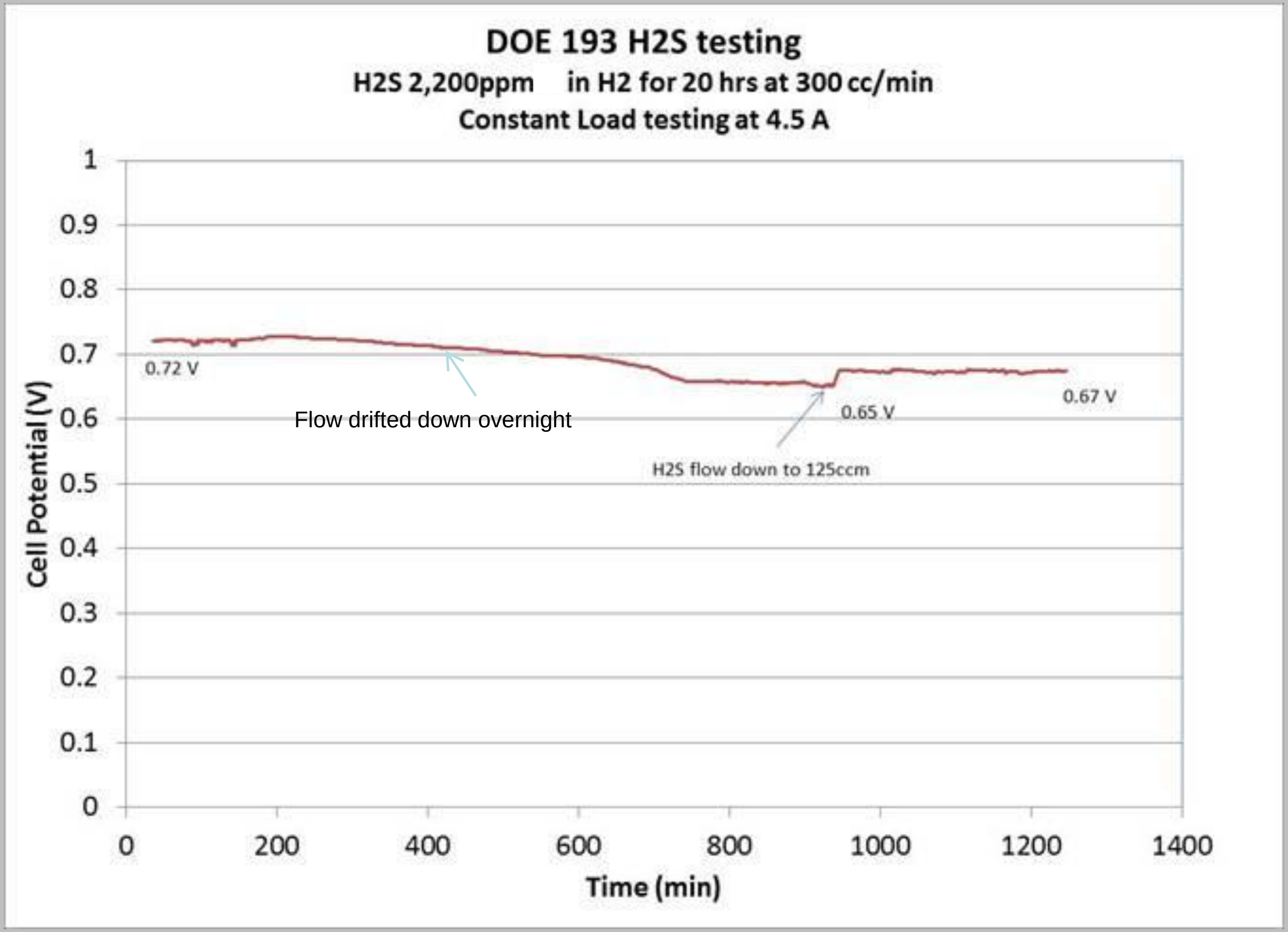
Gen 3.1 LTA-SOFC
#1 H2S 2,134 ppmv MaineOxy
#2 H2S 36,900ppmv MaineOxy

