Direct Conversion of Coal and Coal-Derived Carbon in Fuel Cells

The Washington Coal Club

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by

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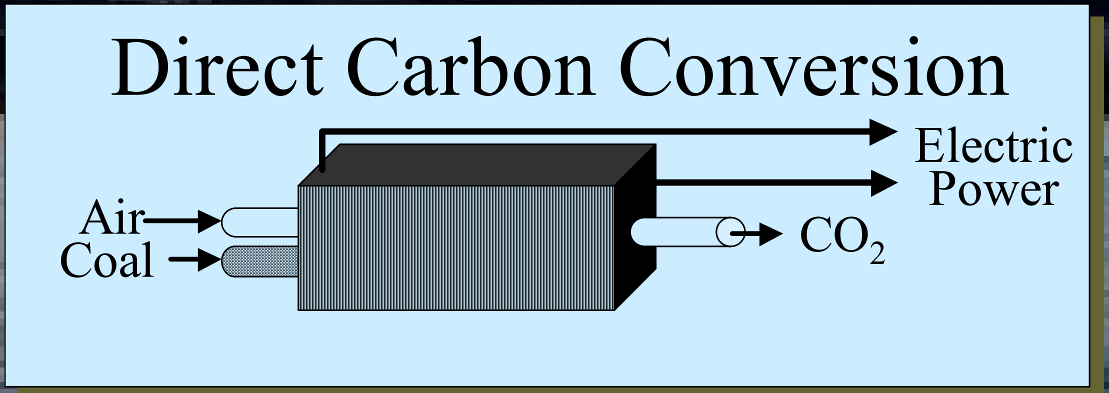
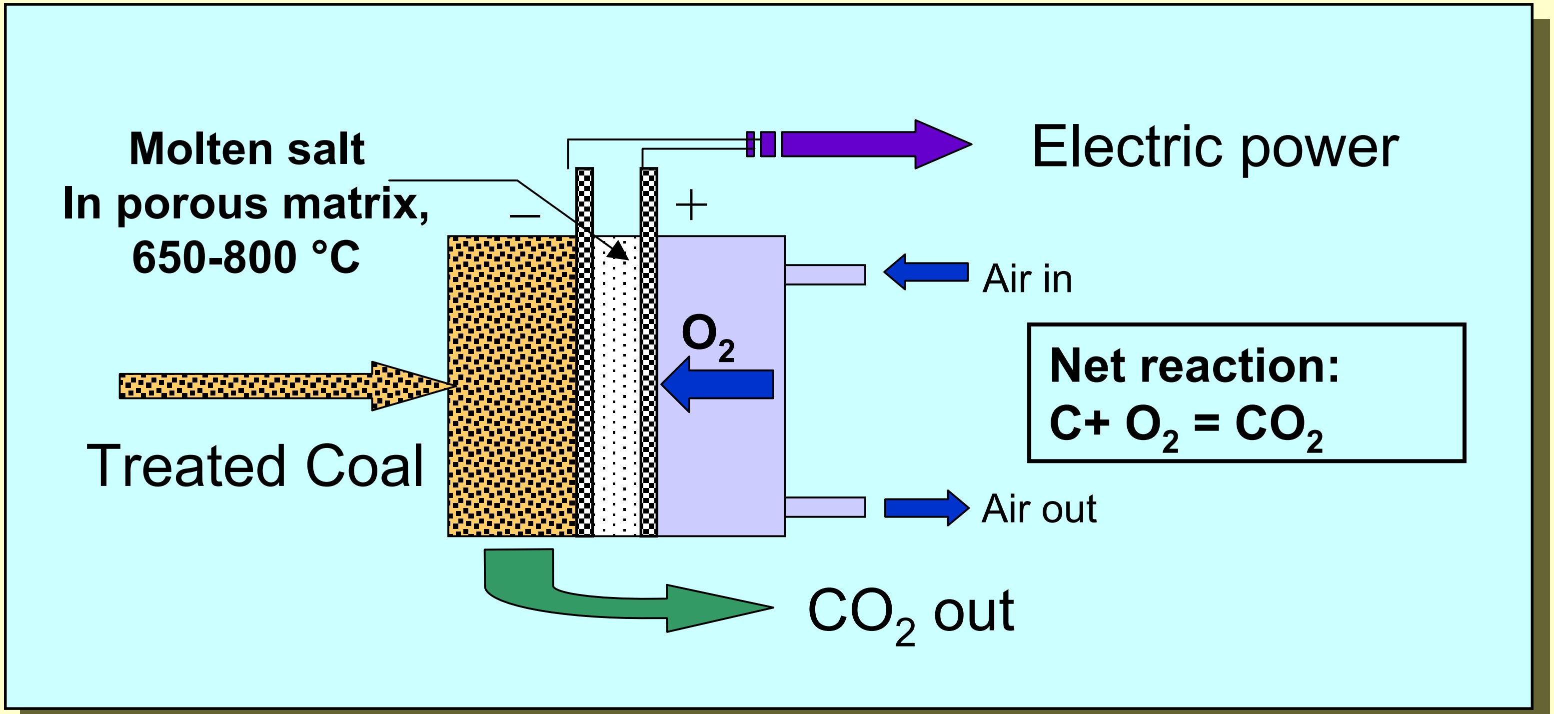
We Propose a New Vision for Coal

