Direct Coal Conversion

In

Liquid Tin Fuel Cell

Fuel Cell Seminar
Palm Springs, CA
November 19, 2009

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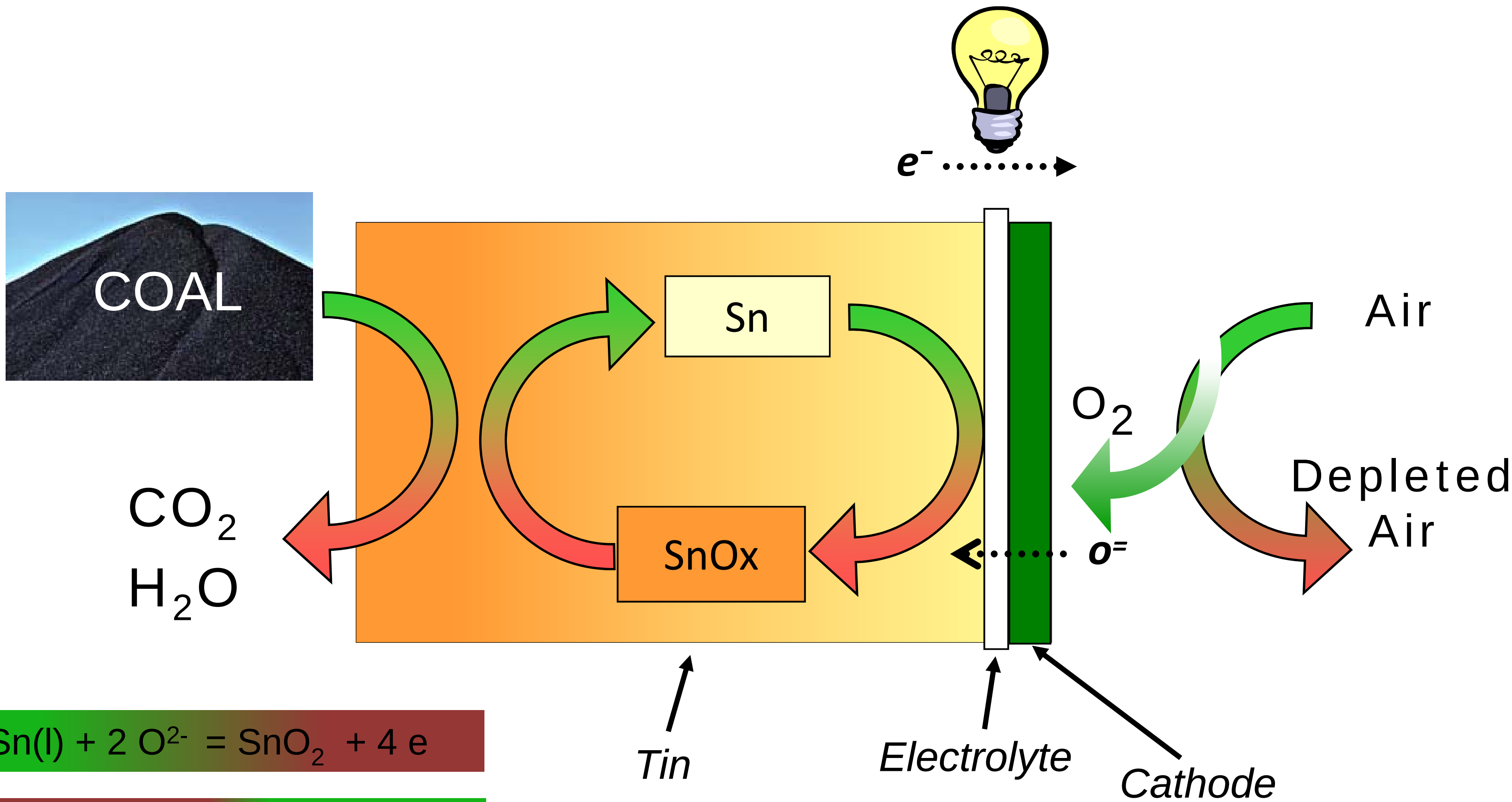
Direct Coal Power

