PUMPED CARBON MINING (PCM)

SUBSTITUTE NATURAL GAS (SNG) PRODUCTION COST ESTIMATE

Underground Coal Gasification with Above Ground Processing

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HCEI-11-04-2

This is a preliminary production cost estimate for the production of natural gas by the Pumped Carbon Mining process and is based on the process design given in HCEI-10-04-3, "Pumped Carbon Mining (PCM), Substitute Natural Gas Production," and shown in Fig. 1.

The following assumptions are made:

1. Production of methane from a coal bed methane well is assumed to be equal to 20,000 m^3 CH_4 / D or 700 MSCF / D (thousand standard cubic feet per day). Reference: David H., S. Law, et al., SPE 75669, paper presented at SPE Gas Tech. Symp., Calgary, Canada, April – May, 2002 (Fig. 8).
2. Production from PCM by underground hydrogasification is assumed to be 20 times coal bedded methane rate equal to 20 x 700 MSCF / D = 14,000 MSCF / D. Reference: HCEI-10-04-3, October 4, 2004.

Based on the above assumptions and the mass and energy balances given in HCEI-10-04-3, the following values are determined:

Methane (CH_4) to Reformer	= 7,600 MSCF / D
Methane (CH_4) burned in furnace	= 2,739 MSCF / D
Hydrogen (H_2) produced	= 30,430 MSCF / D

Preliminary Capital Cost Estimate

The major capital investment is in production of hydrogen needed to make up the hydrogen balance in the process. The preliminary capital cost estimate for producing 30,430 MSCF / D hydrogen in the PCM process is based on a 1987 capital cost estimate for steam reforming of methane for hydrogen production of 100,000 MSCF / D, which was $67 million. Reference: M.

Steinberg and H.C. Cheng, Int. J. Hydrogen Energy 14, 797-820 (1989). The factor correcting for inflation using the Construction index from 1987 to 2004, is 1.5. Therefore, the current capital cost of 100,000 MSCF H_2 / D equals 1.5 x \$67 x 10^6 = \$100 million.

Capital cost reduction for the 30,430 MSCF / D plant applying the 0.6 power rule:

$$\text{Capacity factor } = \left(\frac{100 \text{ x } 10^6}{30.4 \text{ x } 10^6}\right)^{0.6} = 2.03$$

$$\text{Capital cost of 30,430 MSCF / D plant } = \frac{\$100 \text{ x } 10^6}{2.03} = \$50\,x 10^6$$

Total investments are estimated using the above \$50 million cost estimate plus estimates for the other parts of the PCM process

Unit	Capital Cost in Millions of Dollars
Hot Gas Cleanup	1
Heat Exchanger	1
Water Gas Shift Reactor	3
Differential Pressure Swing Adsorption	8
Circulator	1
H_2 Plant	50
Total Capital Investment	64

Production Cost Estimate

A production cost estimate is made based on the following assumptions:

1. The coal bed methane well is paid for by the initial extraction of the methane so there is no cost to PCM for drilling the injection and extraction boreholes and connecting them.
2. The capital investment fixed charge rate assumes a 20 yr life (5% / yr.); return on investment (6%) Insurance (2%); administrative charge (1%). The total fixed charge (FC) adds up to 20% per year of the investment.
3. Operation and maintenance equal 15% of FC

Production Cost Estimate				$ / D
Fixed Charges	=	$\dfrac{0.20 \times 64 \times 10^6}{365 \frac{\text{days}}{\text{yr}}}$	=	35,060
Operations and Maintenance	=	0.15 x 35,060	=	5,260
Total			=	40,320
Unit Production Cost for CH_4	=	40,320 / 14,000	=	$2.88 / MSCF

Considering that current natural gas market price fluctuates between $6.00 / MSCF and $8.00 / MSCF, the PCM process offers a profit of between about $3.00 / MSCF and $5.00 / MSCF.

Comments as to the Assumptions

1. The cost estimate is sensitive to the Coal Bedded Methane production rate. If the production rate is less than 700 MSCF / D, the production cost will increase.
2. Since the major capital cost item appears to be the steam reforming of methane for providing hydrogen, one way of reducing cost is to have a larger hydrogen plant servicing more than one well. This would decrease the capital cost charges per unit of methane produced.

