INSTITUTE OF GAS TECHNOLOGY

HYDROGEN PRODUCTION FROM COAL

Interim Report

Project 8963

Based on

"Study of Conversion of Coal to Hydrogen, Methane, and Liquid Fuels for Aircraft"

for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LANGLEY RESEARCH CENTER

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EDUCATION · RESEARCH

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MONTANA SUBBITUMINOUS COAL

PROXIMATE ANALYSIS		wt %
MOISTURE		22.0
VOLATILE MATTER		29.4
FIXED CARBON		42.6
ASH		6.0
	TOTAL	100.0

ULTIMATE ANALYSIS (Dry)		
CARBON		67.70
HYDROGEN		4.61
NITROGEN		0.85
OXYGEN		18.46
SULFUR		0.66
ASH		7.72
	TOTAL	100.00

DRY HEATING VALUE, Btu/lb 11,290

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MONTANA SUBBITUMINOUS COAL

Typical of Western coals (subbituminous and lignite)
In contrast to Eastern bituminous

- High moisture
- Low sulfur
- High oxygen
- Low-heating value

Low sulfur allows burning under boiler without exceeding 1.2 lb SO_2/million Btu.

GASIFICATION

COAL + WATER ⟶ HYDROGEN + CARBON DIOXIDE

$$CH_{0.8} + 2H_2O \longrightarrow 2.4H_2 + CO_2 - HEAT$$

$$CH_{0.8} + 1.2O_2 \longrightarrow 0.4H_2O + CO_2 + HEAT$$

SHIFT

$$CO + H_2O \longrightarrow H_2 + CO_2 + HEAT$$

METHANATION

$$CO + 3H_2 \longrightarrow CH_4 + H_2O + HEAT$$

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GASIFICATION REACTIONS

- Most of H_2 produced comes from H_2O
- C of coal used to remove the O of H_2O as CO_2
- H_2 production requires heat
- Heat required comes from burning coal
  O_2 for combustion from air
  N_2 from air cannot be tolerated in product H_2
- CO formed along with CO_2
  Shift converts CO to H_2 and CO_2
- Methanation removes CO to safe level

TYPES OF GASIFIERS

- SUSPENSION (Entrained) COMBUSTION
  KOPPERS-TOTZEK
- FLUIDIZED BED
  U-GAS™
- MOVING BED
  LURGI

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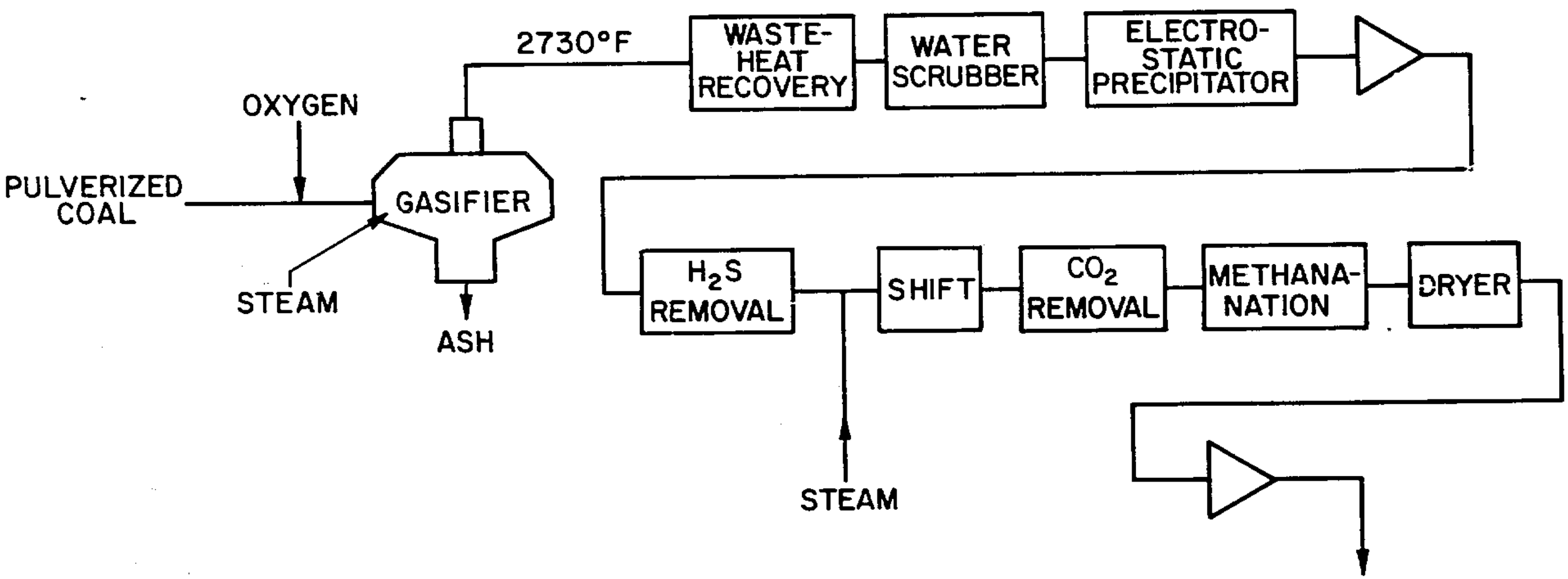
TYPES OF GASIFIERS

