Near-Zero CO_2 Emissions from the Clean, Shale-Oil Surface (C-SOS) Process

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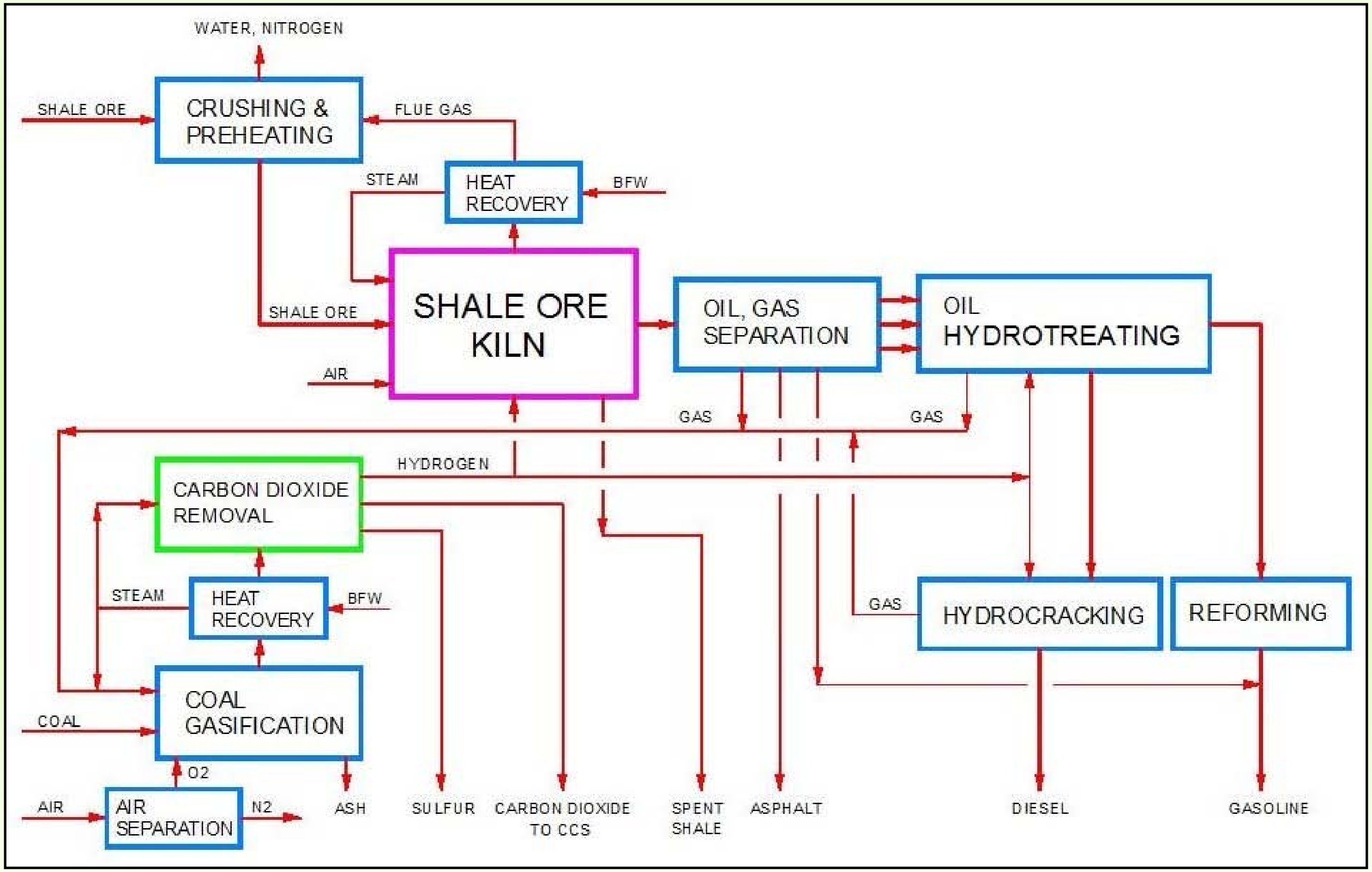
PATENT-PENDING C-SOS PROCESS FEATURES