- We invented a carbon fuel cell that doubles the MWH per ton of coal
- We demonstrated 80% efficiency, which cuts CO_2 emissions in half
- The process is low-cost eases and the problem of pollution control



Direct Carbon Conversion Fuel Cell Converts Carbon to CO_2 and Electricity



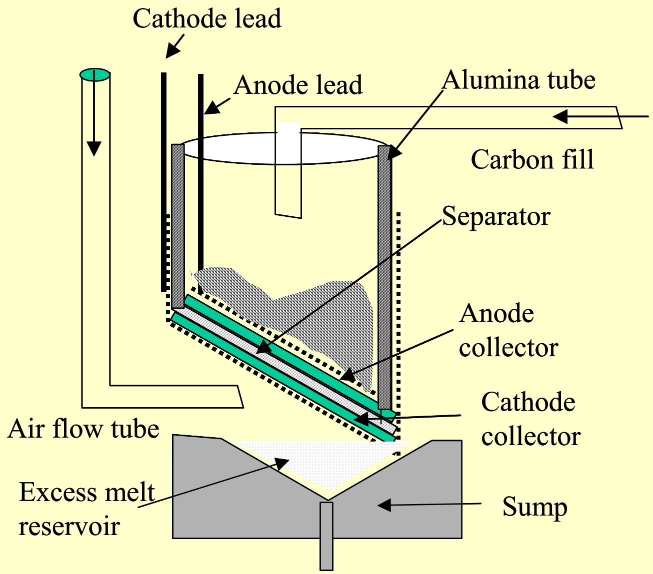
- All carbon consumed in single pass, and the product is pure CO_2
- Treated coal with reduced ash behaves similarly to "pure" carbon
- The electric energy produced is equal to 80% of the treated coal energy

DCC Eases Pollution Control

- DCC emission is nearly pure CO_2
- Ten-fold Reduction in offgas volume per MWH
  - 5X—no nitrogen in “flue gas”
  - 2X—80% efficiency cuts all “flue gas” in half per ton of coal
  - Reduces costs of sulfur removal
- Fuel cell retains regulated emissions in molten salt (e.g., mercury, vanadium, thorium)

Test Configuration Controls Fuel Wetting, Scales, and Points to Industrial Configuration