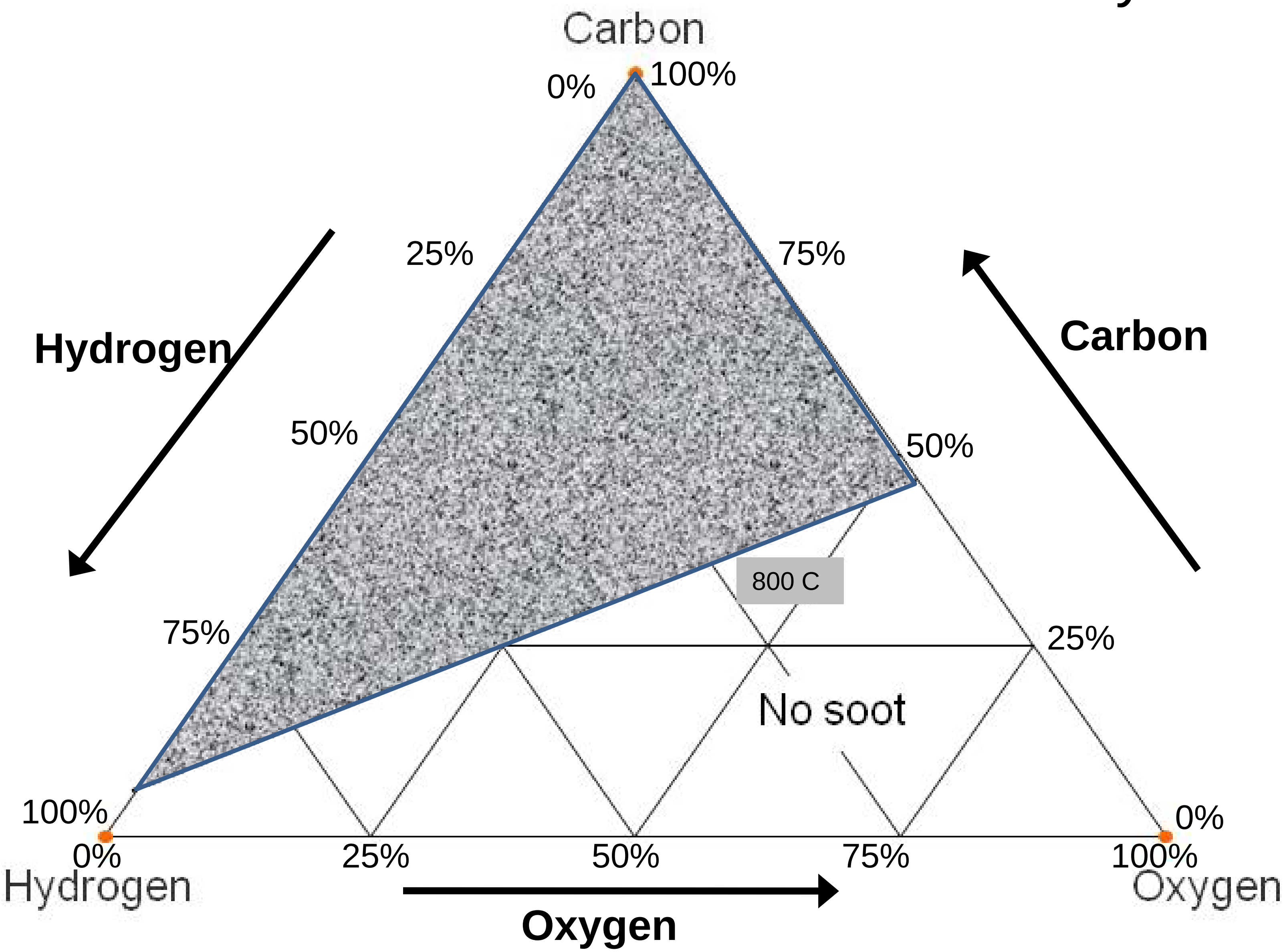


$Sn(l) + 2 O^{2-} = SnO_2 + 4 e$

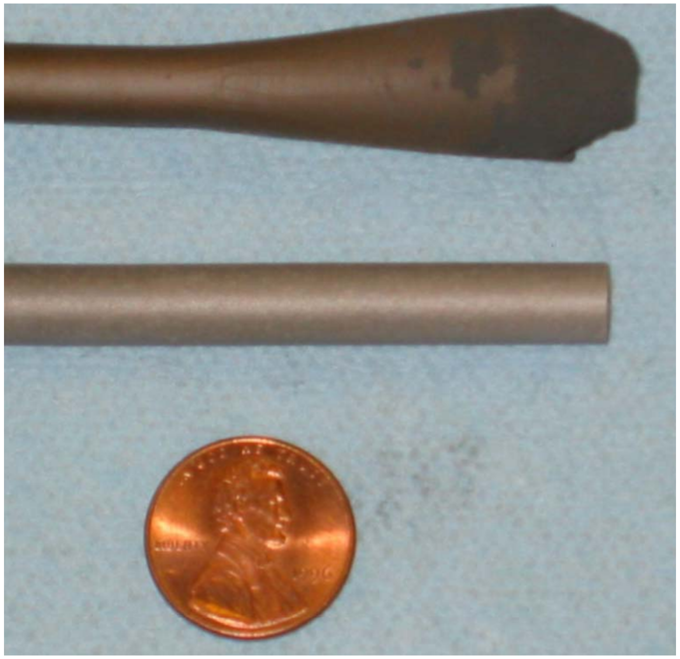
$SnO_2 + C(s) = 2 CO_2(g) + Sn$

C-O-H Chemistry Defines Soot

And Soot Defines Commercial Viability

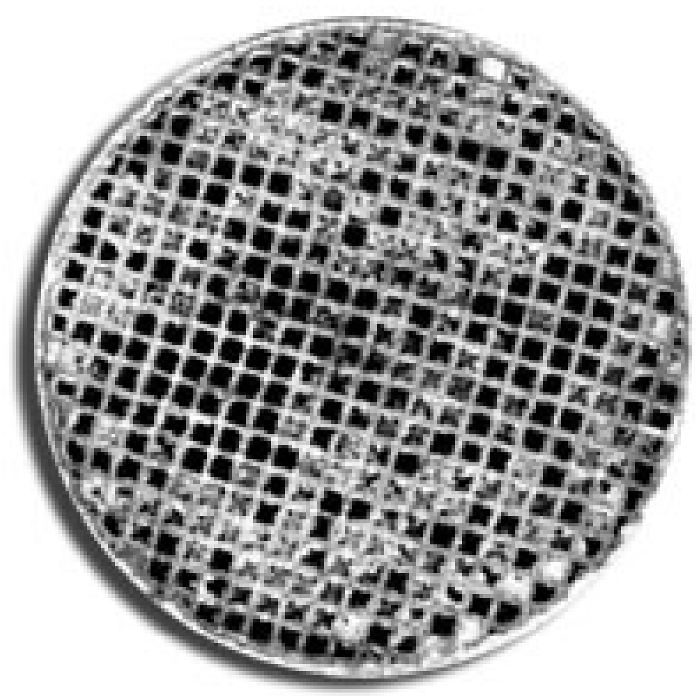


Soot: Biggest Enemy of Fuel Cells



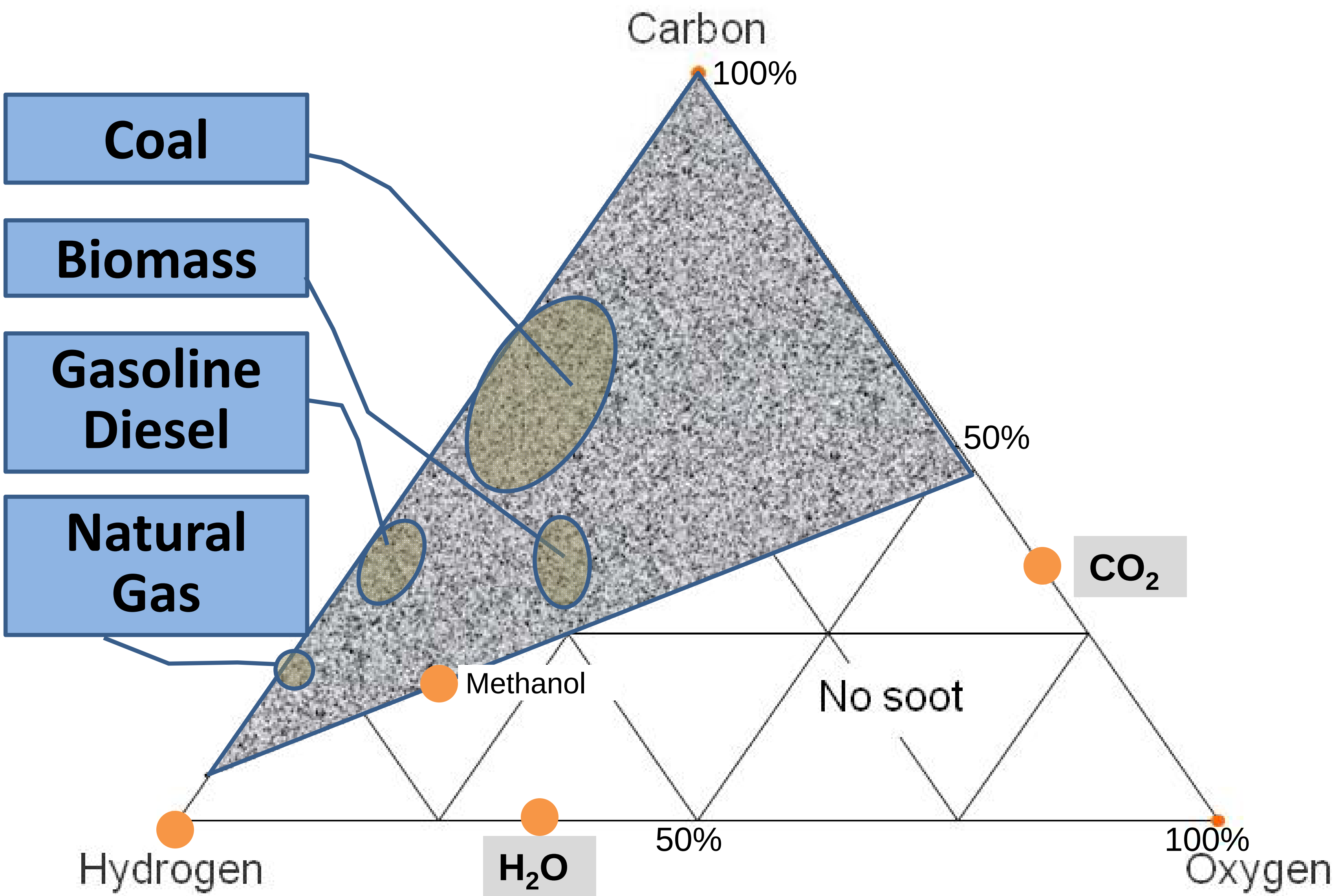
80% CO, 20% CO_2 800° C