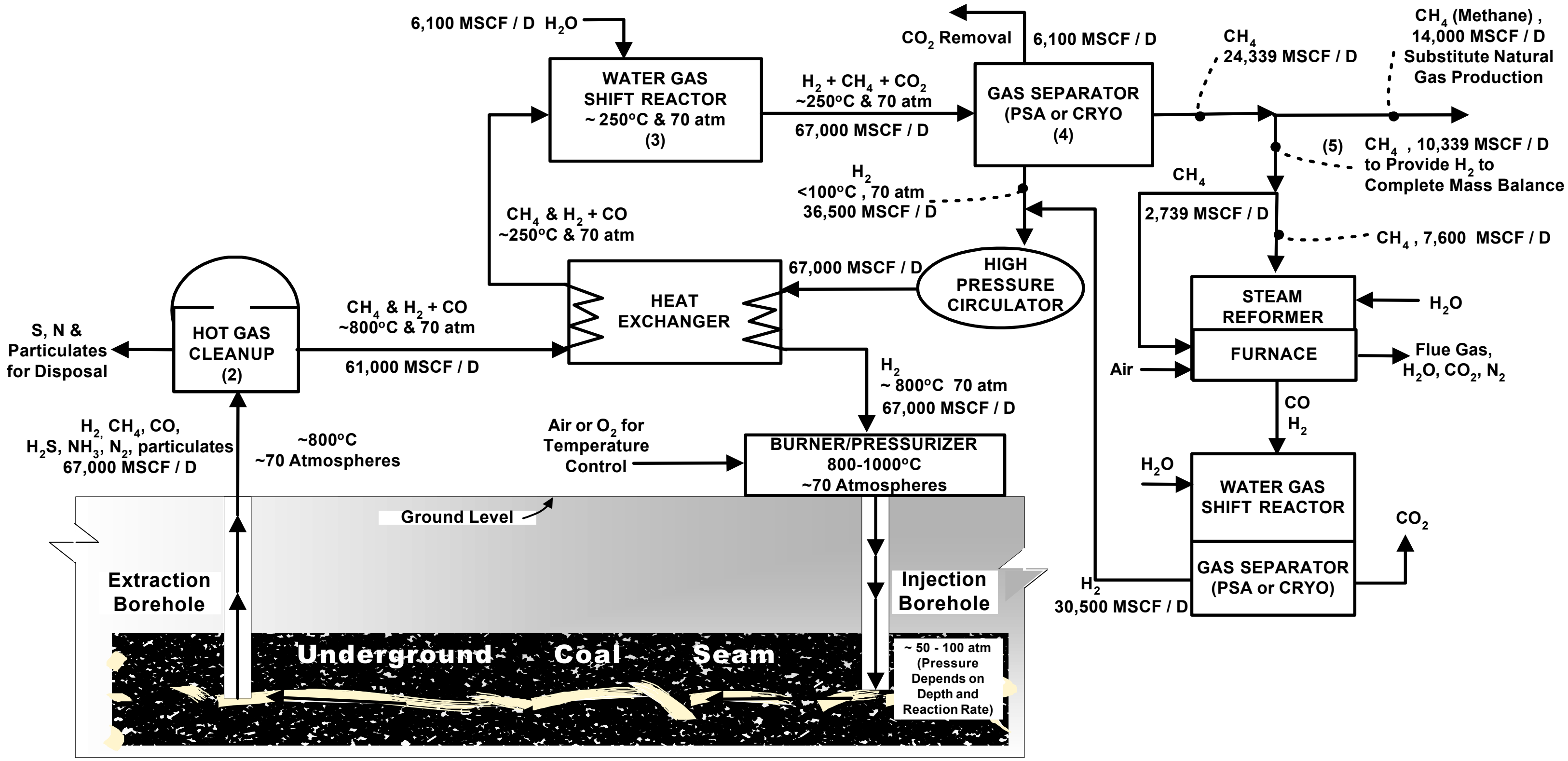
Conclusion

A significant economic incentive exists to develop the PCM process in greater detail and to initiate an underground hydrogasification test, which would confirm methane production volumes and provide an estimate of well lifetime. Well lifetime will depend on the thickness and length of the seam.

FIG 1. PUMPED CARBON MINING: SUBSTITUTE NATURAL GAS PRODUCTION

Underground Coal Hydrogasification With Above Processing

Process to Increase Initial Coal Bedded Methane Net Production Rate of 700 MSCF / D to 14,000 MSCF / D



<u>REACTION CHEMISTRY</u>

(1) Hydrogasification of Coal Lignite: $CH_{0.8}O_{0.2} + 1.2H_2 = 0.8CH_4 + 0.2CO$

1.2 H_2 excess is circulated to reach equilibrium CH_4 concentration (40%). Other gases formed are H_2O, CO_2, H_2S, NH_3, N_2

(2) Hot Gas Cleanup removes N, S & particulates

(3) Water Gas Shift $0.2CO + 0.2H_2O = 0.2CO_2 + 0.2H_2$

(4) Gas Separator, e.g. Differential Pressure Swing Adsorption or Cryogenic Separation, takes out all gases except hydrogen. PSA removes CO_2 with zeolite, CH_4 on carbon adsorbant.

(5) To complete balance, 1 mole H_2 must be added. It is obtained by steam reforming

0.25 mole CH_4: $0.25 CH_4 + 0.25 H_2O = 0.25 CO + 0.75 H_2$

$0.25 CO + 0.25 H_2O = 0.25 CO_2 + H_2$; Furnace heat required: $0.09 CH_4$ + Air $= 0.09 CO_2 + 0.18 H_2O$

Overall Mass Balance: $CH_{0.8}O_{0.2} + 0.7 H_2O = 0.55 CH_4 + 0.45 CO_2$; Net CH_4 Production $= 0.8 - 0.34 = 0.46 CH_4$