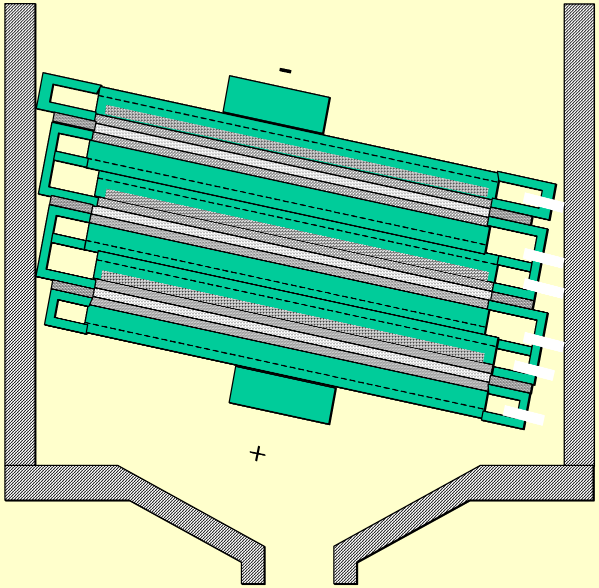
2.8 cm² angled cell



60 cm² cell

(4 x 8 inches)

Approach to industrial scale

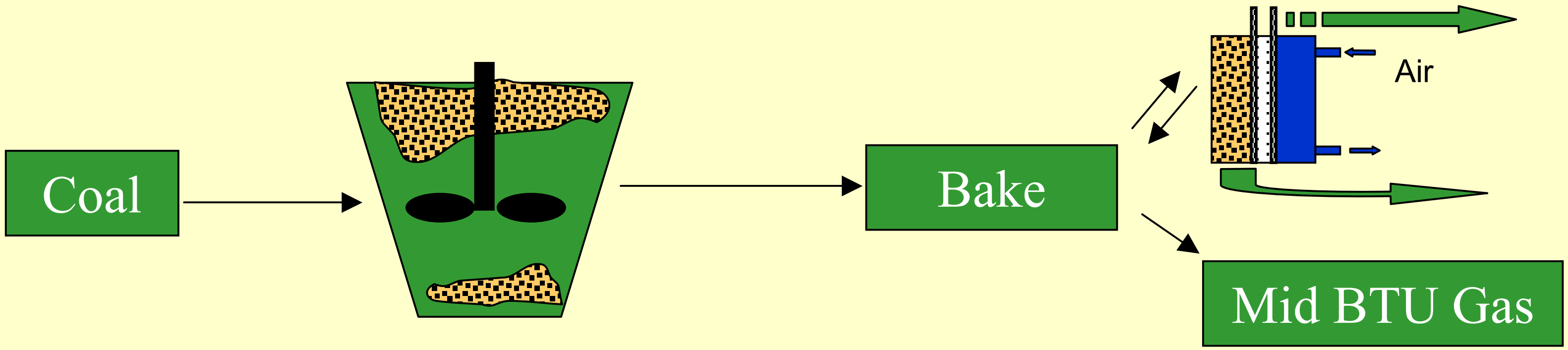


Preliminary costs of stack ~ \$250/kW @ 2 kW/m²

5-year life of cell (graphite corrosion at 50 µm/y)

Cooper, Krueger ,Cherepy, IL-10848

Treated Coal (Mechanical Method)

