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Hydrogen from Coal

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Mitretek Systems

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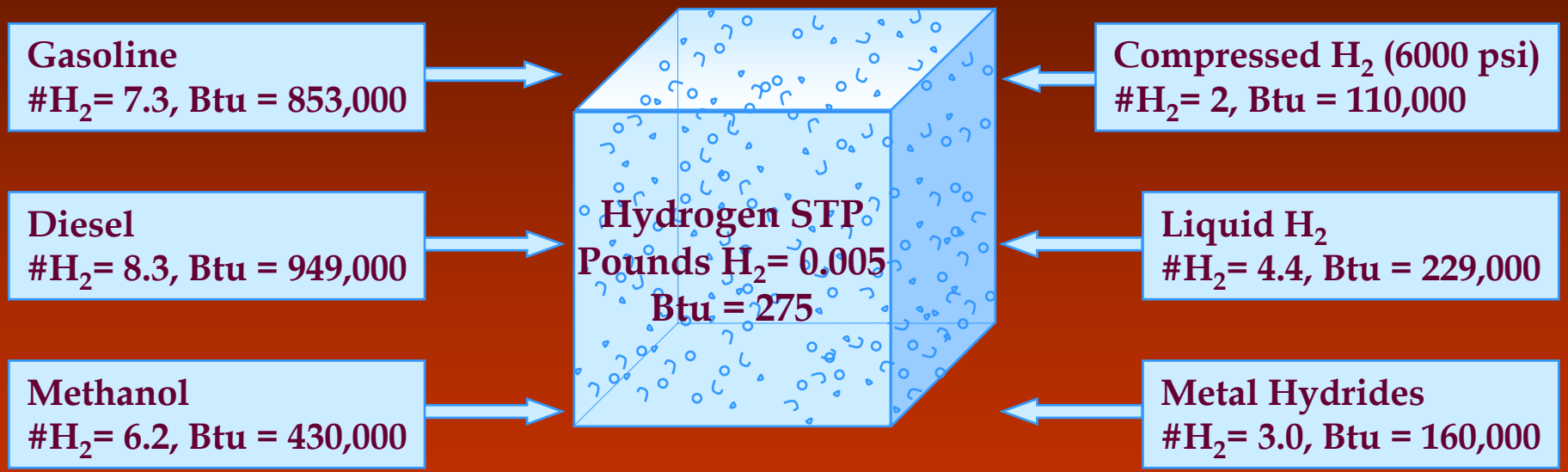
- **Current hydrogen from coal technology**
- **Coproduction of hydrogen and power from coal**
- **Carbon dioxide implications**
- **Advanced SOFC configuration for hydrogen and power production from coal**
- **Comparison with natural gas**
- **Challenges**

Issues & Drivers for Hydrogen

- **ISSUES:**
  -low volumetric energy content (storage)
  -Infrastructure for Hydrogen Delivery
  -Carbon capture & Sequestration
  -Resources for Mass Production
- **DRIVERS:**
  -energy security
  -petroleum resource depletion
  -climate change & pollution