Sulfur Impact on LTA-SOFC



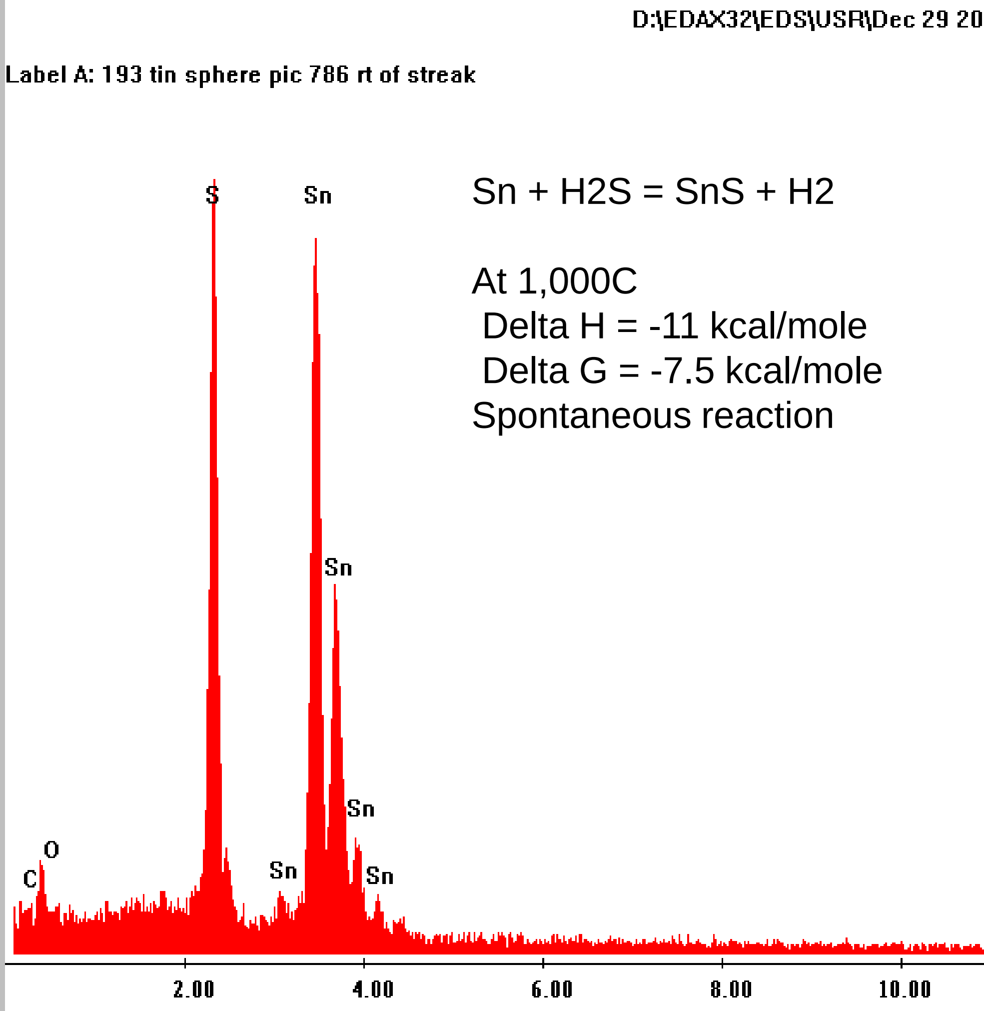
H2S 2,134 ppm as comparison with hydrogen