- Classify according to method of contacting coal with gasification agent
- Temperature and pressure important

KOPPERS-TOTZEK GASIFICATION FOR HYDROGEN



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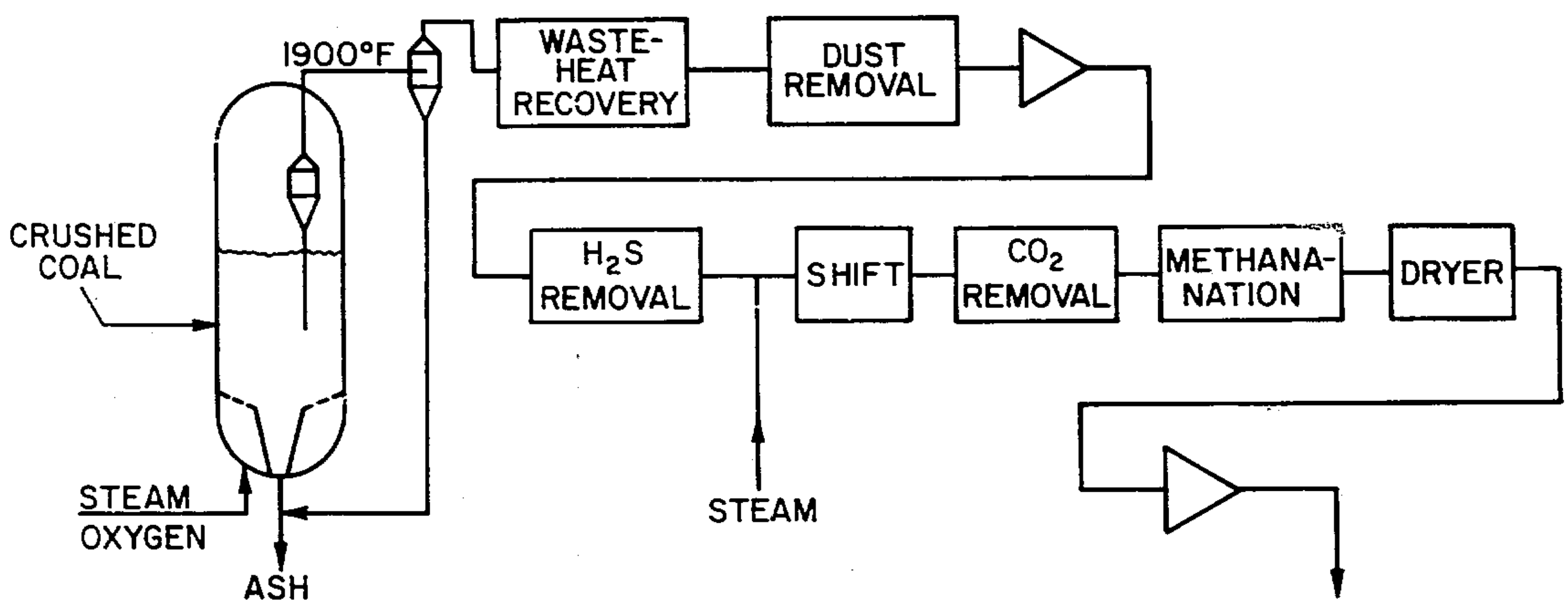
KOPPERS-TOTZEK PROCESS