Hydrogen Storage



1 Cubic Foot Volume

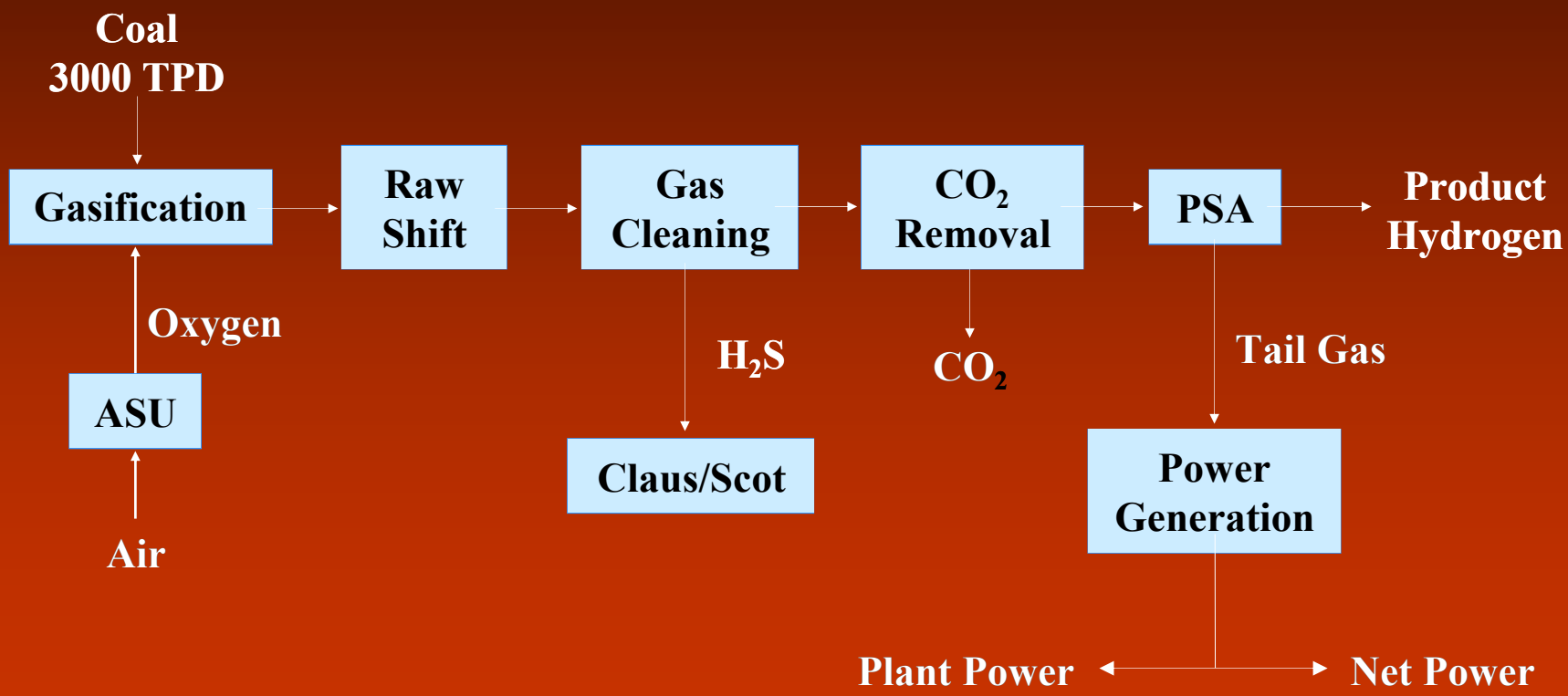
Coal Analysis

- Illinois #6 Old Ben #26 Mine:
- Proximate as-received (wt %)
  - Moisture 11.12
  - Ash 9.7
  - Volatile matter 34.99
  - Fixed carbon 44.19
  - HHV Btu/# 11,666
- Ultimate as-received (wt %)
  - Moisture 11.12
  - Carbon 63.75
  - Hydrogen 4.5
  - Nitrogen 1.25
  - Chlorine 0.29
  - Sulfur 2.51
  - Ash 9.7
  - Oxygen (bd) 6.88

Financial Assumptions

- 25 year plant life
- 67/33 % debt/equity financing
- 15 % return on equity
- 8 % interest, 16 year term
- 3 % inflation (coal de-escalation of 1.5 % per annum below general inflation)
- 16 year DDB depreciation
- 40 % combined Federal and State tax rate
- 3 year construction, 50 % output in start-up year
- Sequestration of high pressure CO_2 stream costs $10/ton carbon

