Demonstration and Commercial Design of the Clean Shale Oil Surface Process

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- **CR Colleagues**
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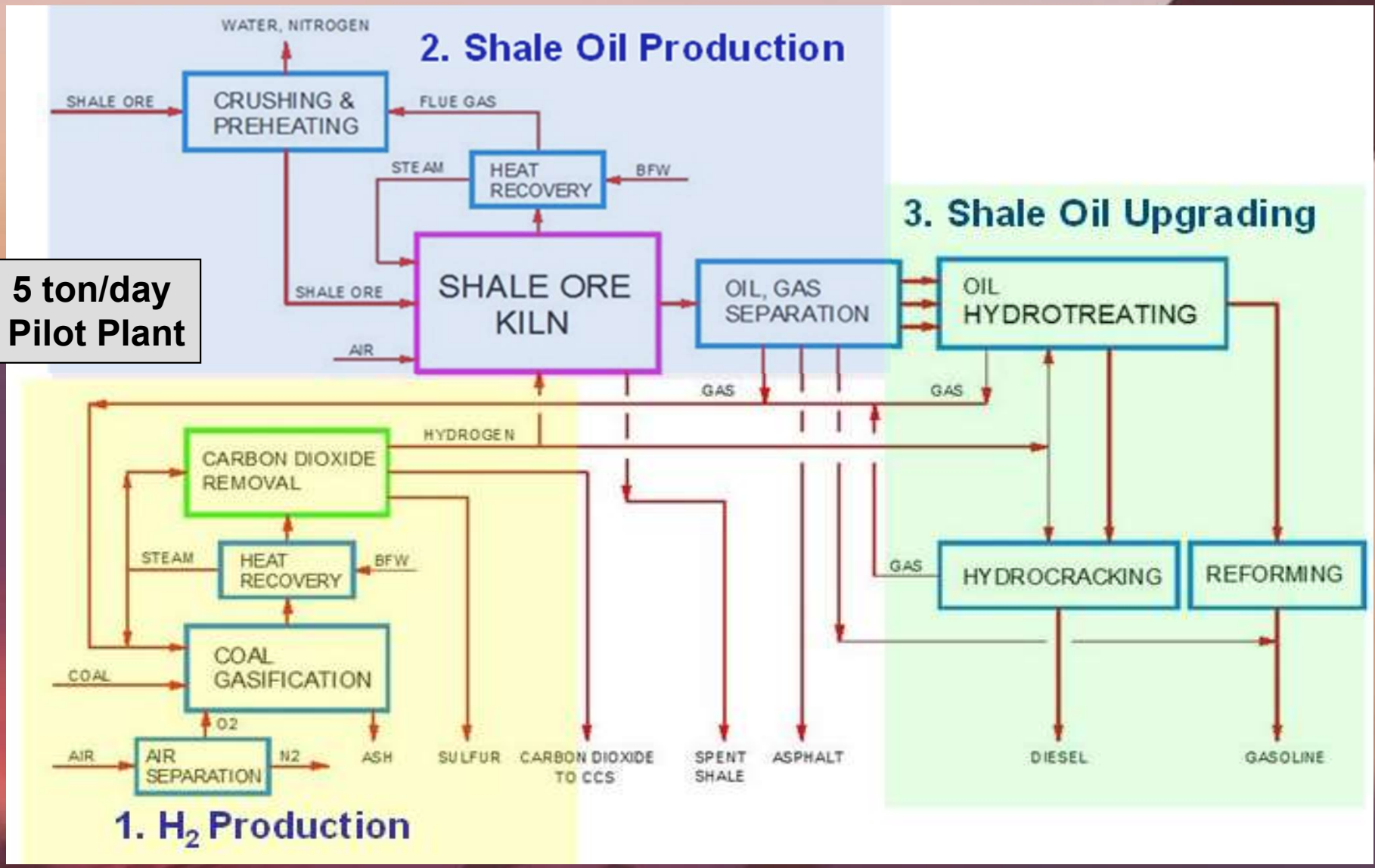
  - Robert Jackson
  - Ambar M. Ochoa
- **Intertek PARC, Inc**
  Shale Oil Upgrading Tests