- Coal entrained in oxygen to burner
- Low pressure
- High temperature
- Ash removed as slag

U-GAS™ GASIFIER FOR HYDROGEN



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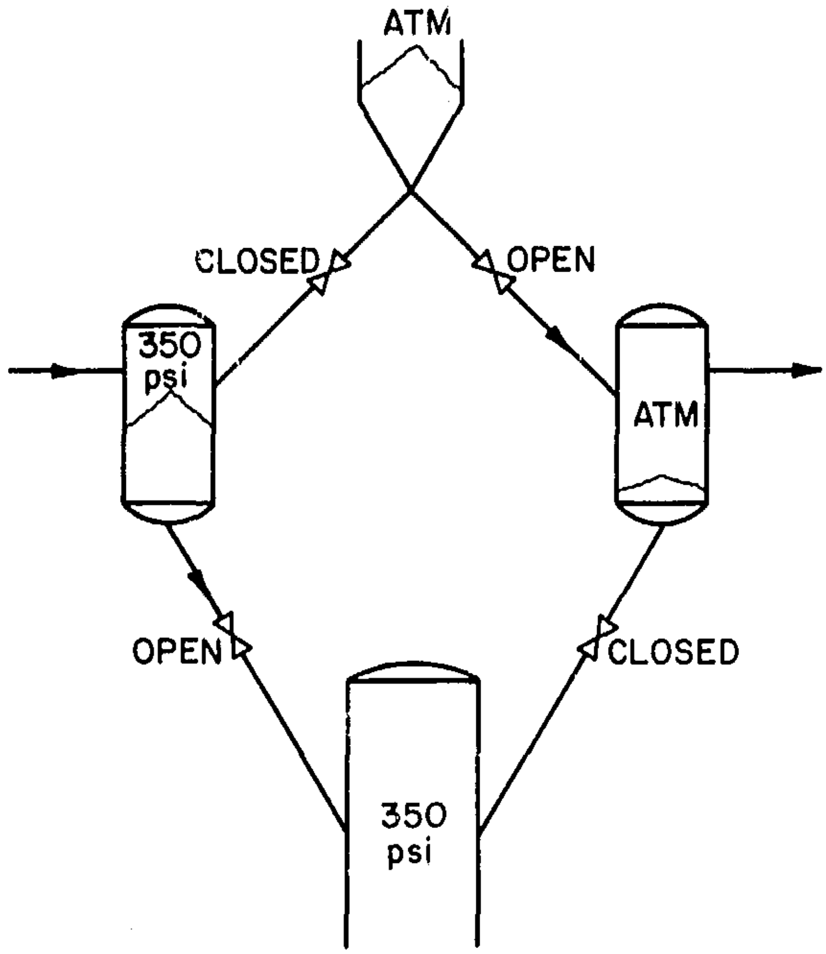
U-GAS™ PROCESS

- Coal fluidized by steam and oxygen mix
- Medium pressure (350 psig)
- Moderate temperature
- Ash removal as agglomerates

LOCK HOPPER FEED SYSTEM



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LOCK HOPPER FEED SYSTEM

- Moves coal from low pressure to high pressure
- Not commercialized over 350 psi
- Alternate is pumped slurry feed

STEAM-IRON REACTIONS

OXIDIZER: $3FeO + H_2O \longrightarrow Fe_3O_4 + H_2$

REDUCTOR: $Fe_3O_4 + H_2 \longrightarrow 3FeO + H_2O$

PRODUCER: $C + H_2O \longrightarrow CO + H_2 - \text{HEAT}$

$$C + \underbrace{O_2 + N_2}_{\text{AIR}} \longrightarrow CO + N_2 + \text{HEAT}$$