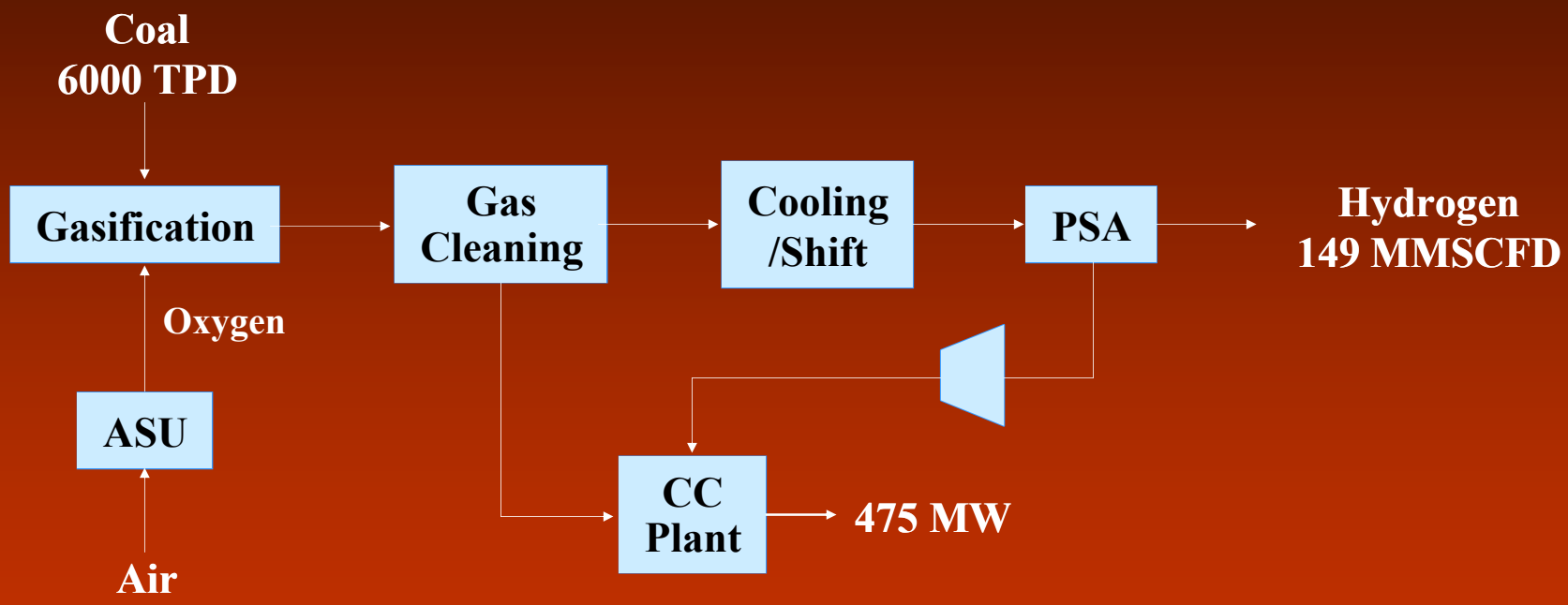
Cases 1 and 2: Hydrogen from Coal



Summary of Hydrogen from Coal Cases

	Case 1	Case 2
Carbon Sequestration	**NO**	**YES (87%)**
Hydrogen MMSCFD	**131**	**119**
Coal T/D (AR)	**3000**	**3000**
Efficiency (% HHV)	**63.7**	**59**
XS Power MW	**20.4**	**26.9**
Power Value (MILS/k Wh)	**35.6**	**53.6**
Capital $MM	**367**	**417**
RSP of Hydrogen $/MMBTU	**6.83**	**8.18**