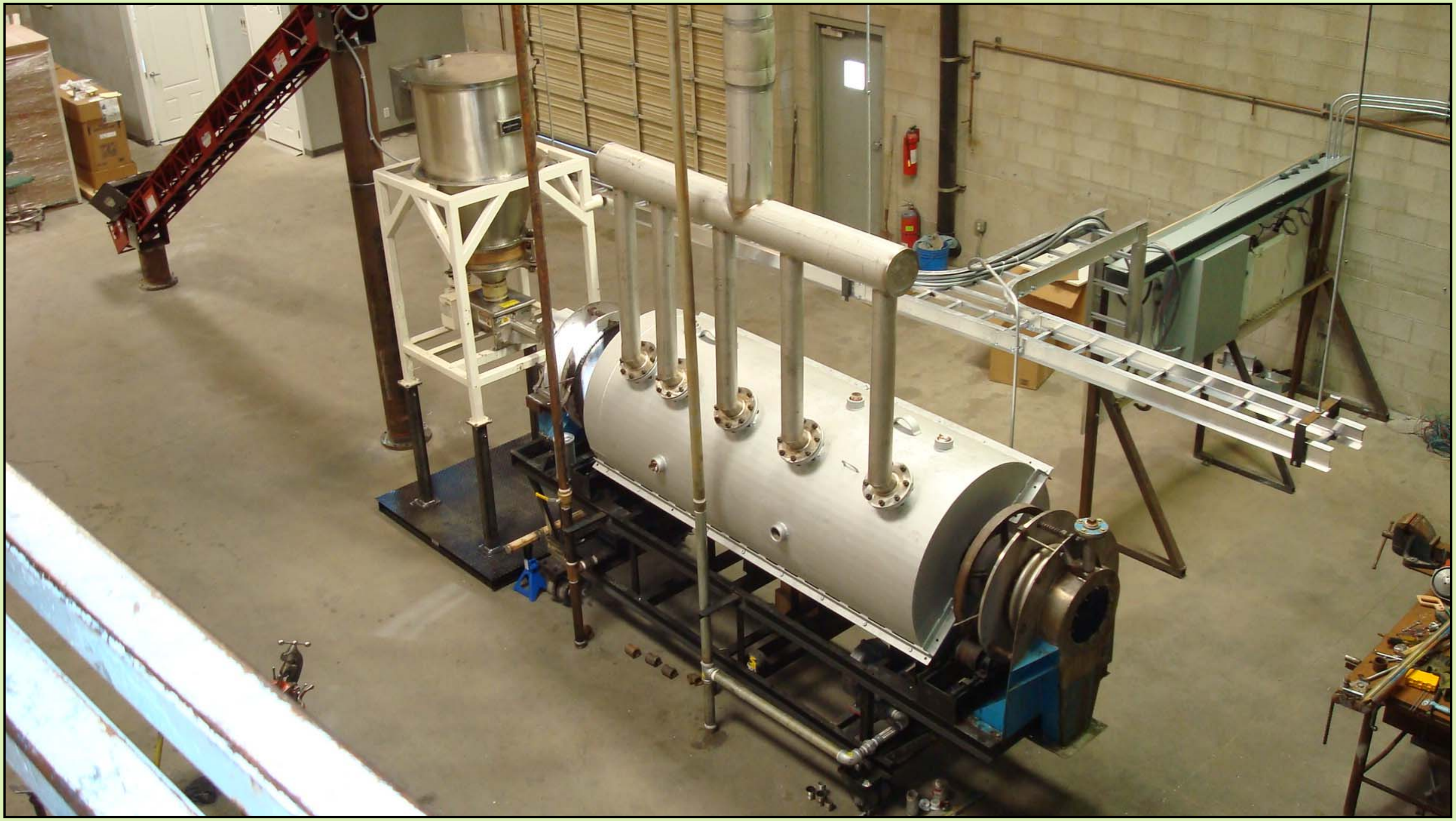
- **PROPRIETARY, HIGH-CAPACITY, INDIRECT-FIRED ROTARY KILN**
- **LOW-COST COAL FOR ON-SITE PROCESS ENERGY AND HYDROGEN**
- **NEAR-ZERO CO_2 EMISSIONS FROM OIL SHALE PROCESSING**
- **SIMPLE HORIZONTAL PROCESS—COMMERCIAL EQUIPMENT**
- **MARKETABLE MOTOR FUELS PRODUCED ON-SITE**