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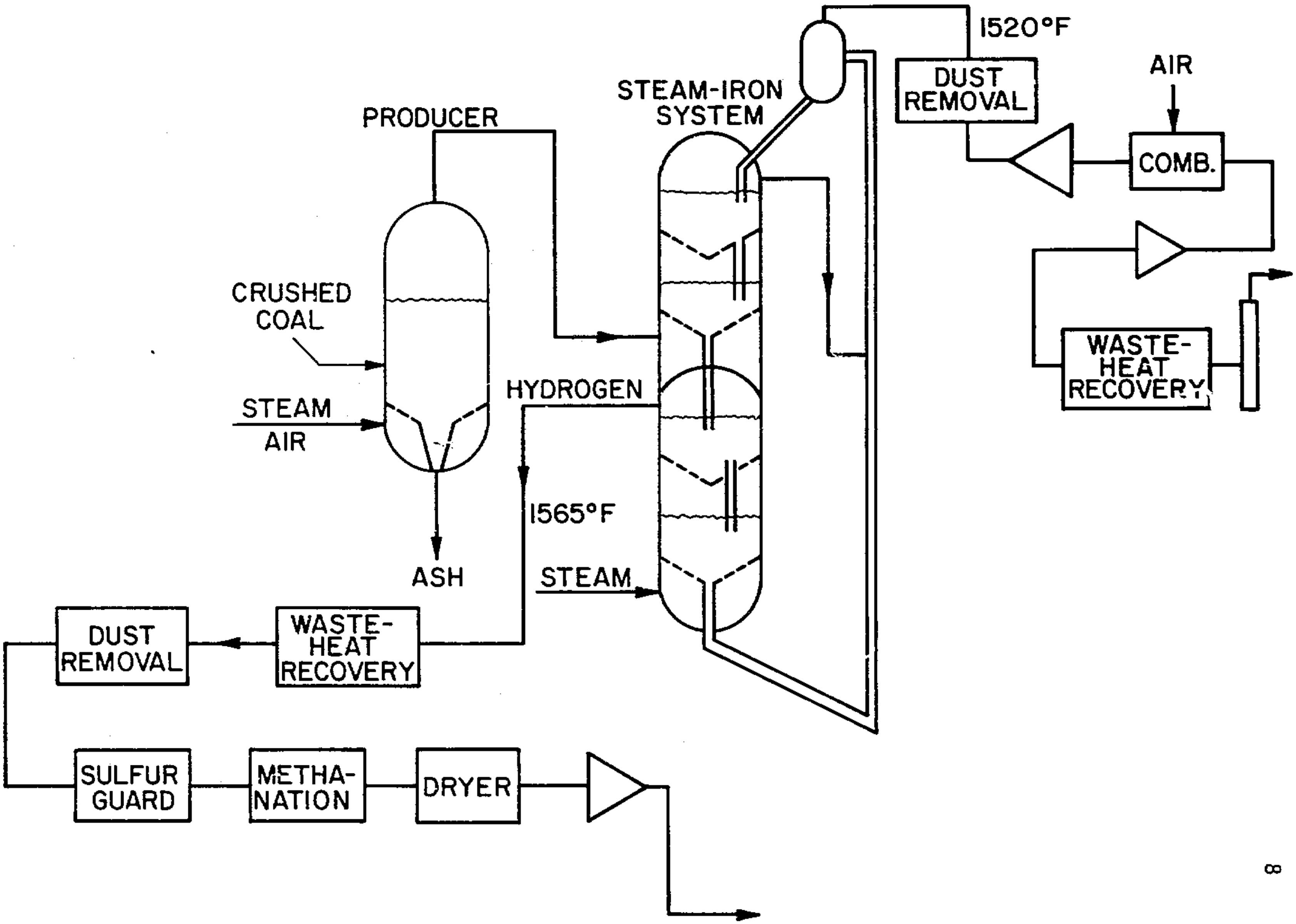
STEAM-IRON REACTIONS

- Makes very pure H_2
- No need for separating N_2 from O_2

STEAM-IRON GASIFICATION FOR HYDROGEN



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STEAM-IRON PROCESS

- Medium pressure
- Moderate temperature
- Simplified raw gas treating (no shift)
- Spent producer gas utilized for power generation

RAW GAS COMPOSITIONS
mol % (Dry Basis)

	K-T	U-GAS™	STEAM-IRON
CO	58.3	50.1	1.4
CO_2	10.0	11.5	0.2
H_2	30.4	35.3	95.9
CH_4	—	2.1	—
N_2 + Ar	1.0	0.7	2.5
H_2S + COS	0.3	0.3	—
	100.0	100.0	100.0
PRESSURE, psia	15	350	350

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RAW GAS COMPOSITIONS

- K-T and U-GAS™ require extensive shift
- Very low sulfur in steam-iron gas

PRODUCT GAS COMPOSITION
mol% (Dry Basis)