Quickly Kills Catalysts

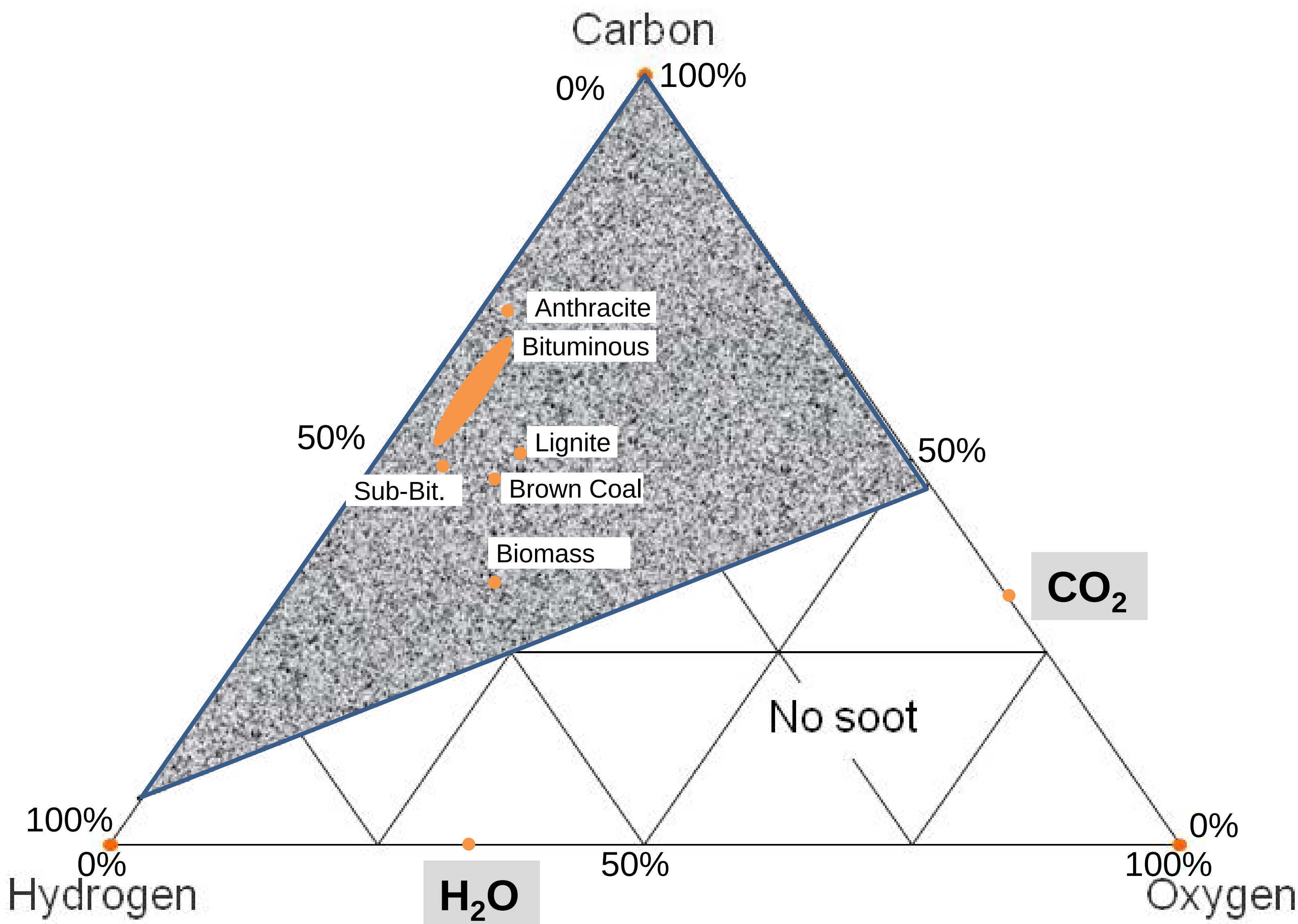


Clogs Passages

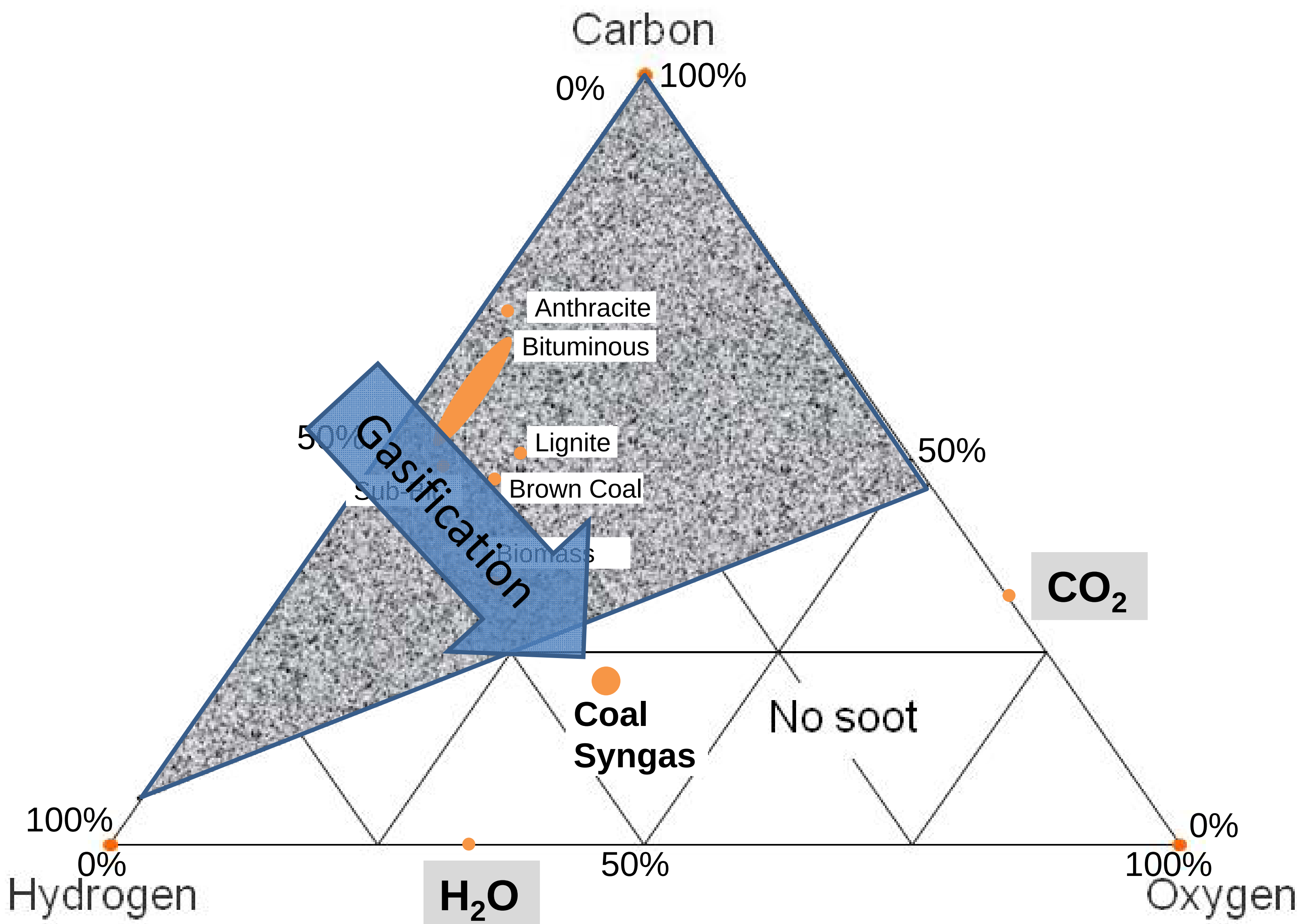
Most Useful Fuels Make Soot



All Forms of Coal Will Make Soot

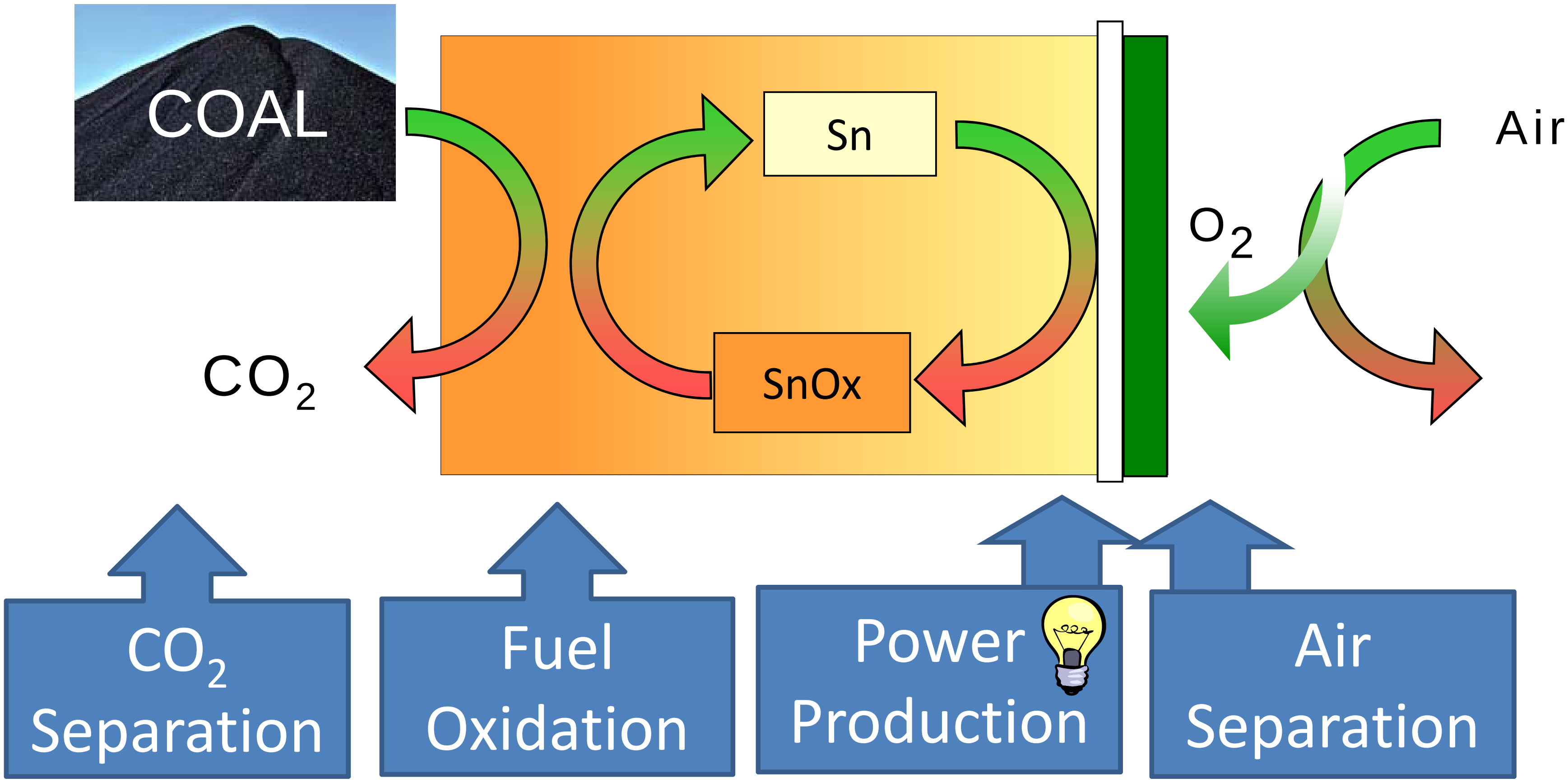


Gasification Consumes Energy



ElectroChemical Looping

Direct Coal Power using Liquid Tin Anode



Direct Coal Power Using Liquid Tin

- Simpler, more efficient than other coal tech
  - 60+% efficiency at same/lower capital cost
- Enhanced CO_2 capture
  - low efficiency impact
  - Near 100% pure CO_2 stream
- NO Combustion- Integral Air Separation
  - Chemical Looping w/ Integrated Power Production
- Scale up of existing Direct JP-8 technology
- Contamination resistance looks promising