C-SOS Process



LOCATION OF PILOT PLANT COATES CONSTRUCTION SHOP AND YARD, 461 WEST 800 NORTH, SLC

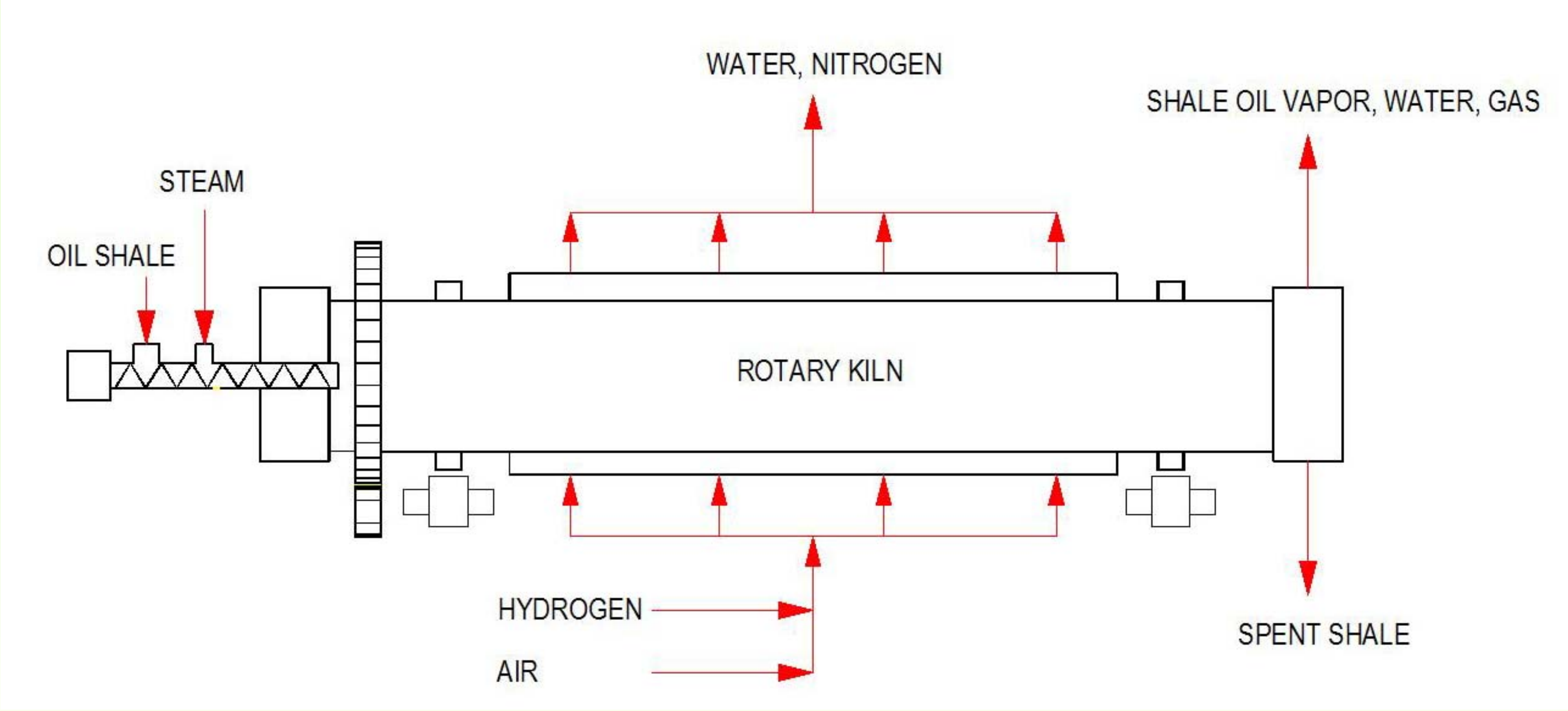
PILOT PLANT INDIRECT-FIRED KILN



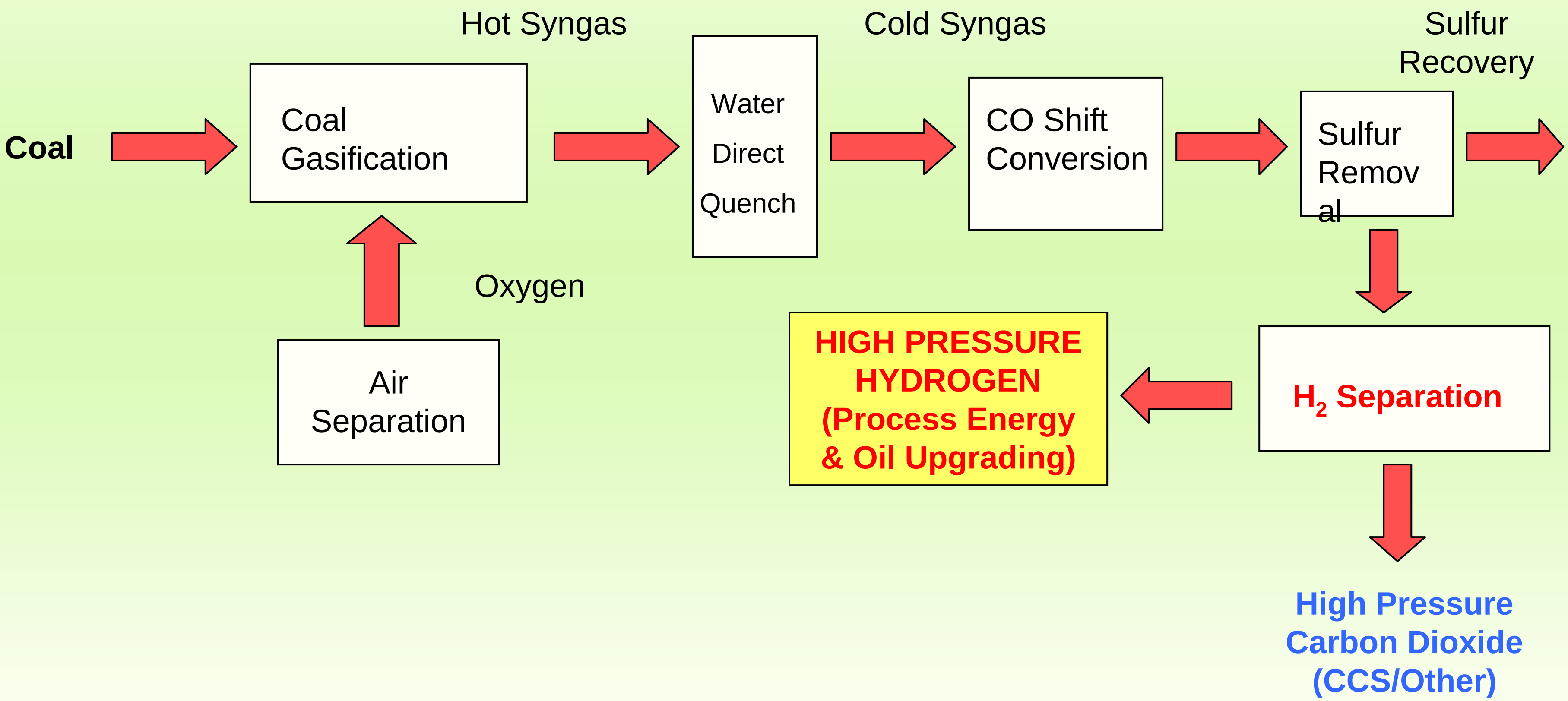
5 STEPS FOR CONTROL OF CO_2

1. INDIRECT-FIRED ROTARY KILN WITH H_2/AIR COMBUSTION
2. CONTROLLED PEAK SHALE ORE KILN TEMPERATURES
3. NO RECOVERY OF SPENT SHALE CARBON
4. RECYCLE OIL SHALE OFF GASES TO GASIFIER
5. SHIFT GASIFIER SYNGAS TO H_2/CO_2 AND CAPTURE CO_2