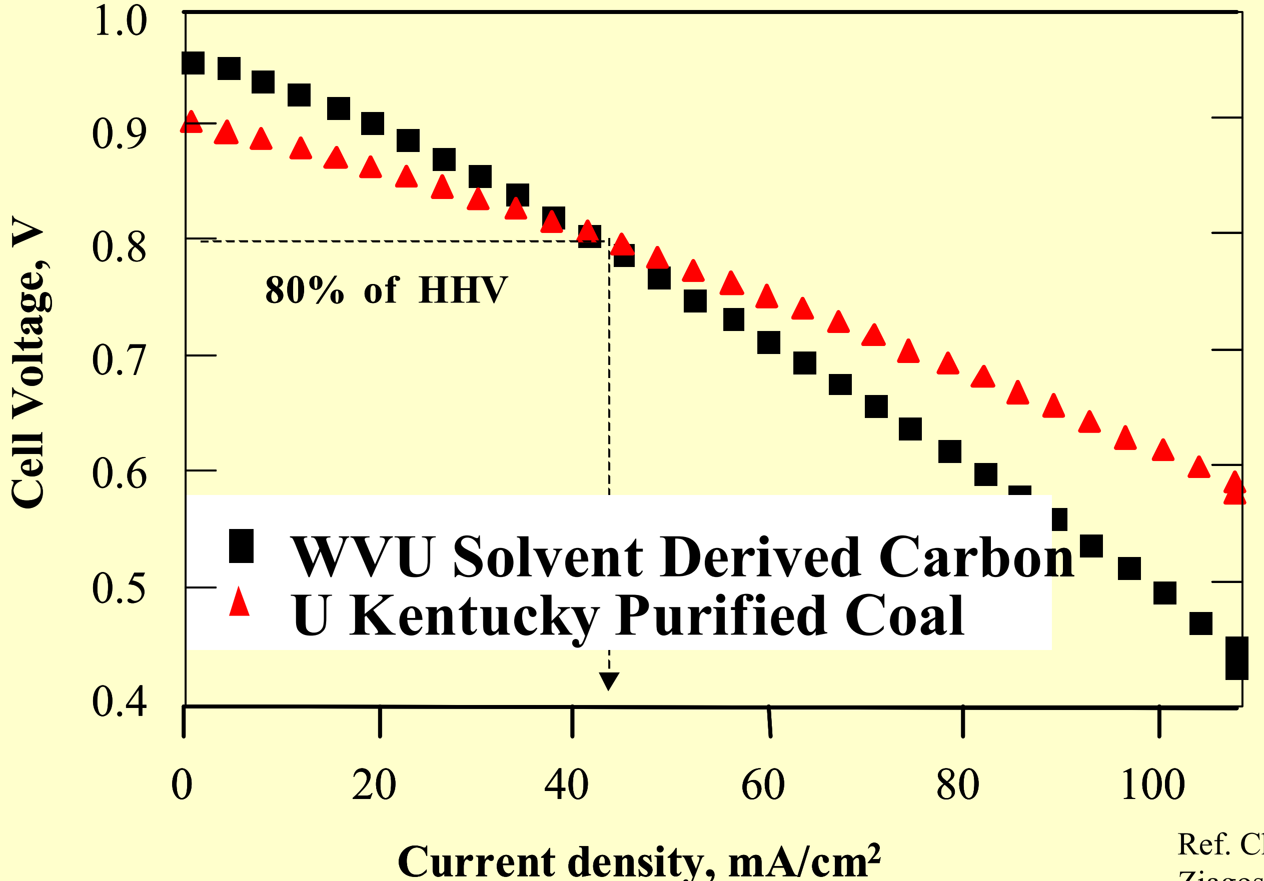


Ash and pyrite separation by
fine grinding of coal,
using surface chemical methods
(65 kWh/ton)

- Mechanical separation yields fuel with <1 % S, ash (Kentucky low S, bituminous)
- Total fuel cost $60/ton => 0.8 ¢/kWh ; energy 65 kWh/ton
- Ash requires electrolyte exchange (2-3x per year)