Objectives

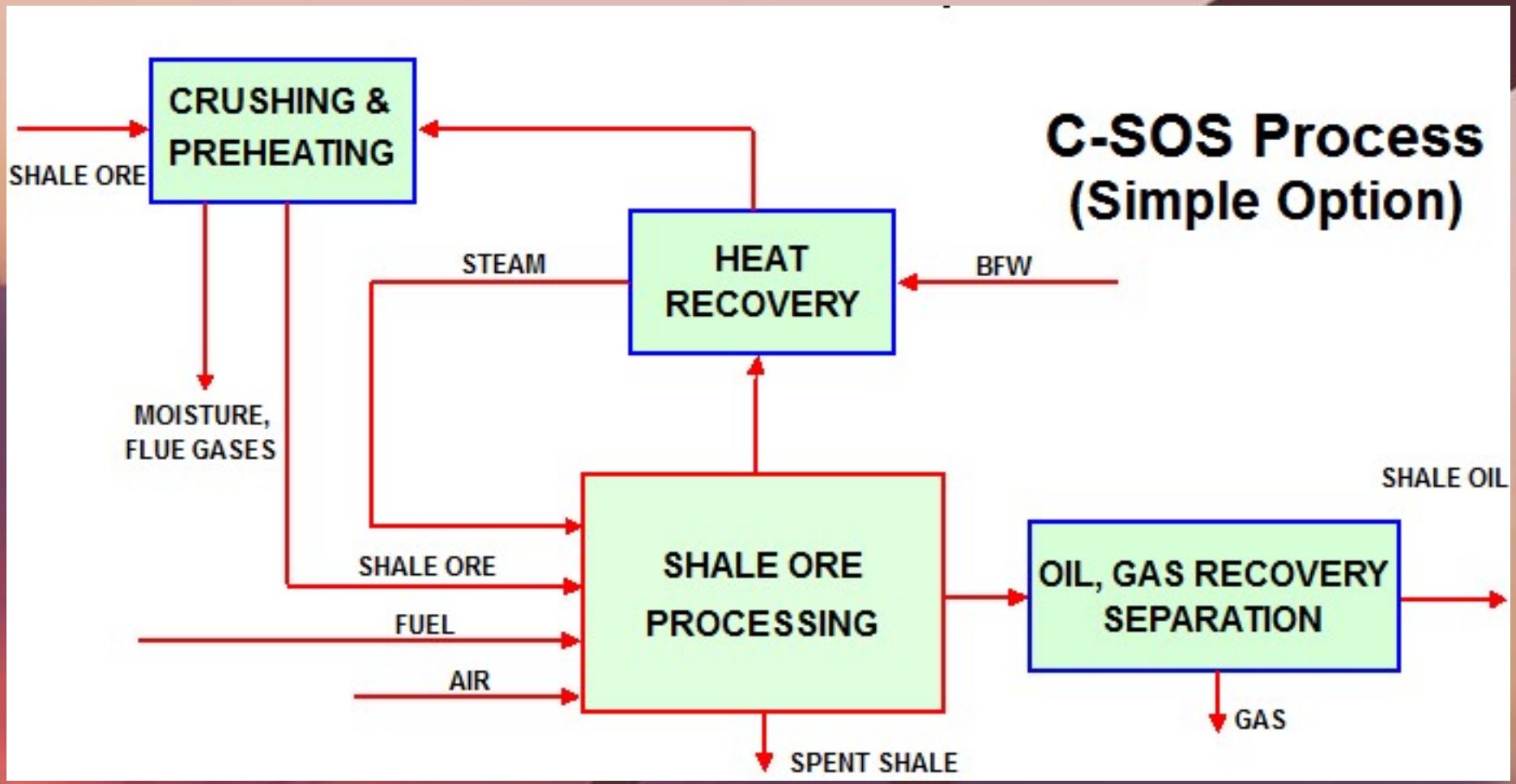
- **Contract Objective – Demonstrate and Evaluate an Advanced Technology for Surface Processing of Oil Shale**

- **Presentation**
  - Process Description
  - Pilot Plant Process Testing and Modeling
  - Preliminary Commercial Design and Cost