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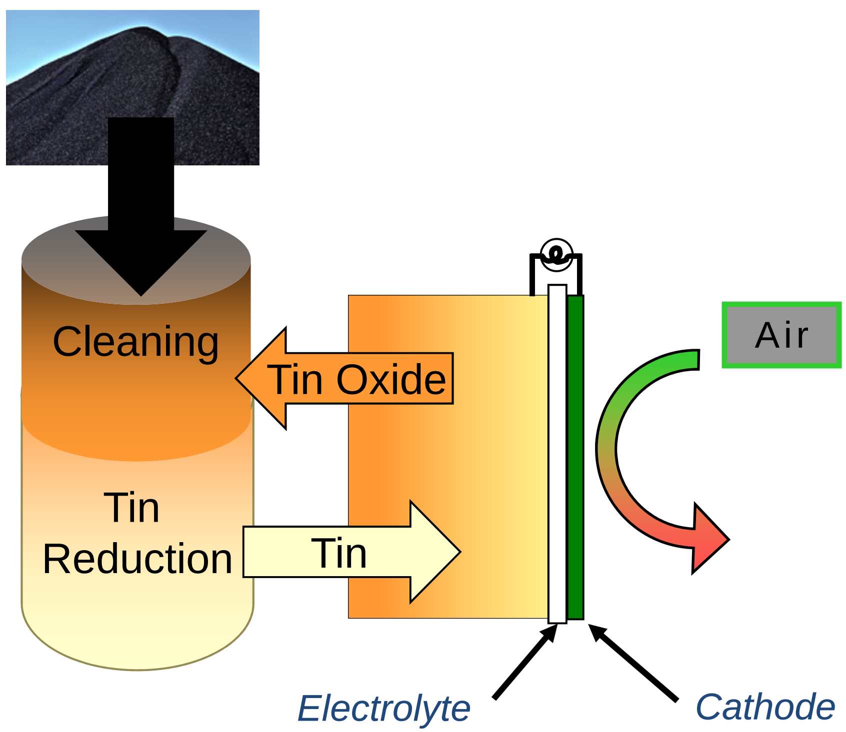
Architecture Options

ElectroChemical Looping

Tin Reactor - Direct Coal

Cathode/Electrolyte cell

Chemical reactor separate from fuel cell power reactor

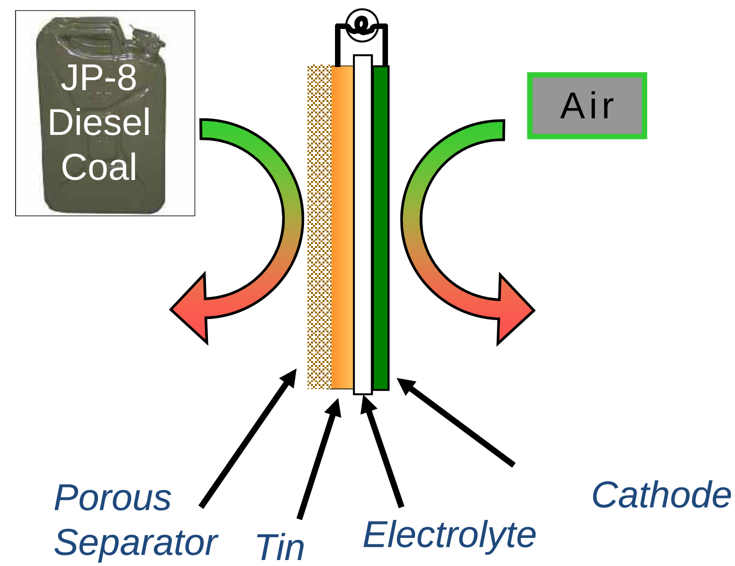


In-Situ Gasifier– alternative

Based on Gen 3.1 cell design used for portable power

Thin static tin layer

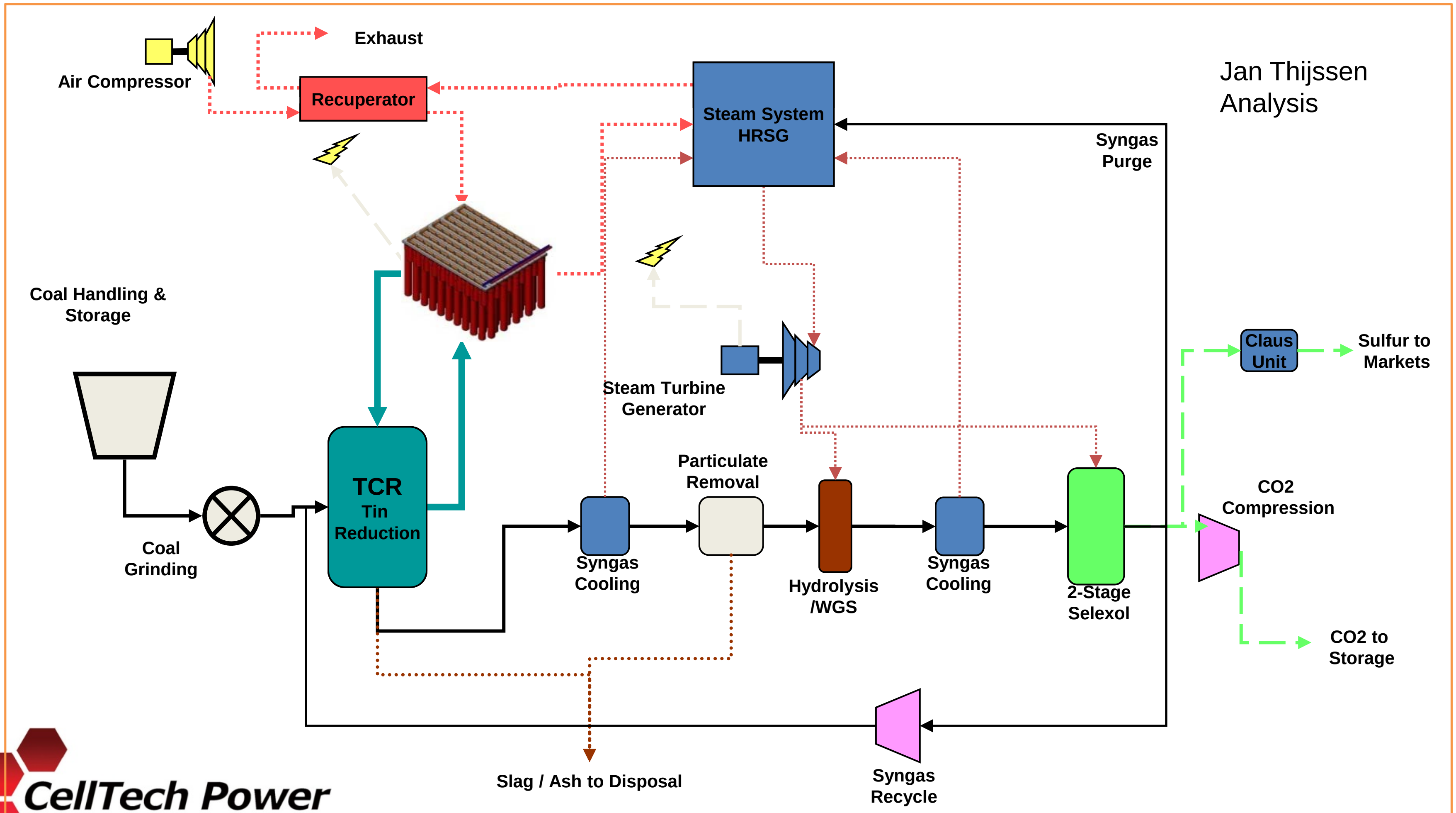
Contained by separator



Baseline concept: ElectroChemical Looping

TCR processes coal and all recycled syngas. LTA-SOFC immersed in tin pool. Circulating tin provides all species transport to anode.