Sulfur Impact on LTA-SOFC



Last 5 hours no degradation observed

Post Mortem – Tin Sulfide



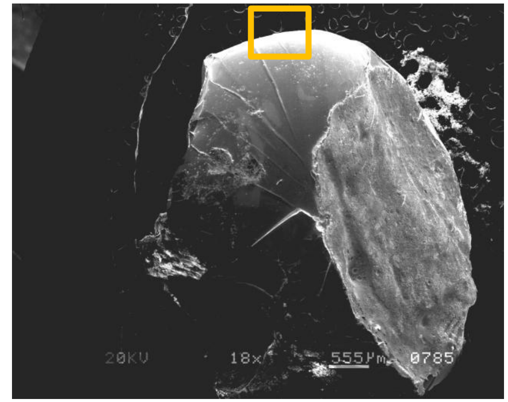
$Sn + H_2S = SnS + H_2$

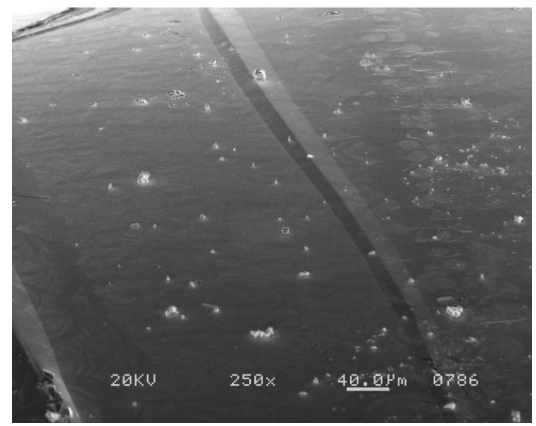
At 1,000C

Delta H = -11 kcal/mole

Delta G = -7.5 kcal/mole

Spontaneous reaction



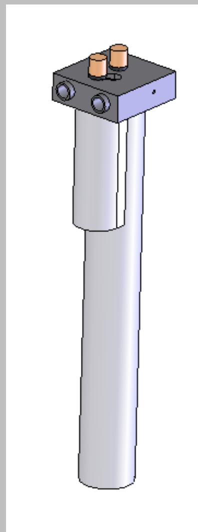


Conclusion

- **Summary of results:**
  - **Degradation of 1.1% for 1,000 hours is adequate for Portable Power. More work needed for Stationary Power requiring 5 to 10 years longevity**
  - **Exceptional sulfur tolerance for direct JP-8 (3,000ppm S) conversion and possible for direct coal (5wt% S Illinois #6) conversion**

- **Future R&D**
  - **Better understanding of tin and tin oxide impact**
  - **Gas bubble impact on degradation and triple phase boundary degradation**
  - **Impurities from different fuels**

Army JP-8 LTA-SOFC stack and system development



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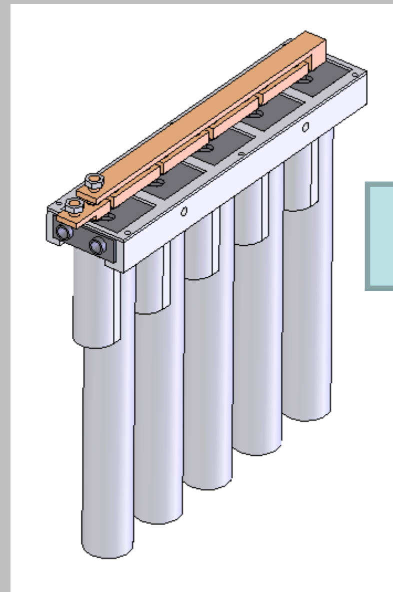
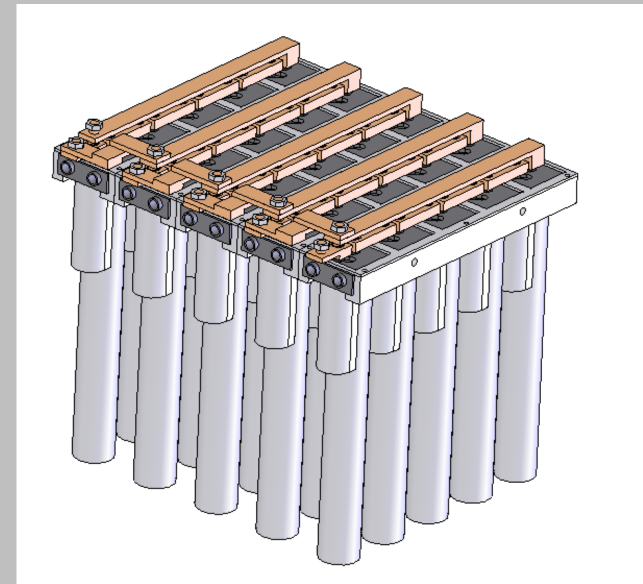
Gen 3.1 Cell
3-5 Watts on JP-8