Ref.: B. K. Parekh,
CAER, U. Kentucky

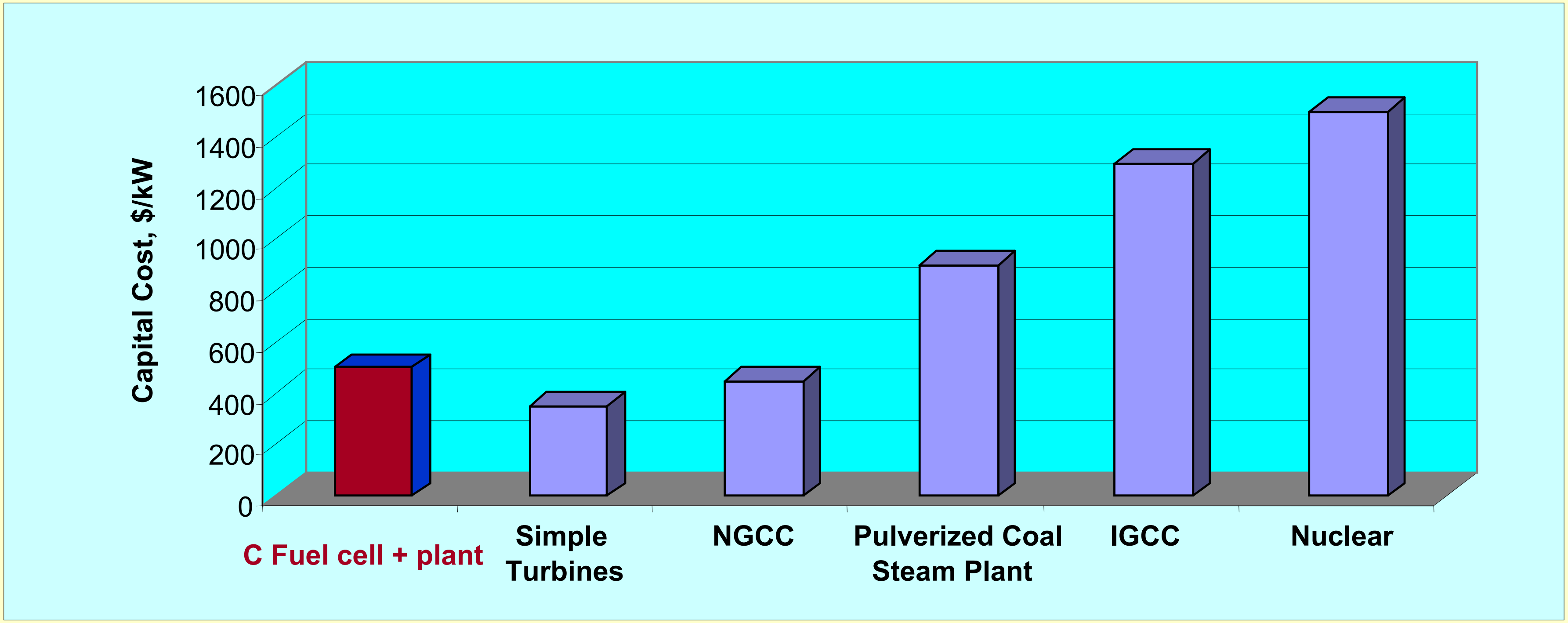
Our Data Supports the Conclusion of 80% Efficiency



Ref. Cherepy, Cooper, Ziagos UCRL-144849 6/2002

80% Efficiency Achieved at Practical Rates for two of Many Treated Coal Methods

Estimated Relative Capital Cost



- Stack costs at $250/kW based on current cell designs
- Balance of plant: powder feed, offgas clean, heat recovery to feed

Challenges and Benefits

Engineering Challenges

- Scale up laboratory cells
- Determine coal fuel cell life time
- Demonstrate entrapment and removal of regulated emissions in salt
- Removal of sulfur from “flue gas”

Benefits

- Very high efficiency achieved—in single step
- No explosive gases (no hydrogen)
- Facilitates emissions control
  - 10x lower offgas per MWh
  - ash retained in liquid

We are Starting Small, but We're Definitely Onto Something Good

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LLNL Team

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Advice and collaboration

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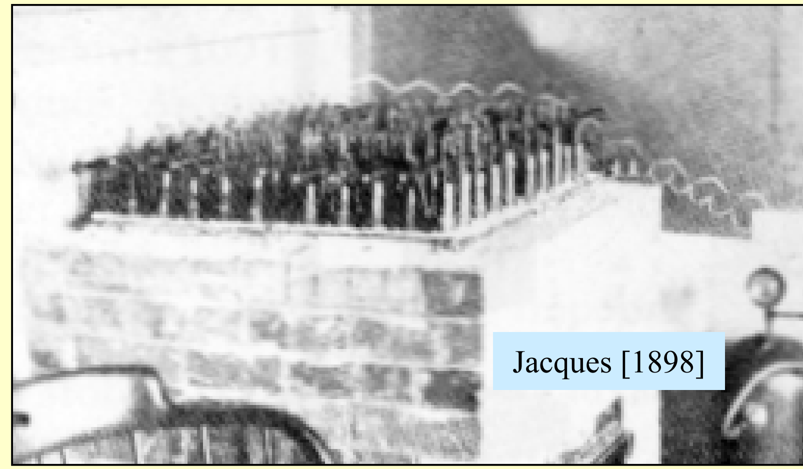
Questions or Comments?