Case 3: Coal to Hydrogen and Power



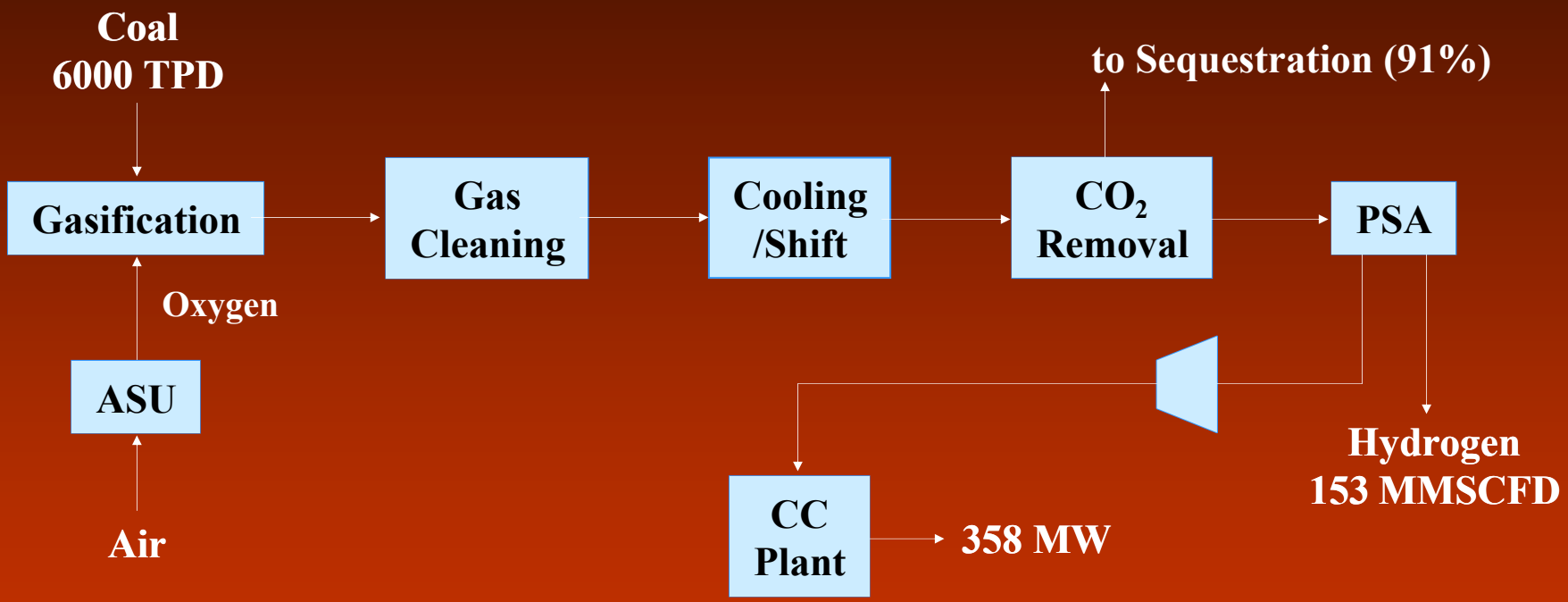
Capital $910MM

COE 35.6 Mills/kWh

Hydrogen RSP $5.42/MMBTU

Efficiency 62.4%

Case 4: Coal to Hydrogen and Power (Sequestration)

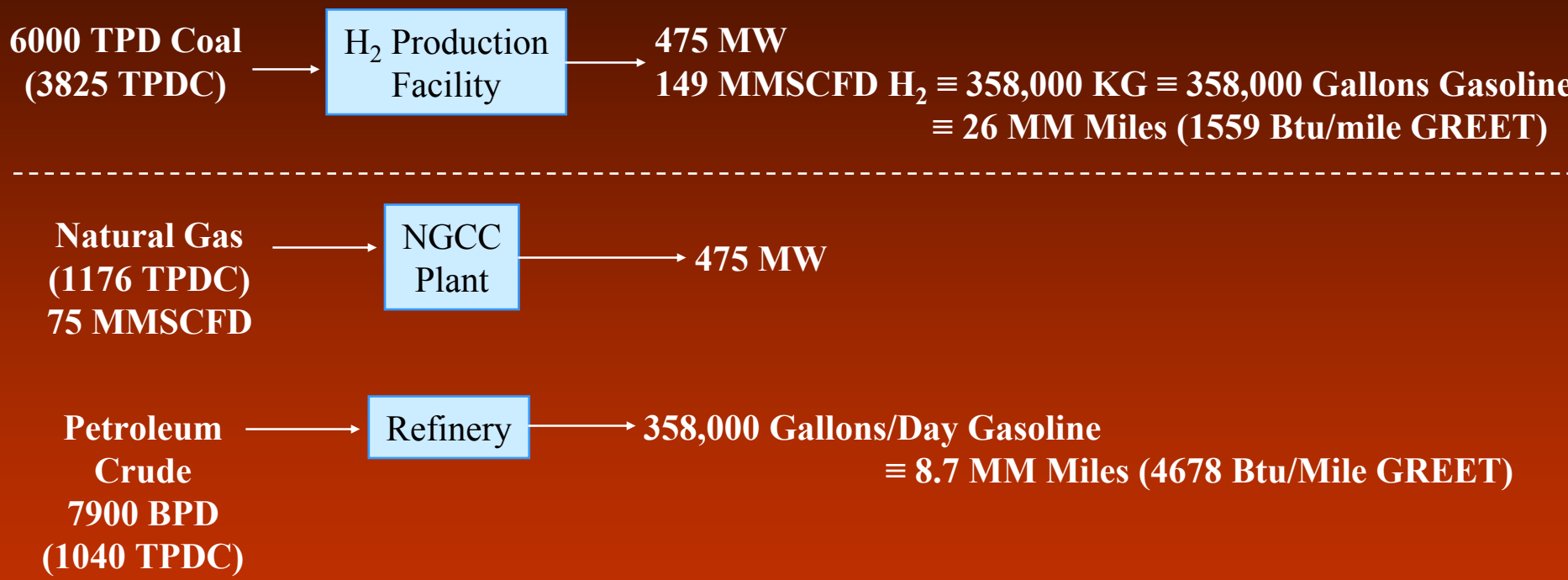


Capital $950MM	H_2 RSP $/MMBTU	COE Mills/kWh	Efficiency 56.5%
	5.64	53.6 (Gas CC, sequestration)	
	6.89	46.3 (Coal IGCC, sequestration)	
	8.73	35.6 (Coal IGCC, no sequestration	