High-Level PFD of LTASOFC with CCS



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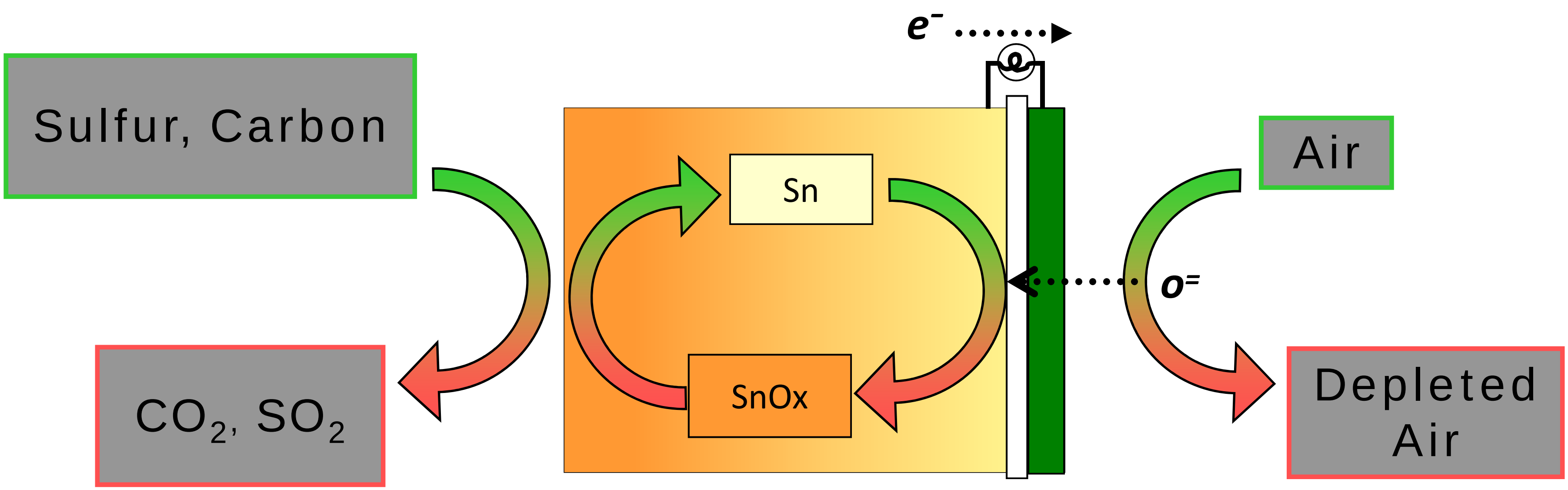
Fuel Cells for Real Fuels

Poisons Become Fuels

Sulfur and Carbon: The Achilles Heel of all other fuel cells



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Coal Contamination

Tin is unique anode for Direct Coal

- Liquid = no physical structure (no sulfur attack)
- High contact with fuel
- Gravimetric separation of ash
- Demonstrated high efficiency with YSZ electrolyte

Direct Coal Challenge: Impurities

- Metals such as Vanadium attack YSZ
- Can tin reduce or eliminate impurities?
- Is what remains in tin harmful to fuel cell?

Contamination Evaluation

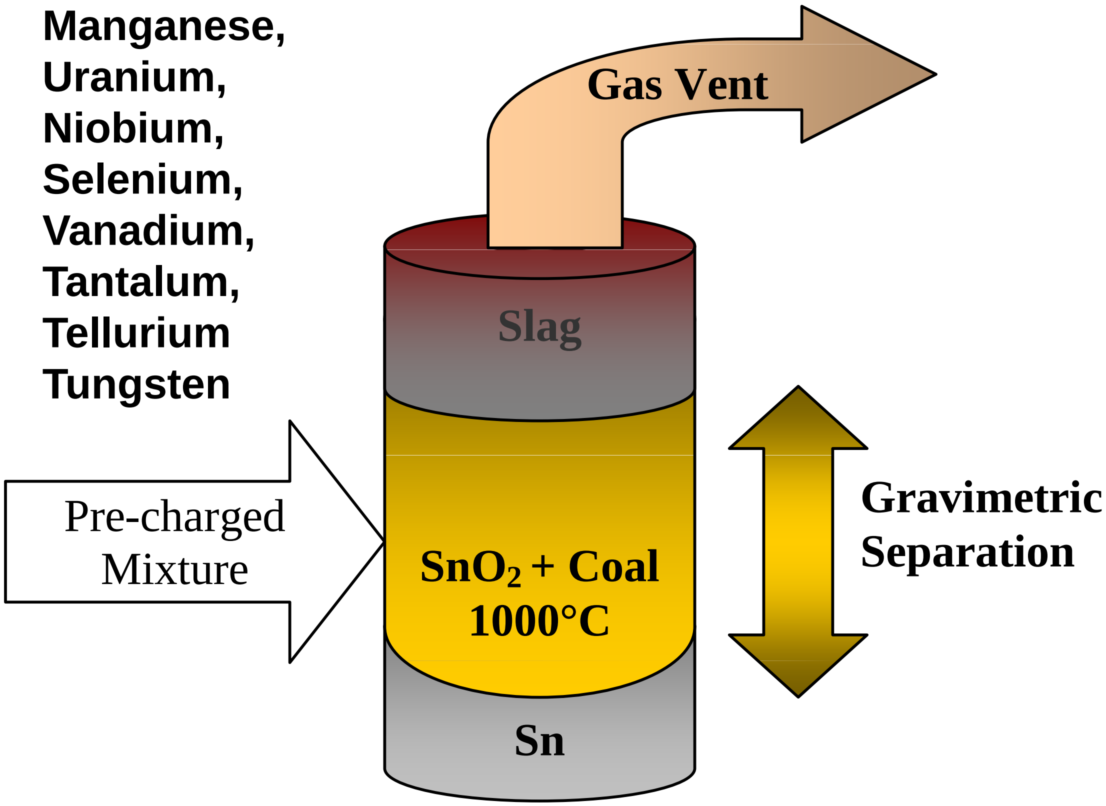
YSZ
- Analysis of contaminants that can harm YSZ electrolyte
- Experimental confirmation

Tin
- Experimental evaluation of contaminants solubility
- Coal/tin equilibrium reactor

Cell
- Electrochemical testing of cell spiked with contaminants.
- Using existing Gen 3.1 cells

Experimental Evaluation of Contamination Levels

Arsenic,
Chromium,
Molybdenum,
Manganese,
Uranium,
Niobium,
Selenium,
Vanadium,
Tantalum,
Tellurium
Tungsten



Procedure
Batch mode
Coal in tin reactor 1000° C
Wyoming-DECS 26
Slightly reducing stoich
Coal reacted to completion
GDMS analysis of tin

Results
Arsenic, Selenium present after reaction
All others below detectable limits 10ppb

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Experimental Efficiency Evaluation

Batch mode, single cell

	Bio-char Univ of Hawaii	**Coal** Pulverized East/West
Net power measured at test stand load	34%	37%
IR and Air Corrected	67%	>57%