5-cell panel
August 2010 Demo



25-cell Stack
April-Aug 2011 Demo

Battery charger brassboard system
To be demonstrated Dec 2011
The first complete Direct JP-8
conversion LTA-SOFC system
without any fuel reforming

CellTech Power
Proprietary
Information

DOE Supported Direct Coal Power Plant

<u>30 W – 1 MW</u>

"In-Situ Gasifier"

Tubular

Thin static tin layer

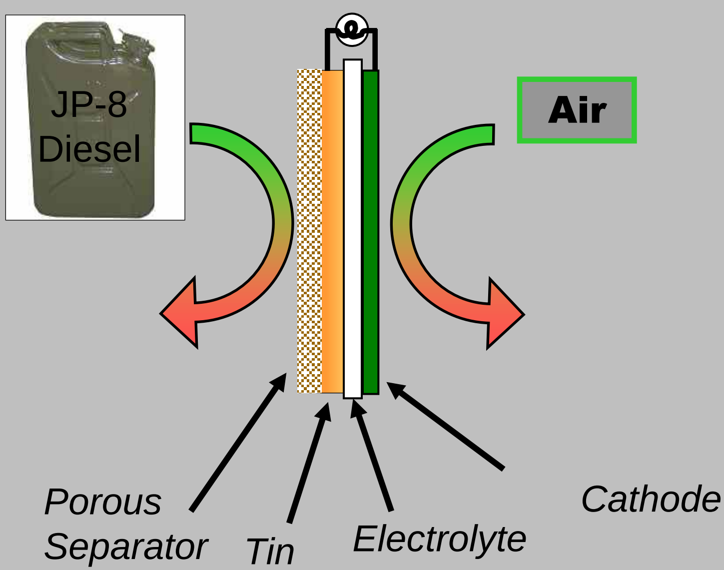
Contained by separator

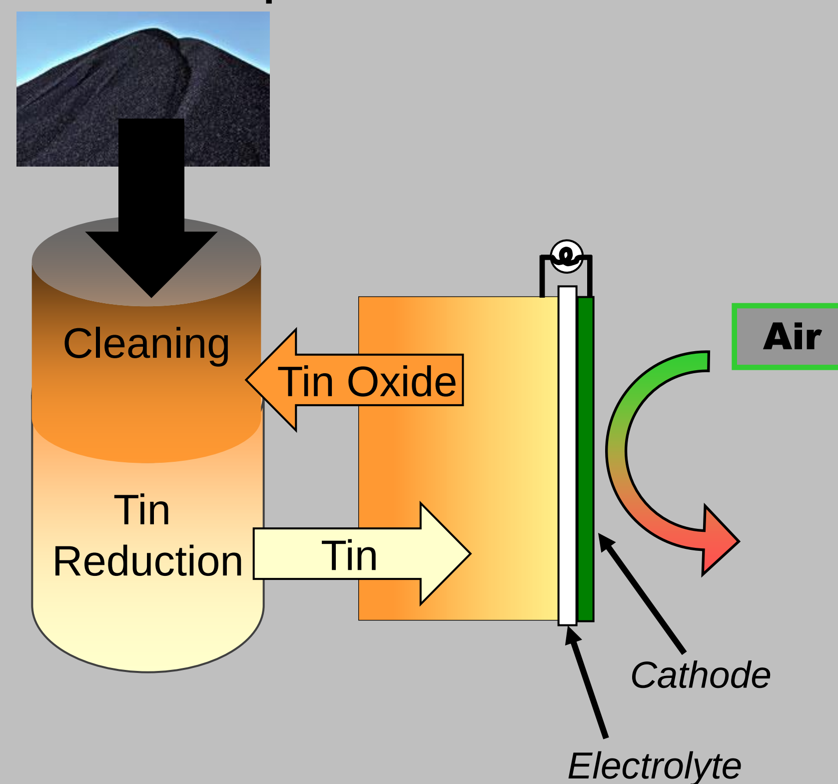
<u>Above 1 MW</u>

"Direct Coal Fuel Cell"