C-SOS General Flow Diagram



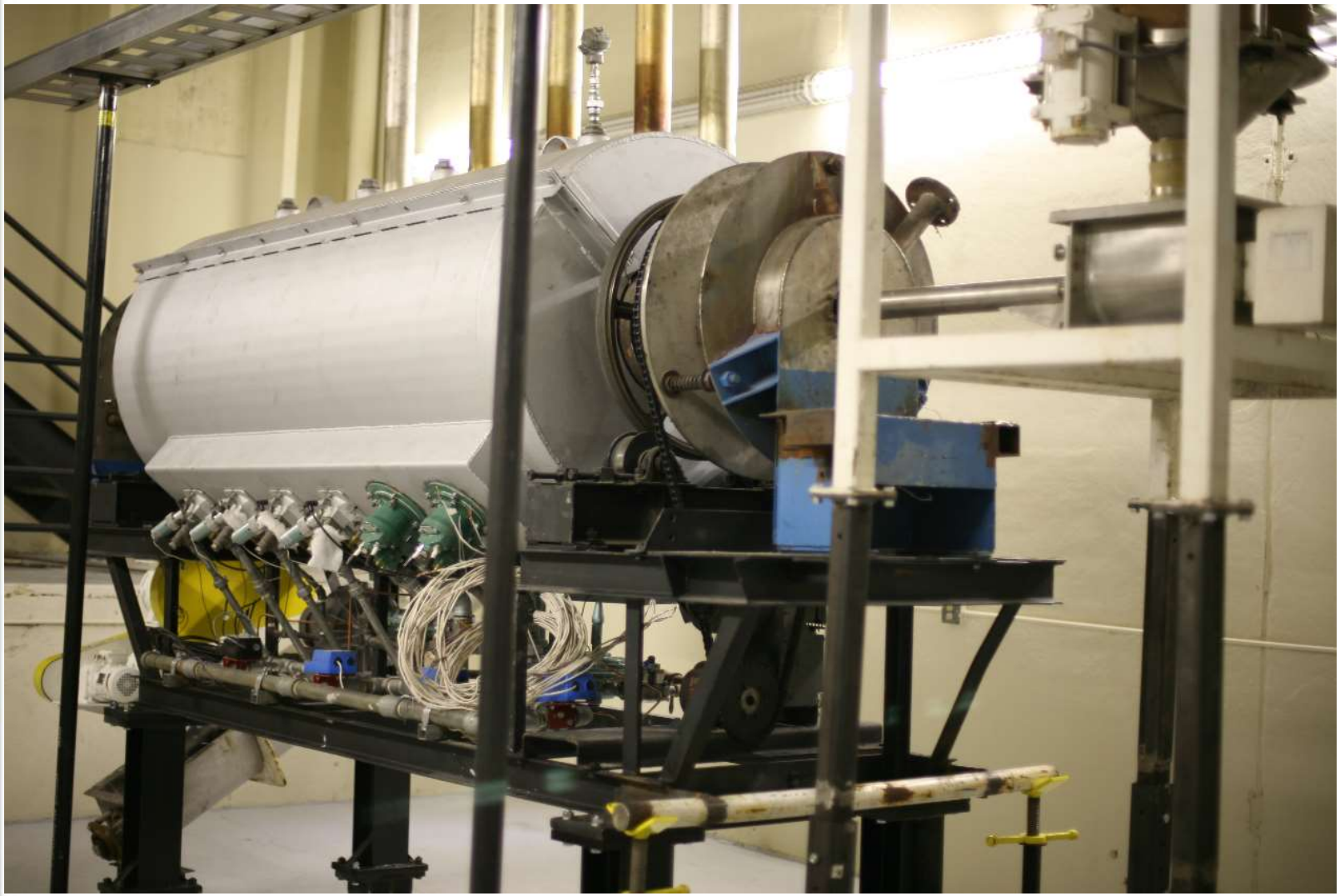
Simple Process Option for Production of Crude Shale Oil



C-SOS Process Characteristics

- Simple, low capital cost, horizontal design
- Commercially-available components
- Unique, high-capacity kiln
- Processing of fines
- Projected low process water use
- Minimum shale carbonate decomposition
- Option for on-site production of motor fuels
- Option for little or no carbon dioxide emissions
- Option for on-site hydrogen production