We Believe We Have Overcome Historical Barriers to "Electricity Direct From Coal"

History

- Jacques: 15 – 40 kW coal batteries
- SRI found 10^5 x range in rates for fuels
- Vutetakis (OSU) tested coal slurries

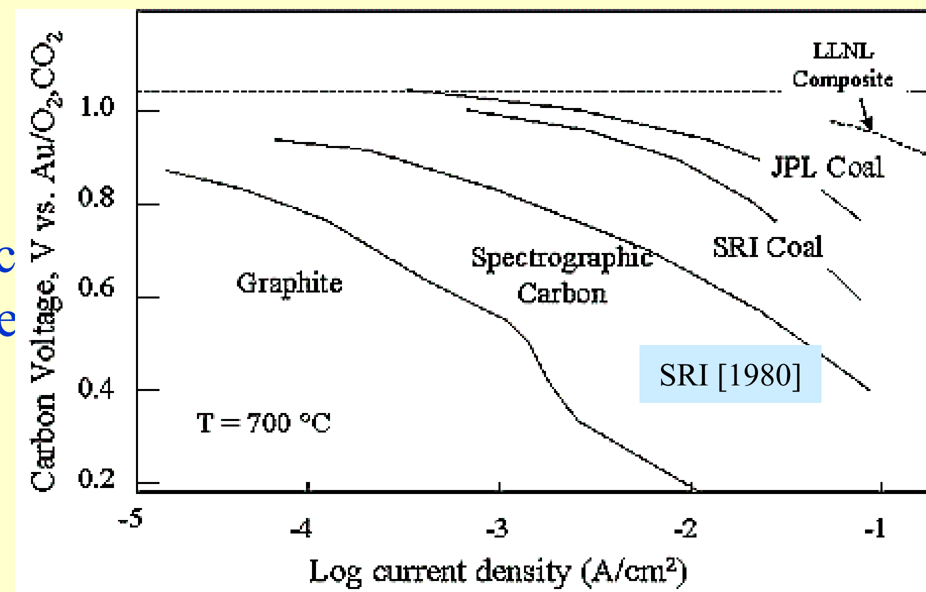


Barriers to "Electricity Direct from Coal"

- Low rates, Boudouard [C+ CO_2=2CO]
- Fouling of melt
- Feeding solid fuels

What's New Here?

- LLNL [1999] built first DCC fuel c
- Found atomic disorder controls rate
- Slurry cells, powder distribution
- Boudouard corrosion avoided



Carbon is an "Ideal" Fuel for a Fuel Cell

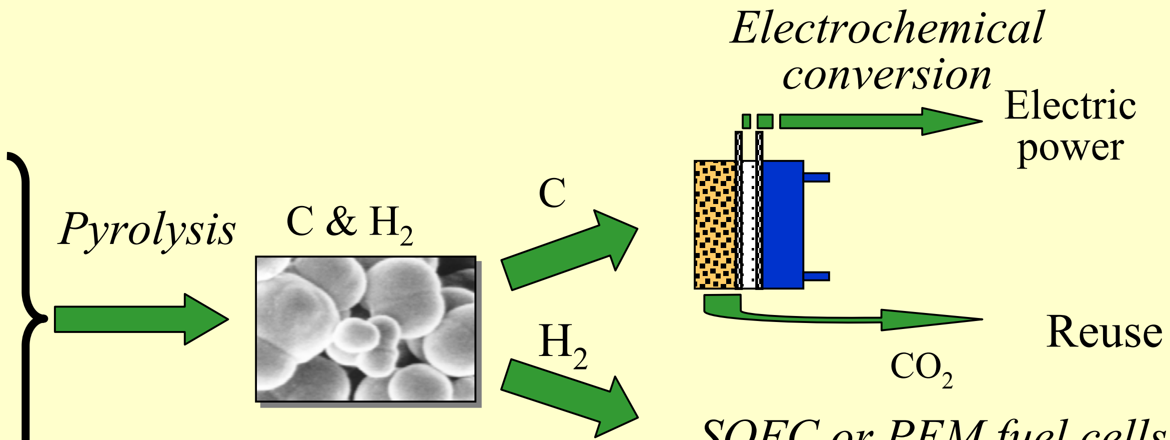
- "Efficiency" is kWh-net/HHV_{fuel}
- Theoretical x Utilization x Voltage = Efficiency
- DCC has 100% theoretical yield and utilization, and modest voltage losses