Summary of Coproduction Cases

	CASE 3	CASE 4
Carbon Sequestration	NO	YES (95%)
Hydrogen MMSCFD	149	153
Coal T/D (AR)	6000	6000
Efficiency (%HHV)	62.4	56.5
XS Power MW	475	358
PowerValue (MILS/kWh)	35.6	53.6
Capital $MM	910	950
RSP of Hydrogen $/MMBTU	5.42	5.64

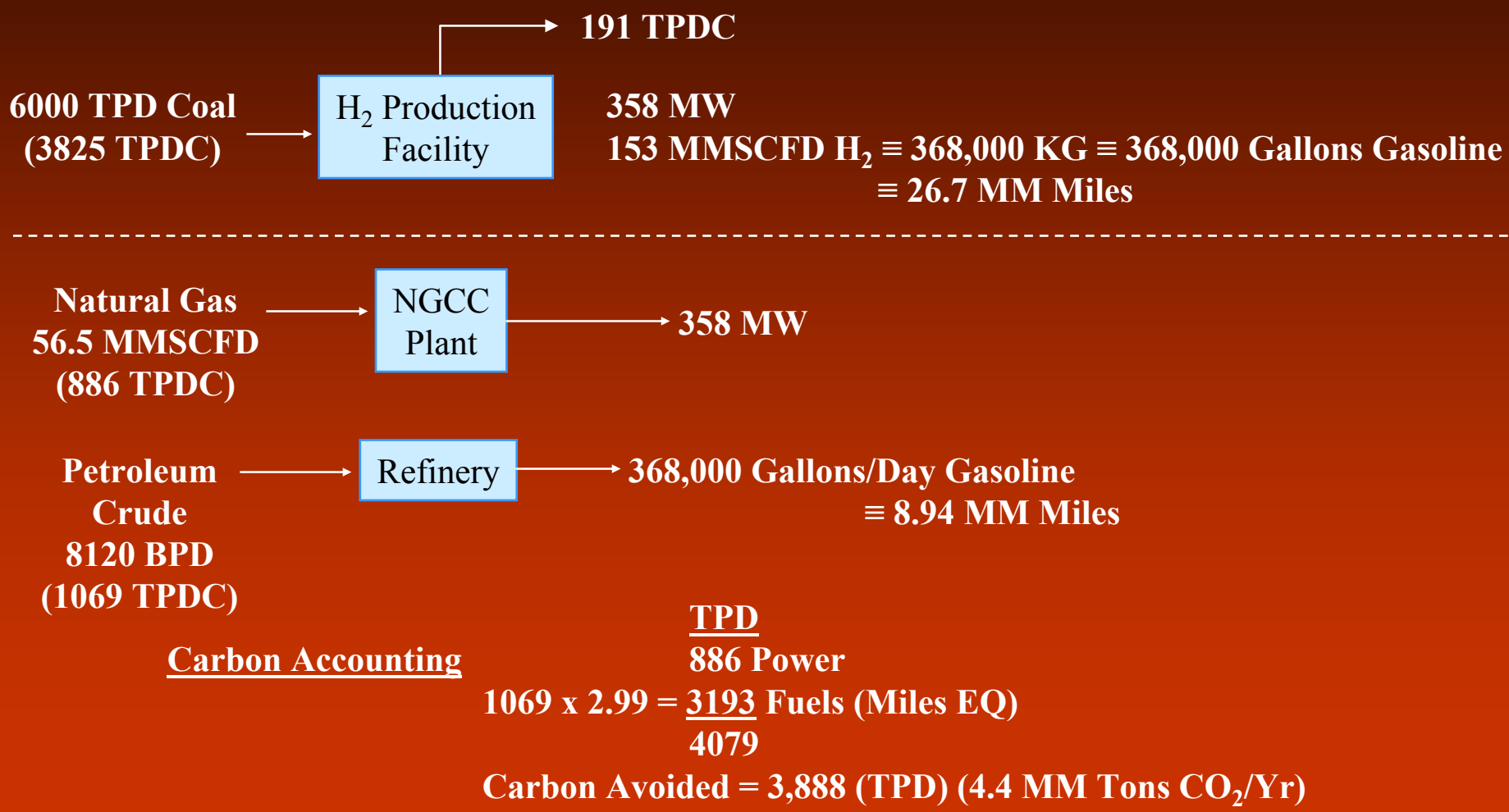
CO_2 Implications of Coal to Hydrogen and Power (Case 3)