Pilot Plant Kiln and Burners



Aft-End Oil Product Separation Unit

Pilot Plant Description

- Indirect-Fired Rotary Kiln
- 0.83 ft diameter shell
- 7 ft shell heated length
- Natural gas
- Patent-pending firing configuration
- Medium grade 28 gal/ton

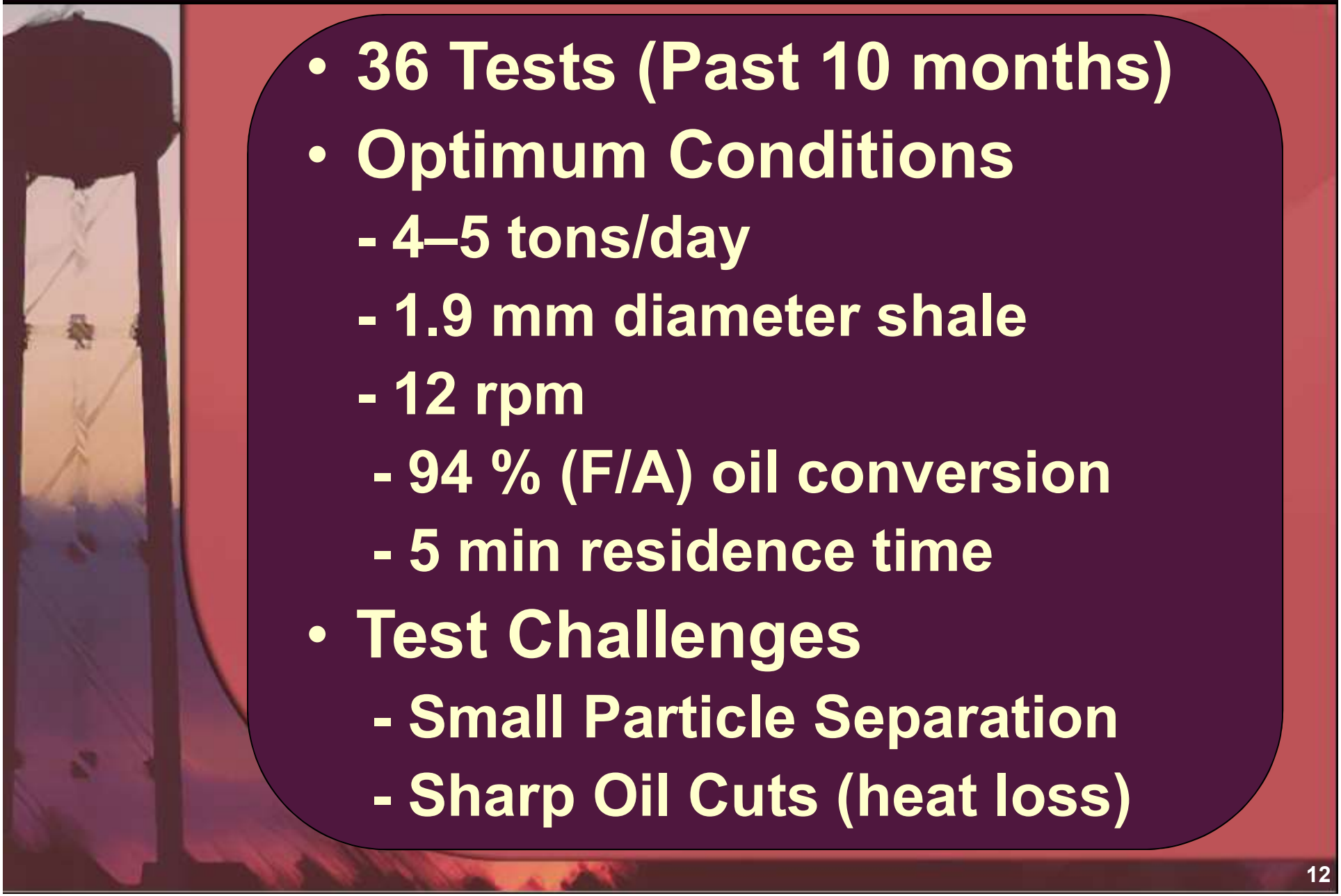
Pilot Plant Operating Parameters

- Shale Feed Rate – 2-6 TPD
- Shell rotation rate, 6-18 rpm
- Shell temperature, 800-500 °C
- Residence time, 5-15 min
- Avg. particle dia., 1.9-2.2 mm
- Steam sweep gas, 0-5 %