Fuel	Theoretical limit = $\Delta G^o(T)/\Delta H^o_{std}$	Utilization efficiency, μ	V(i)/V(i=0) = ε_v	Efficiency = $(\Delta G/\Delta H^o_{std})(\mu)(\varepsilon_v)$
C	**1.003**	**1.0**	**0.80**	**0.80**
CH_4 [a]	0.895	0.80	0.80	0.57
H_2	0.70	0.80	0.80	0.45

Consequently, DCC efficiencies of 80% are no surprise

When all Losses Are Considered, the 70-80% of Resource Energy can be Recovered as Electric Power

- Coal, lignite
- Petro-coke
- Natural gas
- Petroleum
- Biochars

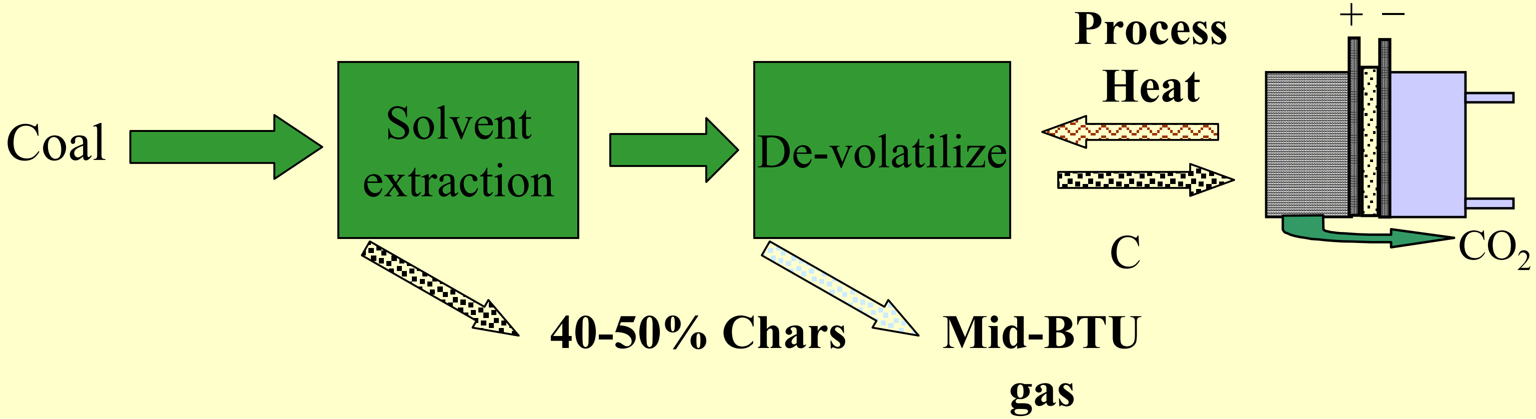


SOFC or PEM fuel cells, hybrids, turbines, ICE, feedstock, refinery, etc.