	K-T	U-GAS™	STEAM-IRON
CO	0.1	0.1	0.1
CO_2	<50ppm	<50 ppm	0.1
H_2	93.1	94.3	95.7
CH_4	5.5	4.8	1.5
N_2 + Ar	1.3	0.8	2.6
	100.0	100.0	100.0

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PRODUCT GAS COMPOSITIONS

- All CO reduced to 0.1 %
- CO_2 for K-T and U-GAS™ reduced to <50 ppm during acid-gas removal
- CO_2 for steam-iron reduced to 0.1 % by methanation

GASIFIER FEED QUANTITIES

FOR 250 X 10^9 Btu/day

	K-T	U-GAS™	STEAM-IRON
COAL, lb/hr (Dry Basis)	1,276,454	1,124,128	2,070,426
STEAM, lb/hr	270,164	375,776	4,599,209
OXYGEN, tons/day	12,092	8,631	17,368*
			(* in Air)
	STEAM TO SHIFT		
lb/hr	8[illegible],585	790,758	—

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GASIFIER FEED QUANTITIES

- Coal, steam, and oxygen to steam-iron higher than to K-T or U-GAS™
- But steam-iron does not require air separation plant. Also no shift steam

PROCESS EFFICIENCY

	K-T	U-GAS™	STEAM-IRON
REACTOR COAL, lb/hr (Dry Basis)	1,276,454	1,124,128	2,070,426
BOILER COAL, lb/hr (Dry Basis)	340,314	269,634	—
TOTAL COAL, lb/hr (Dry Basis)	1,616,768	1,393,762	2,070,426
HHV TOTAL COAL, 10^6 Btu/hr*	18,253	15,736	23,375
HHV PRODUCT GAS, 10^6 Btu/hr†	10,416	10,416	10,416
% CONVERTED TO PRODUCT GAS	57.1	66.2	44.6
BY-PRODUCT POWER, kW	—	—	980,000

* At 11,290 Btu/lb.

† At 250 billion Btu/day.

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PROCESS EFFICIENCY

- K-T boiler coal higher than U-GAS™ because of higher oxygen, higher gasification temperature, and more shift
- High total coal for steam-iron because of heat in spent reductor gas

PROCESS EFFICIENCY

	K-T	U-GAS™	STEAM-IRON	METHANE BY HYGAS
REACTOR COAL, lb/hr (Dry Basis)	1,276,454	1,124,128	2,070,426	1,108,198
BOILER COAL, lb/hr (Dry Basis)	340,314	269,634	—	206,407
TOTAL COAL, lb/hr (Dry Basis)	1,616,768	1,393,762	2,070,426	1,314,605
HHV TOTAL COAL, 10^6 Btu/hr*	18,253	15,736	23,375	14,842
HHV PRODUCT GAS, 10^6 Btu/hr†	10,416	10,416	10,416	10,416
% CONVERTED TO PRODUCT GAS	57.1	66.2	44.6	70.2
BY-PRODUCT POWER, kW	—	—	980,000	—

* At 11,290 Btu/lb.

† At 250 billion Btu/day.

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PROCESS EFFICIENCY

- Methane production by HYGAS® Process has higher efficiency than hydrogen production processes

STEAM-IRON PROCESS FOR HYDROGEN VALUATION OF BY-PRODUCT POWER

BY-PRODUCT POWER, kW	980,000	
EQUIVALENT Btu AT 7300 Btu/kWhr, 10^6 Btu/hr		7154
HHV PRODUCT GAS, 10^6 Btu/hr		10416
TOTAL		17,570
HHV COAL, 10^6 Btu/hr	23,375	
OVERALL EFFICIENCY, %	75.2	

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STEAM-IRON PROCESS – VALUATION OF BY-PRODUCT POWER

- Power valued at 7300 Btu/kWhr added to gas values raises overall efficiency of steam-iron to 75.2%

POWER FOR HYDROGEN LIQUEFACTION

QUANTITY OF HYDROGEN	733×10^6 SCF/day (161,000 lb/hr)
POWER REQUIRED FOR LIQUEFACTION at 5 kWhr/lb*	805,000 kW
POWER TO COMPRESS H_2 1 atm TO 800 psi	220,000
NET TO LIQUEFY 800 psi GAS	585,000
BY-PRODUCT POWER	980,000 kW

*From H_2 at 1 atm.

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POWER FOR HYDROGEN LIQUEFACTION

- By-product power from steam-iron (980,000 kW) is more than enough to liquefy h/drogen produced