STEP 1. PROPRIETARY KILN INDIRECTLY FIRED WITH HYDROGEN



STEP 1. CO_2-H_2 SEPARATION



STEP 1. H_2 vs. CH_4 Costs

RECENT WORLD CLIMATE CONTROL CONFERENCES FOR CO_2 CAPTURE AND SEQUESTRATION:

HYDROGEN FROM COAL GASIFICATION COMPETITIVE WITH NATURAL GAS (CURRENT COSTS)

STEP 2. KILN SHALE ORE TEMP-CONTROL TO MINIMIZE CARBONATE DECOMPOSITION

- PROPRIETARY FIRING SCHEME
- CONTROLLED WALL, ORE TEMPERATURES
- CARBONATE RELEASE RATE MODEL

STEP 2. CARBONATE DECOMPOSITION

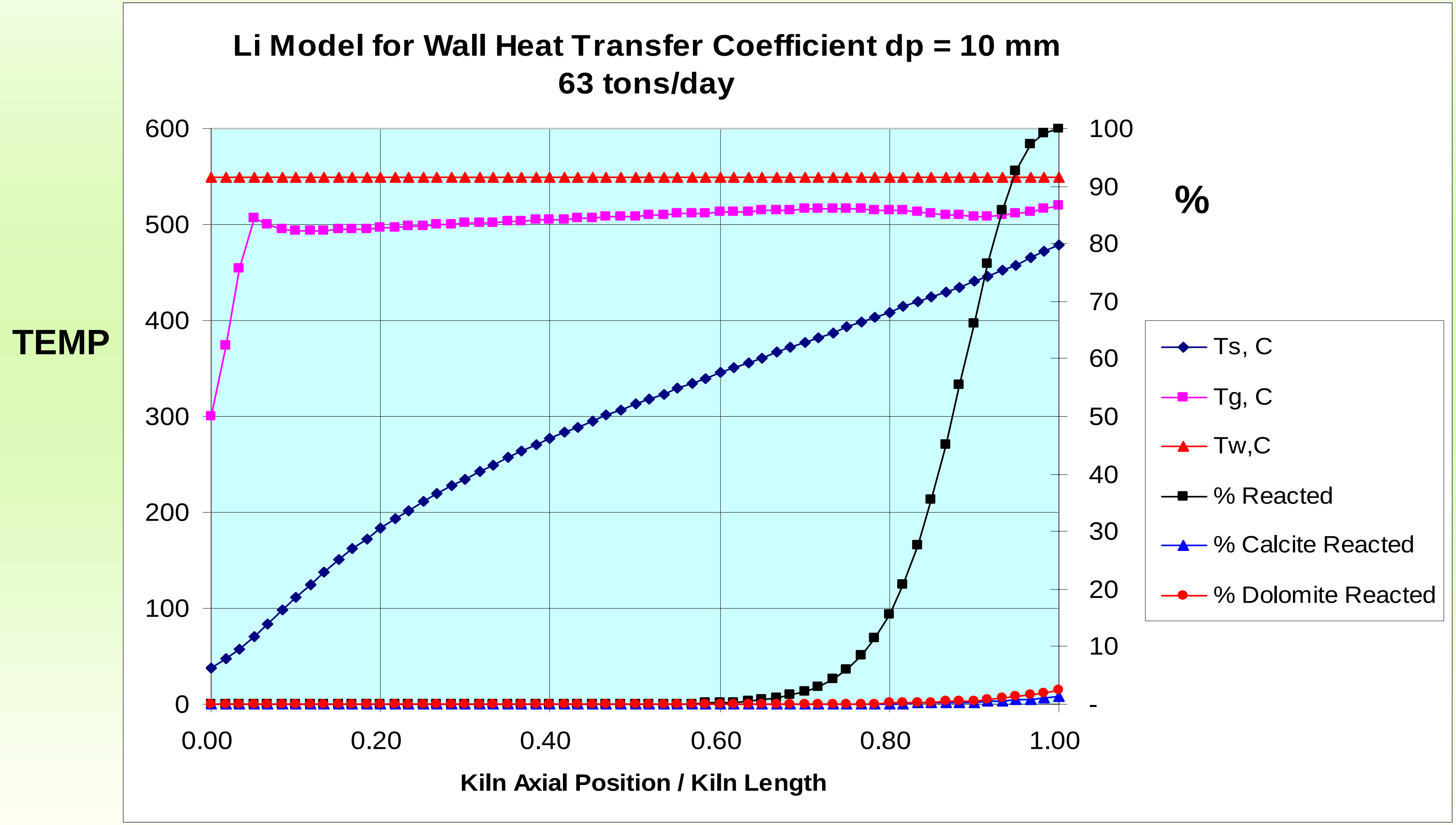
- Dolomite, ($CaCO_3 \bullet MgCO_3$), Calcite ($CaCO_3$), %'s
- First Order Reaction – Decomposition Rate Controlled