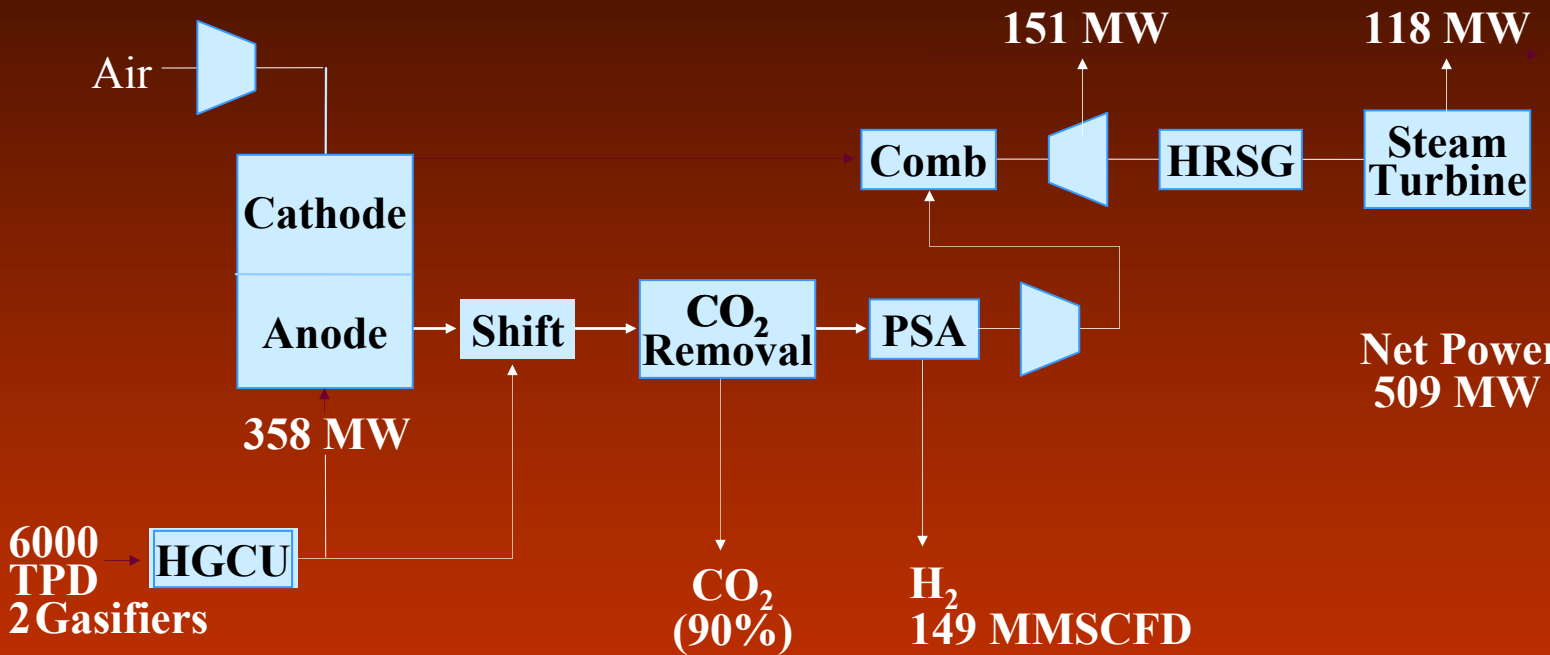
Carbon Accounting

	TPD	
	1176 Power	
1040 x 2.99 =	3108 Fuels (Miles EQ)	
	4284 Total	(-11%)

CO_2 Implications of Coal to Hydrogen and Power (Case 4)



Case 5: SOFC for Power and Hydrogen (Sequestration)