Without correction for fuel utilization

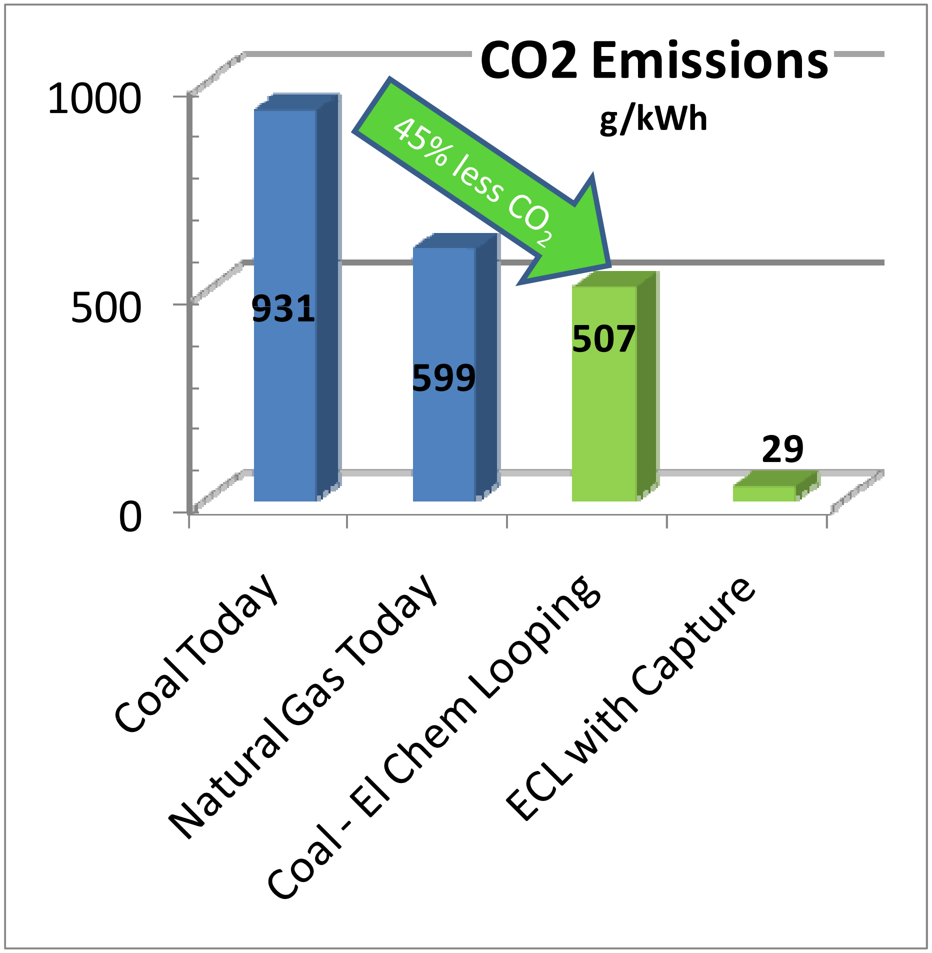
Test Limitations

- Volatile loss – boil off at lower temp, hot loading not practical in this program
- Air Leaks - test article set not ideal

250 MW System Analysis

Projected System Performance		
Fuel Cell Stack	Maximum O Content (mass)	0.1%
	Cathode Stoichiometry	1.22
	Stack Temperature	1000°C
	Cell Voltage	0.69 V
	Fuel Cell Gross Power	250 MW
TCR	Anode Recycle	75%
System	Steam Cycle Power	45 MW
	Parasitic Load	13 MW
	System Efficiency (HHV)	**63.0%**
	Carbon Emissions	**29 g/kWh**

More Energy, Fewer Emissions From Coal Power



ElectroChemical Looping is more efficient- makes 45% less CO_2, pollutants and ash.

Coal power with lower CO_2 than natural gas.

Adding Carbon Capture reduces CO_2 to 3% of today's coal plants (DOE).

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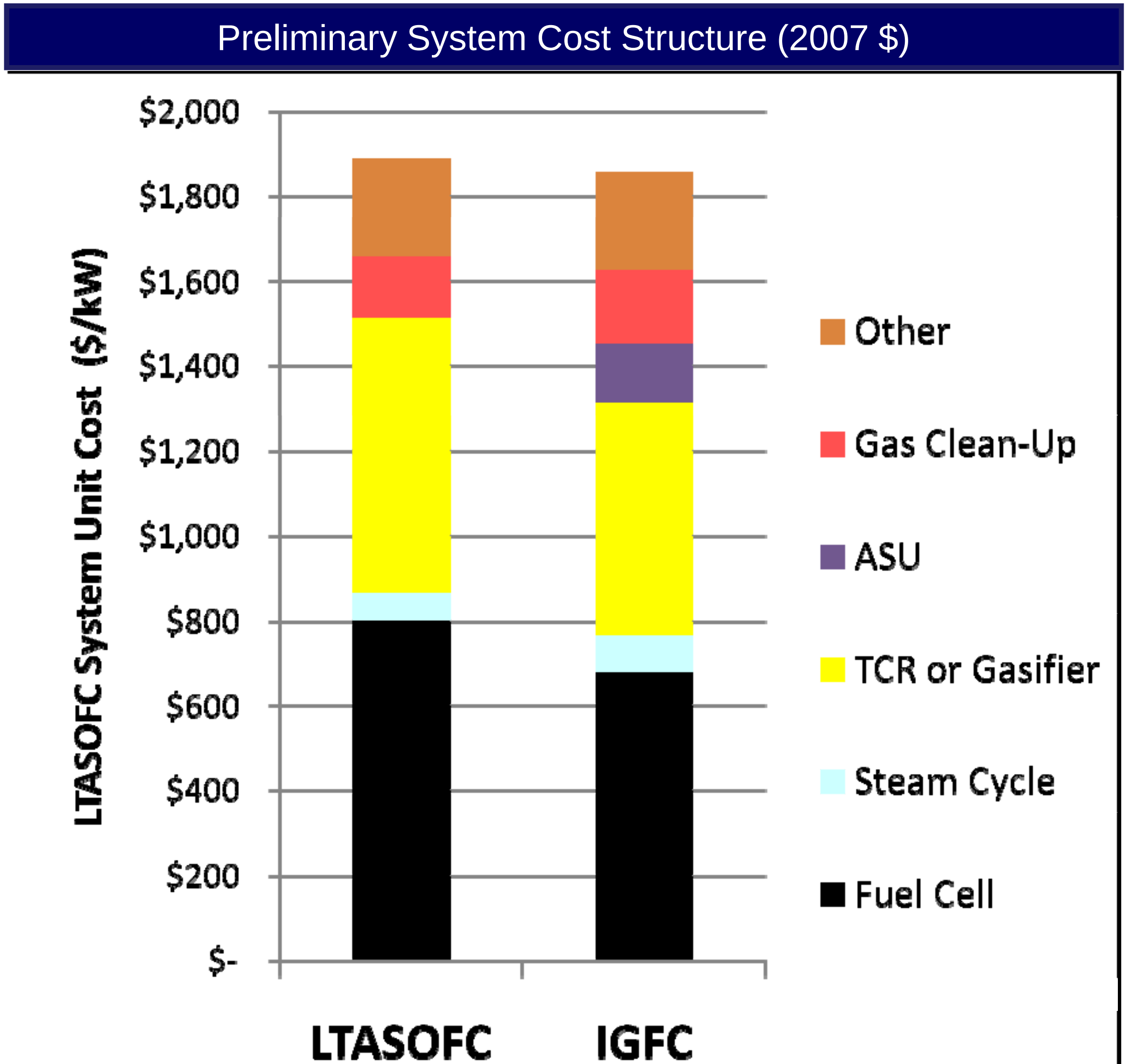
System Cost Estimate