$$\frac{dC_{carb}}{dt} = kC_{carb} \qquad k = A\exp[E/RT]$$

- A, E from data (Hanson, F.V., Univ. Utah, 2004)
- Time (t), Temp (T) from kiln code

STEP 2. CARBONATE DECOMPOSITION

63 Tons Ore/Day; 3/8 in. Ore



STEP 3. NO RESIDUAL SPENT SHALE CARBON BURNING

- **Carbonate CO_2-30% (wt) of ore**
- **600 lbs CO_2/ton ore**
- **750 lbs CO_2/bbl shale oil**
- **Decomposition Temperatures, <1050-1150°F**

STEP 3. NET ENERGY LOSS TO BURN CARBON IN SPENT SHALE

ENERGY FROM SPENT SHALE CARBON

+heat of combustion
-CO_2 from carbon burning
-CO_2 from carbonate decomposition
-Heat losses

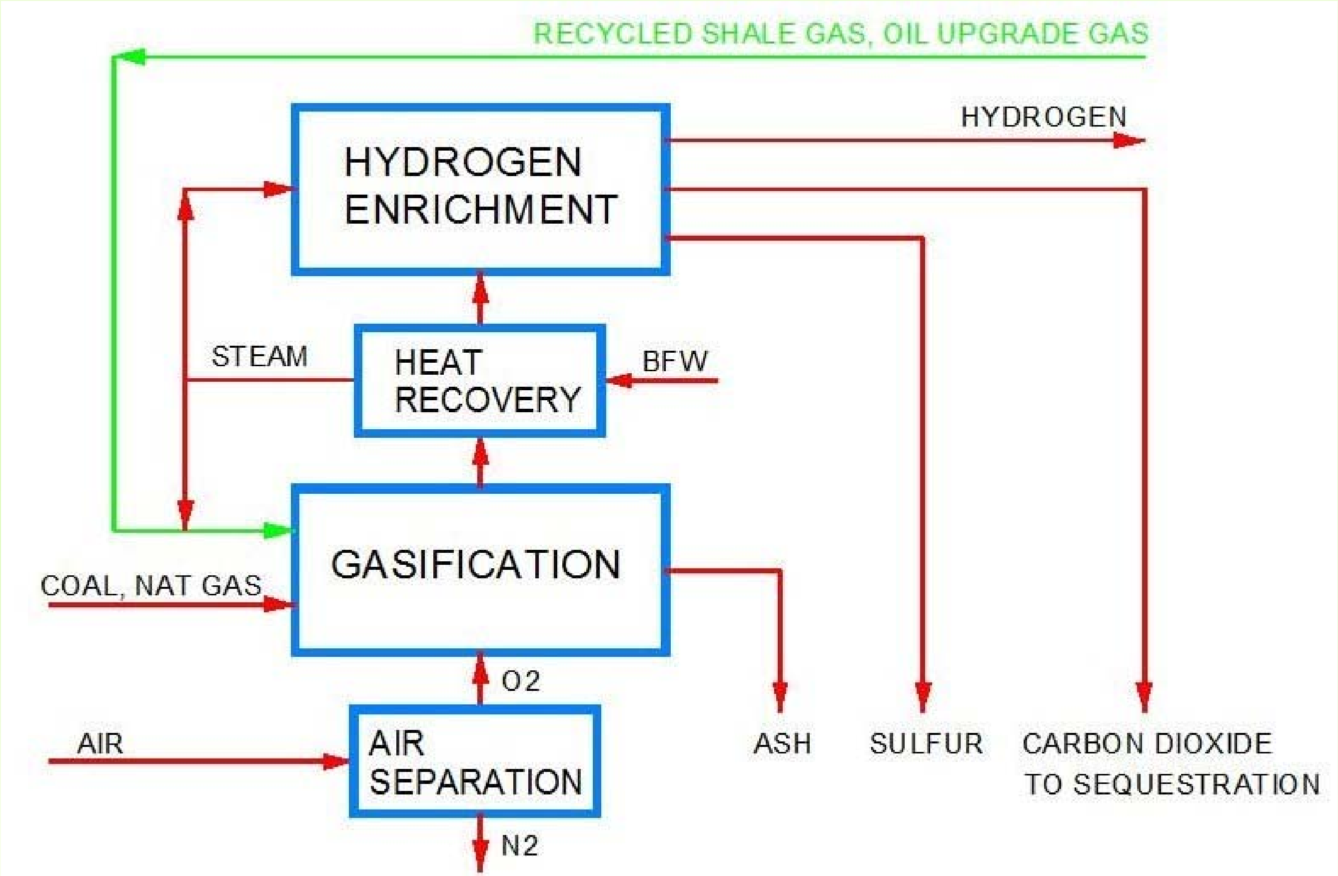
Less than 25%

ENERGY TO CLEAN, CAPTURE CO_2 FROM SPENT SHALE

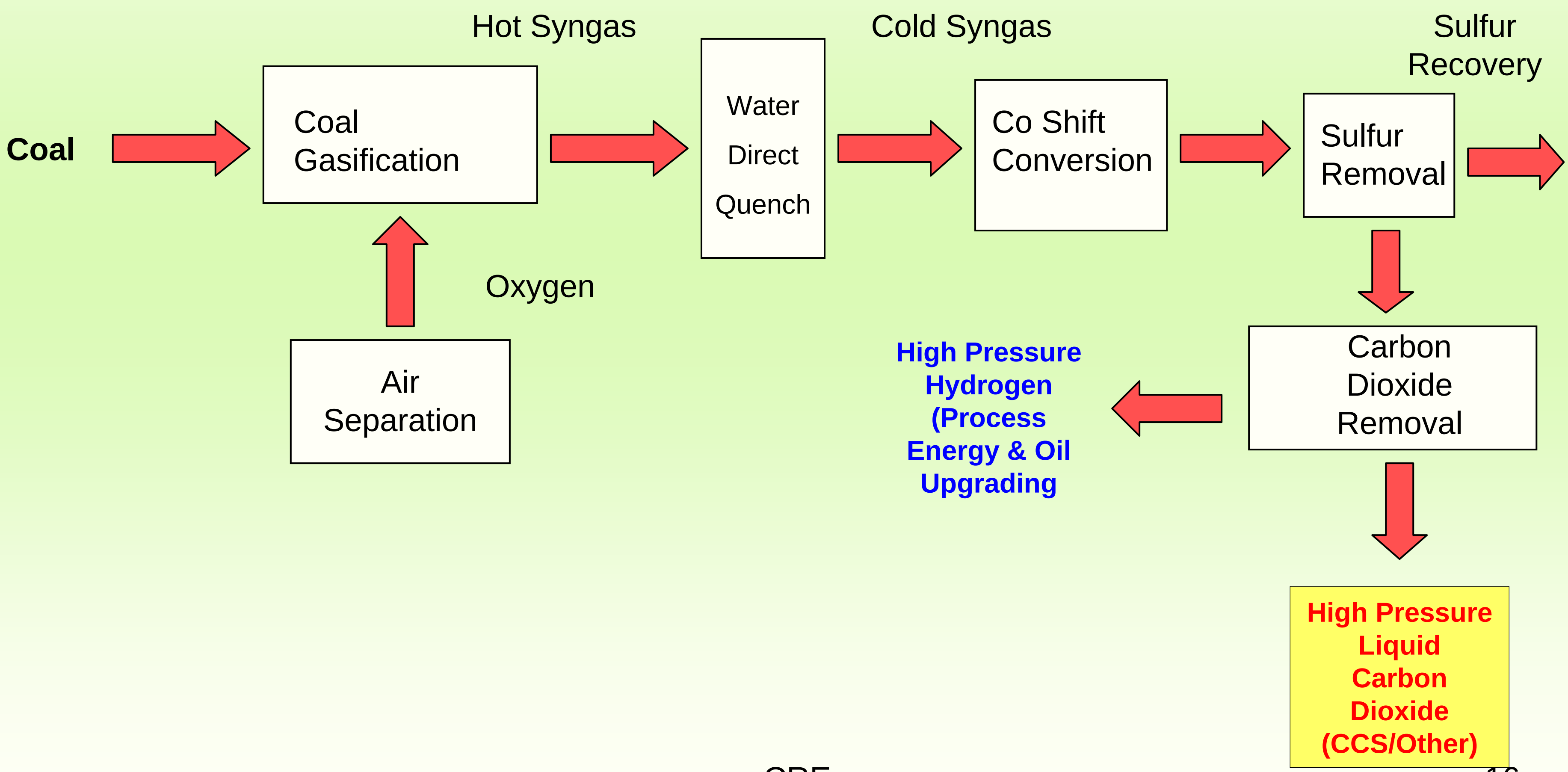
CO_2 from carbon
CO_2 from carbonates
Clean recovery gases