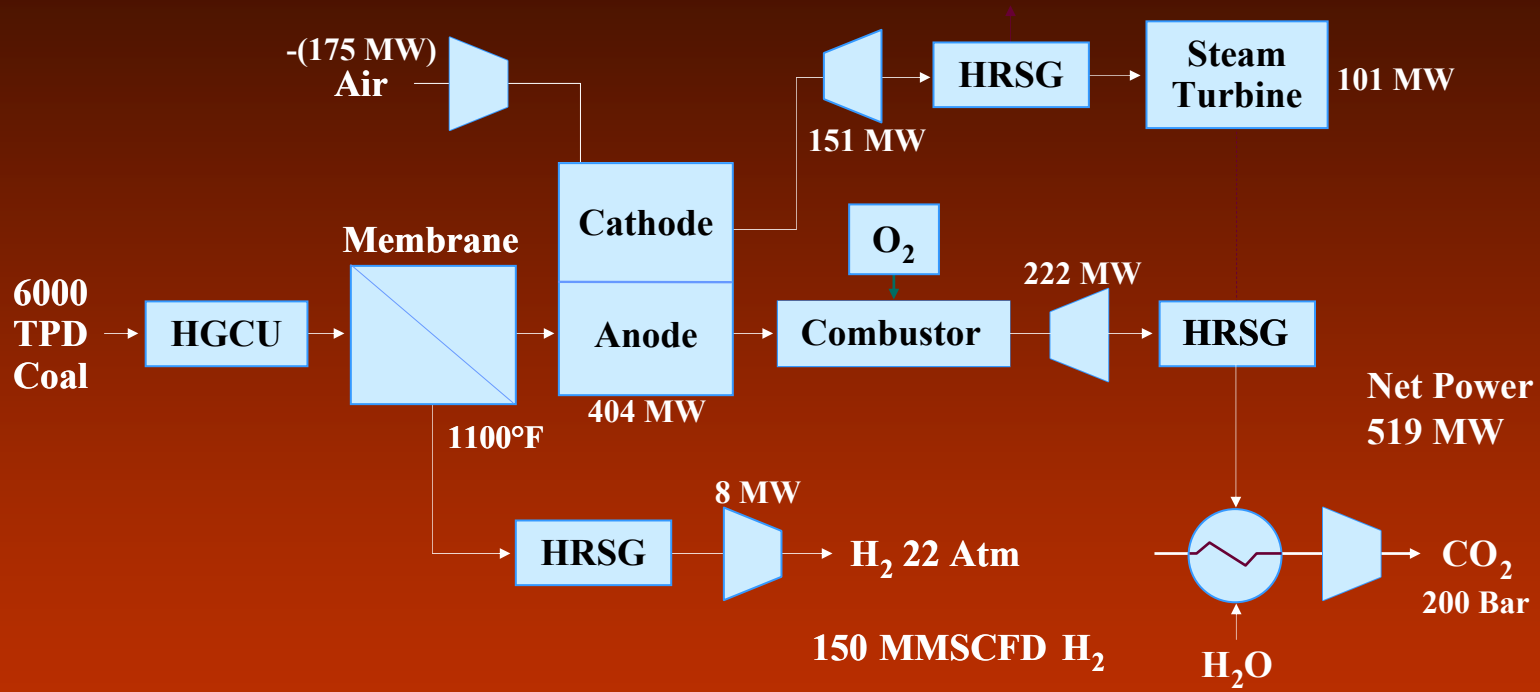


Capital $1,037 Million

Efficiency 64.5% (HHV)

H_2 $/MMBTU	COE mills/kWh
2.79	53.6 Gas CC, sequestration)
4.61	41.3 (Coal IGCC, sequestration)
7.34	35.6 (SOFC/sequestration)

Case 6: SOFC Power/H_2/Membrane (Sequestration)