70 – 80 % efficiency, HHV

- **The pyrolysis of CH_x => C + (x/2)H_2 consumes 3-8% of fuel value**
- **Greatest advantage where C/H ratio is high**

Solvent Extraction of Pitch Yields Fuel

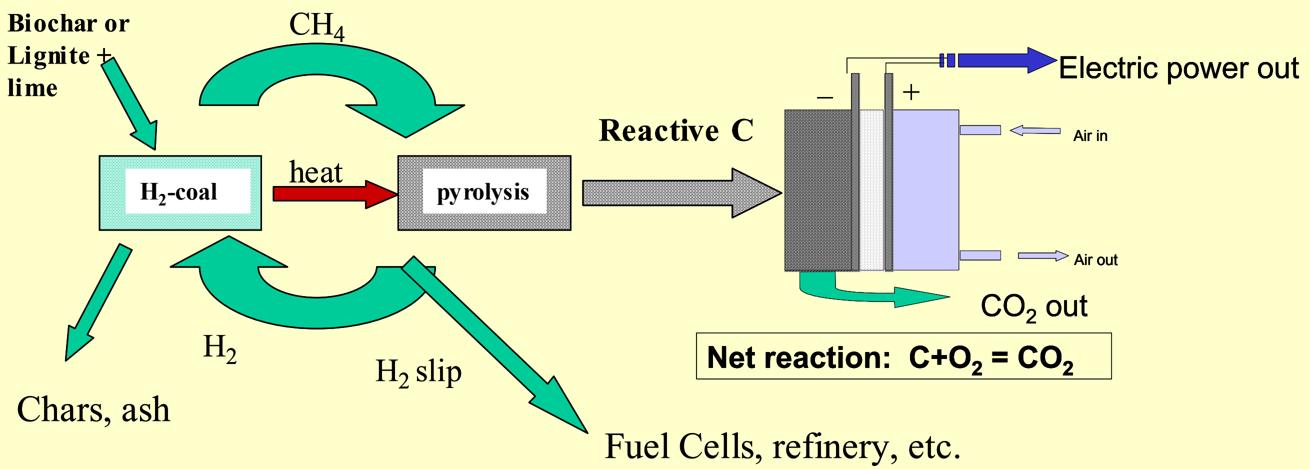


- Solvent extraction yields coal with 0.01% ash
- Solvent loss 0.7% / cycle
- Chars catalyzed for gasification
- Fuel cost ~ \$200/ton => 2.7 ¢/kWh

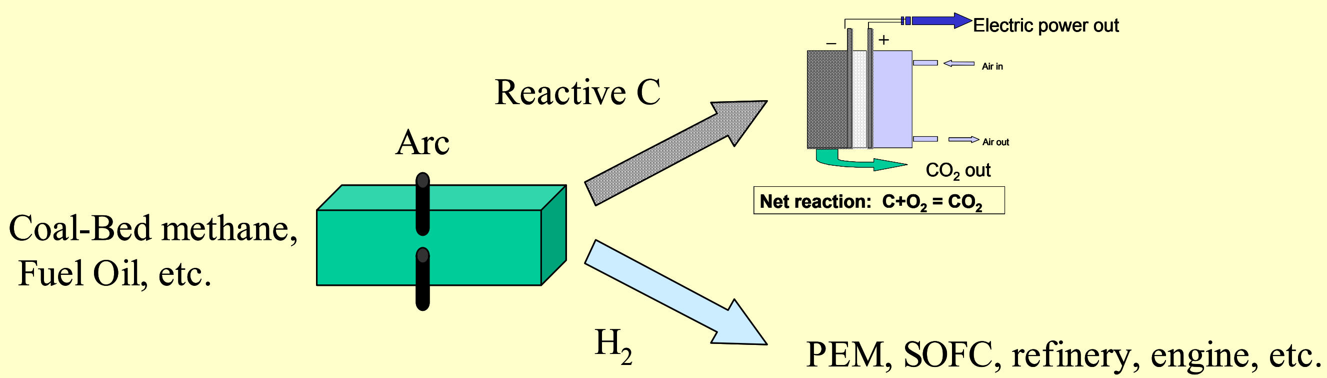
Ref.: Zondlo and Stiller, WVU

There are Other Routes to Extraction of Carbon From Coal

Rhinebraun Process



Kvaerner Process, BNL



Basic Cell Scales Up and Shows Stable Discharge