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Fuel Cells for Real Fuels

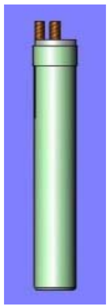
J. Thijssen, LLC

Technical Conclusions

- ElectroChemical Looping based on circulating tin anode looks promising
  - 63% efficient
  - Competitive cost
- Coal contamination is major area of concern
- Tin/Coal Reactor acts as a separator and purifier- rejecting contaminants under certain conditons.
- 1 kW cell feasibility study complete

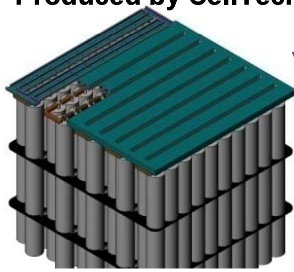
First Market: Portable Power

Liquid Tin Anode
Direct Diesel/JP-8
Produced by CellTech



5 watts
160 mW / m²
49 g
100 cycles
1,000 hours

500 W Stack
Produced by CellTech

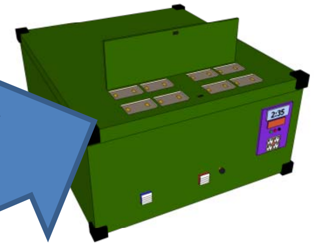


500 Watts
100 cells
6 kg
20x20x25 mm
10 liters

Portable charger
Uses logistics fuel

Diesel generator operates
on low cost fuel

Quiet Efficient Generators
Produced by Integrators

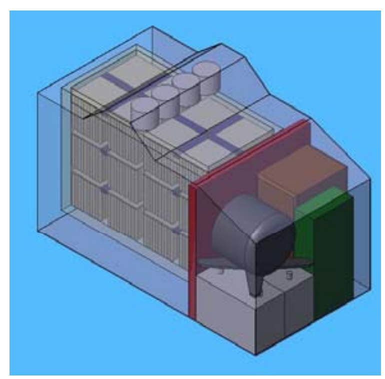


JP-8 Battery Charger

10 kg
20-50 liters
4 x BB-2590
2 hr Recharge

Self Powered Heater

60,000 BTU
No external power req'd
Starts in 5 minutes
Diesel or Kerosene



Diesel APU

5-10 kW
200-400 liters
Same size as engine gen for RV's

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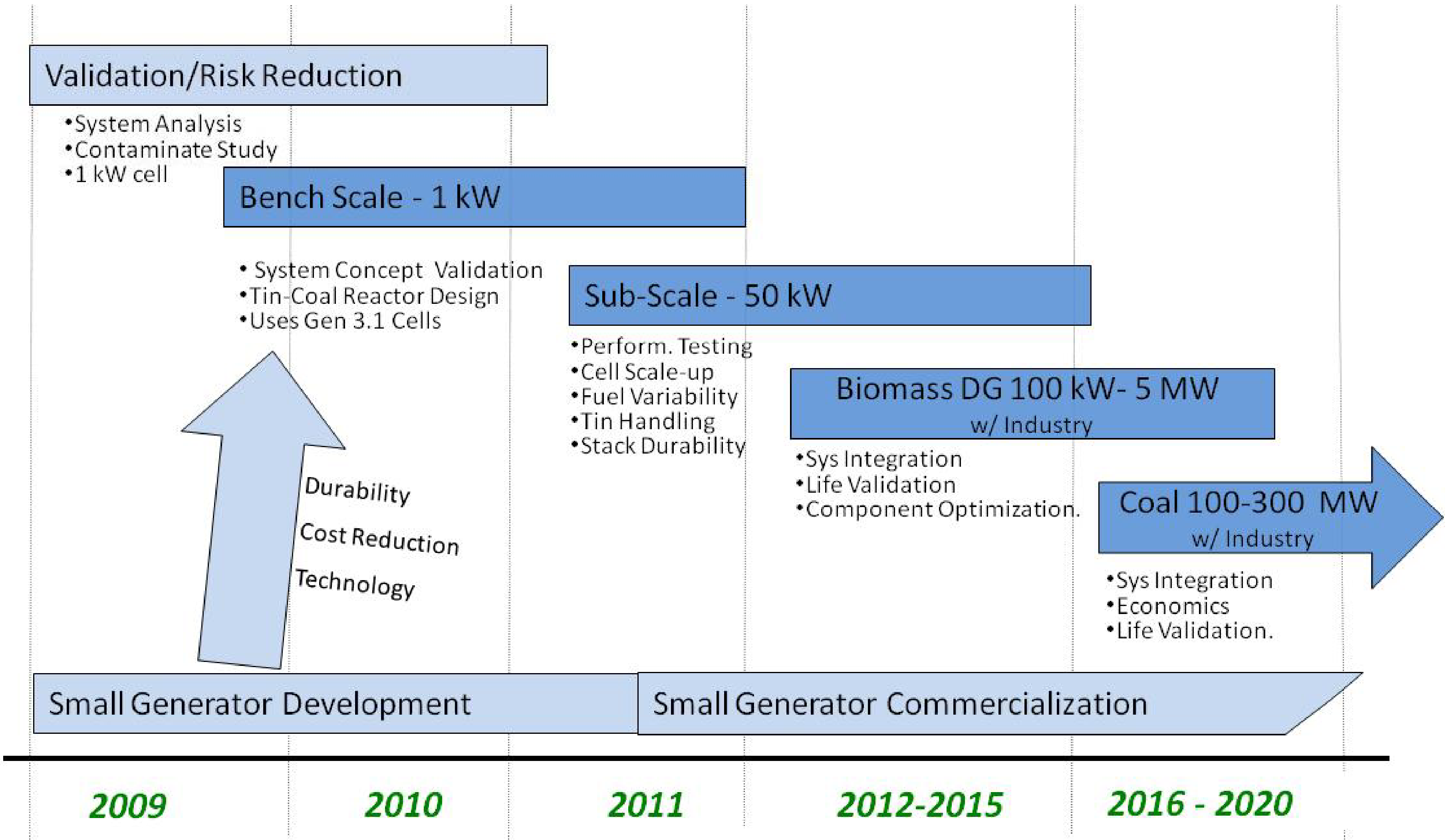
Fuel Cells for Real Fuels

Plan For Commercialization



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Summary – Liquid Tin Anode

- Tin "purification" decouples coal oxidation from power production
- Could achieve breakthrough efficiency and enable 100% CO_2 capture
- EPRI & DARPA programs have established feasibility of Direct Coal/JP-8
- Strong DoD support for small cells provides an R&D platform for coal
- DOE programs focus on impurities
- Cooperative programs planned for "balance of system" technology development

Acknowledgements

Team at CellTech Power

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