If CO_2 Capture Not Required, Burn Spent Shale Carbon for Process Energy

STEP 4. RECYCLE FUEL GASES FROM KILN AND UPGRADE TO GASIFIER



STEP 5. CO_2 SEPARATION AND RECOVERY



STEP 5. CO_2 CAPTURE PROCESSES

- **Chemical Absorption Process**. Monoethylamine (MEA) solvent. Licensed- Girdler Corp (1938). Installed- Atlantic Richfield Refinery, Texas. Many installations
- **Physical Absorption Process.** Selexol as a solvent. Allied Chemical invented by – now licensed by UOP. Few commercial applications. Little technical information available
- **Cryogenic Process** Patent pending invention (Dr. Larry Baxter, 2006, BYU professor), Technique similar to oil field gas plants using compression and turbo-expanders.

STEP 5. CO_2 REMOVAL COMPARISONS

BASIS:

- COMMERCIAL 6000 BPD oil shale plant
- C-SOS process
- Total gas flow: 100 million SCFD
- Gas pressure : 950 psig
- Gas temperature 90 F
- PRO II PROCESS SOFTWARE

STEP 5. FOR CO_2 REMOVAL

Feed Gas: Vol %		Product Gas:
Hydrogen	56.0	Hydrogen 95% recovery
H_20	Tr.	
CO_2	41.0	CO_2 liquid ca. 100% recovery
CO	1.8	
N_2&Ar	1.2	

STEP 5. CO_2 CAPTURE ENERGY REQUIREMENTS (gjoules/ton CO_2)

Processes similar (capital/operating cost) except energy usage

Energy Use	**MEA**	**Selexol***	**Baxter Cryogenic**
pumping power	0.35	0.77*	0.02
compressor power	0.43	0.23	0.18
Reboiler heat	3.7	-	-
CO_2 recovery%	99.8	96.4	92.7
Hydrogen recovery%	98	96	99.6

*possibly high; limited Selexol data

C-SOS PROCESS CONTROL OF CO_2:

	Tons CO_2 Removed/bbl motor fuel
STEP 1. INDIRECT FIRED ROTARY KILN WITH H_2/AIR	0.2
STEP 2. CONTROLLED SHALE ORE KILN TEMPERATURE	0.3
STEP 3. NO RECOVERY OF SPENT SHALE CARBON	0.15
STEP 4. RECYCLE OIL SHALE OFF GASES TO GASIFIER	0.04
STEP 5. SHIFT GASIFIER SYNGAS TO H_2/CO_2 AND CAPTURE CO_2	0.4
Total	1.09

SUMMARY

- C-SOS PROCESS POTENTIAL:
  - Eliminate 1.2 tons CO_2/bbl motor fuel (97%)
  - Eliminate 0.8 tons CO_2/bbl motor fuel w/o CO_2 removal step (67%)
- ROM COST INCREASE - CO_2 Capture – Step 5

  +25%, capital cost

  +20%, operating cost
- GENERAL – Not for Specific CO_2 Removal Technology

THANK YOU

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