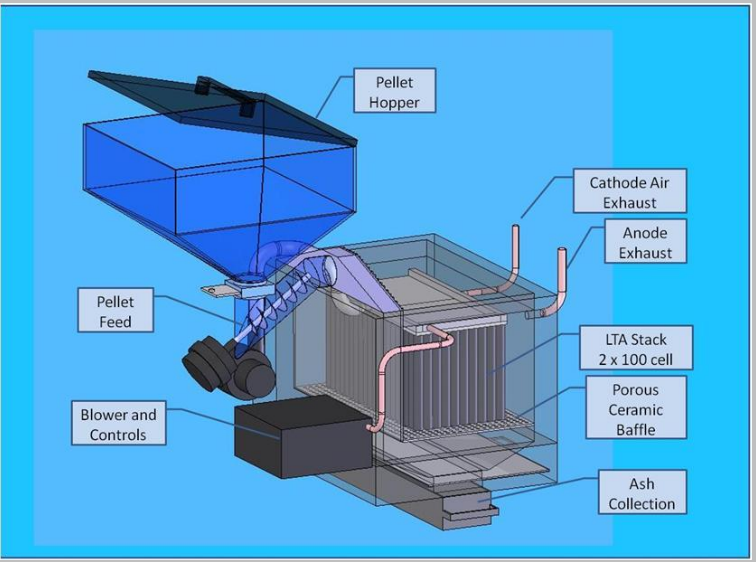
Tubular cath/electrolyte

Chemical reactor separate from fuel cell power reactor

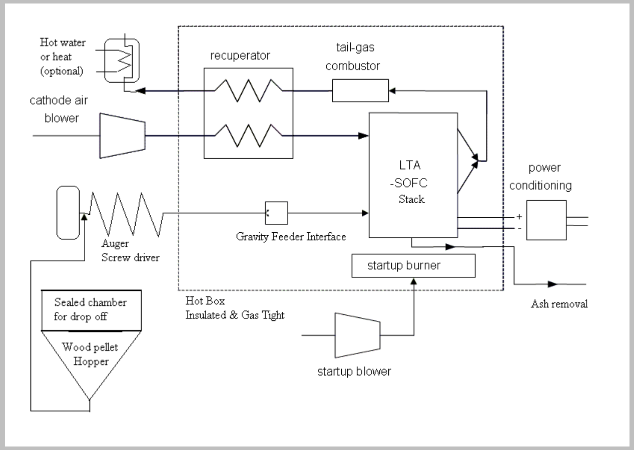




Direct biomass conversion in LTA-SOFC



Direct Wood Pellet Conversion



NSF Phase I: Direct biomass to electricity

- Same ONR cell architecture
- Applicable to recycles & waste
- Factors affect efficiency and performance
- Leads to kWatt to MW biomass system

With modification suitable for

- **Poppy seed (oil)**
- **Waste to Energy**

Acknowledgements

LTA-SOFC Gen 3.0 and Gen 3.1 funded by

- DARPA/DSO, Dr. Rosemary Szostak
- DARPA/ARMY, Dr. Valerie Browning

Advanced Cell Gen 3.2 funded by

- ONR Contract, Mr. Cliff Anderson

JP-8 startup funded by

- Army ARL/CERDEC, Dr. Rob Mantz;

Liquid Tin Anode Fundamental study funded by

- ONR, Dr. Michele Anderson
- ARO, Drs. Dick Paur and Rob Mantz

Liquid Tin Anode 125 watt stack and battery charger for direct JP-8 conversion funded by:

- Army/ARO, Dr. Rob Mantz; CERDEC, Mr. Shah

Direct coal conversion funded by NETL and SBIR

- NETL, Dr. Joe Stoffa

DIECRT biomass conversion funded by NSF

- NSF, Dr. Tony Walters

CellTech Power , led by Dr. Thomas Tao

(M. Koslowske, L. Bateman, J. Brodie, M. Slaney, C. Mackeen, J. Bentley)