Capital $1,019 Million

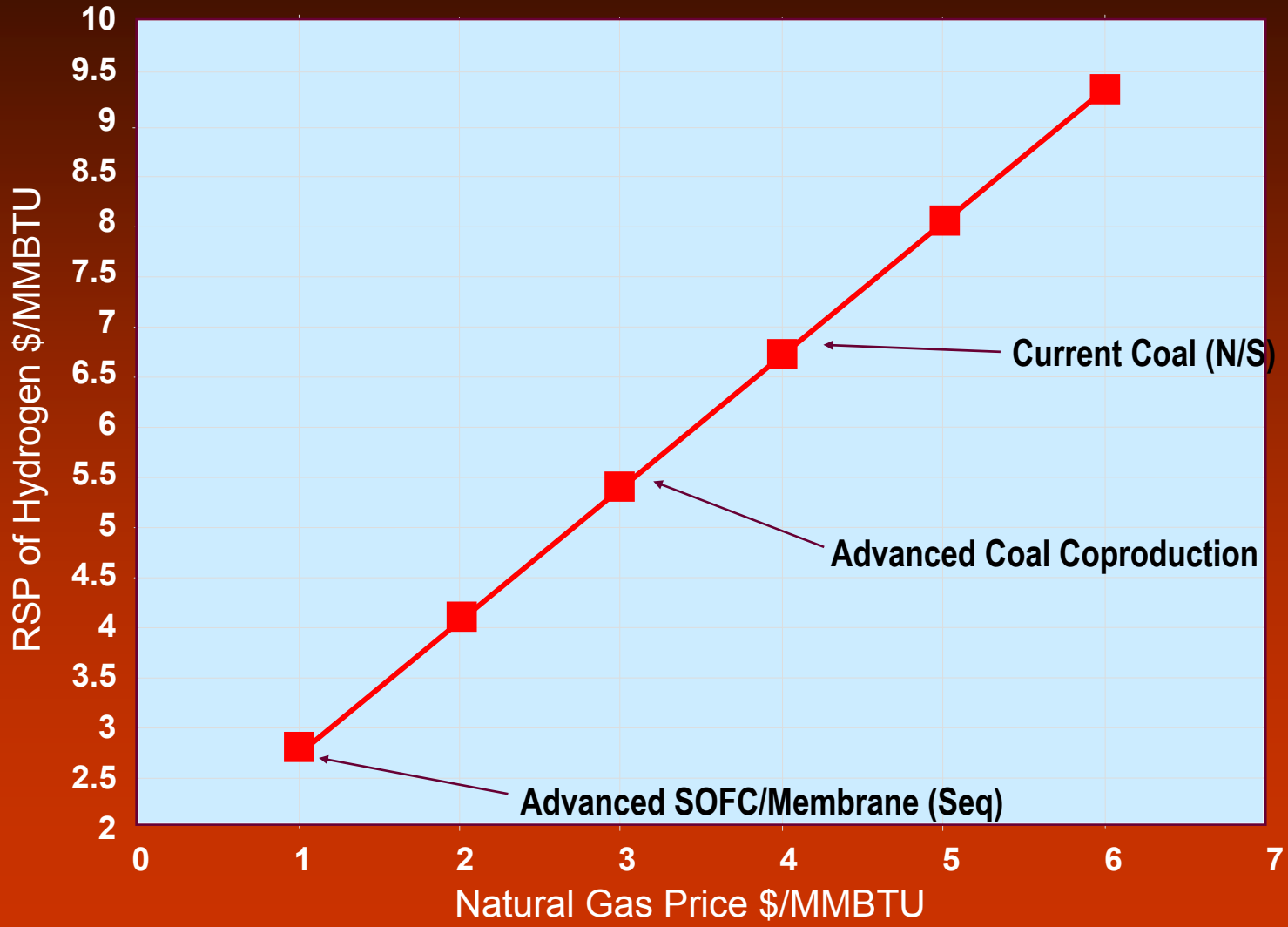
Efficiency 65.2% (HHV)

H_2 $/MMBTU	COE 53.6 Mills/kWh
2.40	53.6 Gas CC, sequestration)
4.24	46.3 (Coal IGCC, sequestration)
5.58	41.0 (SOFC/sequestration)
6.87	35.6 (Coal IGCC, no sequestration)

Summary of Cases using SOFC Systems

	CASE 5	CASE 6
CARBON SEQUESTRATION	YES (90%)	YES (95%)
HYDROGEN MMSCFD	149	150
COAL T/D (AR)	6000	6000
EFFICIENCY (%HHV)	64.5	65.2
XS POWER MW	509	519
POWER VALUE (MILS)	53.6	53.6
CAPITAL $MM	1,037	1,019
RSP OF HYDROGEN $/MMBTU	2.79	2.40

Hydrogen Cost vs Natural Gas Price



Challenges

- **Hydrogen Production:**
  -carbon capture & sequestration
  -improved separations & purification
- **Delivery & Storage:**
  -infrastructure
  -volumetric energy density
- **Hydrogen Utilization:**
  -fuel cell compactness & costs