Pilot Plant Measurements

- Feedstock shale properties
- Kiln exit solid temperature
- Kiln shell temperature along length
- Mass flowrate/properties
  * Spent shale
  * Shale oil/cuts
  * Fuel gas

General Observations - Pilot Plant Test



- 36 Tests (Past 10 months)
- Optimum Conditions
  - 4–5 tons/day
  - 1.9 mm diameter shale
  - 12 rpm
  - 94 % (F/A) oil conversion
  - 5 min residence time
- Test Challenges
  - Small Particle Separation
  - Sharp Oil Cuts (heat loss)

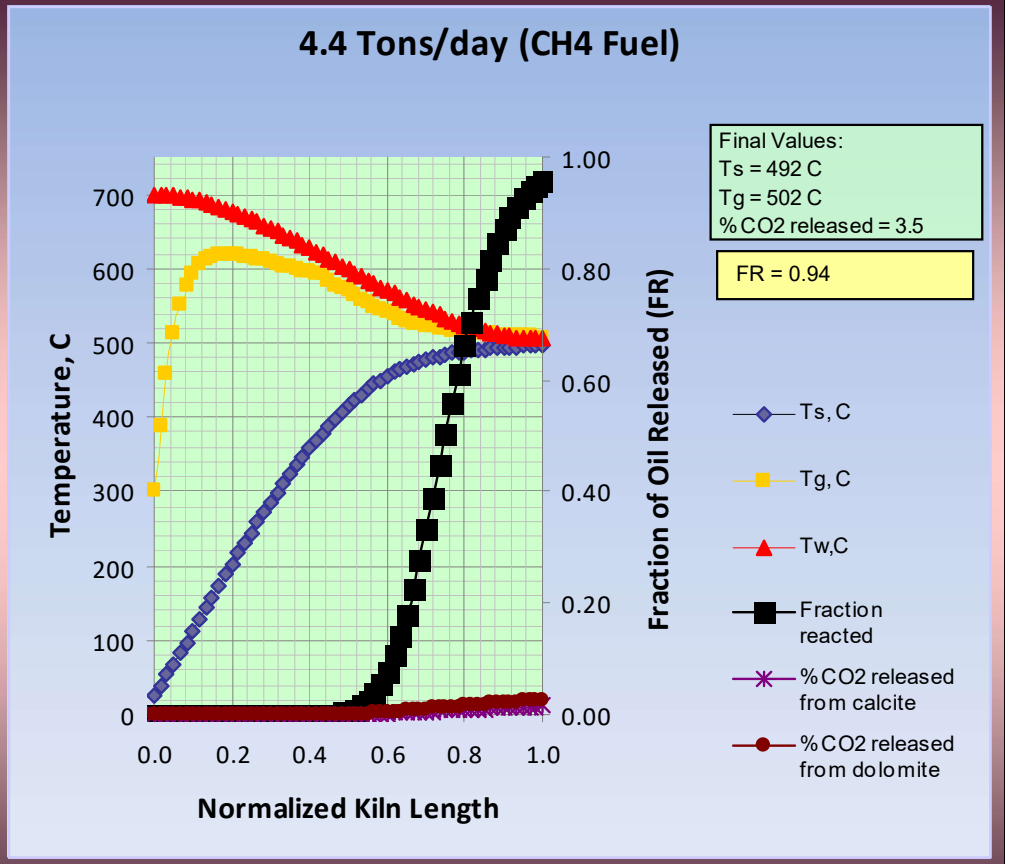
Potential for Kiln Capacity Increase

- Larger Burner Capacity
- Higher Wall Temperatures
- Preheat Feedstock Shale
- Two Stage Cyclone

CR Kiln Code Predictions for Test 23 (Near Optimum)

- **Test Conditions Input**
  - 94 % F/A oil conversion
  - 700 °C initial shell temperature
  - 500°C solid exit temperature
  - 12 rpm
  - 5% steam, 400 °C

	Pilot Test	Kiln Code
Shale Feedrate, TPD	4.2	4.4
Residence Time, min	-	4.6
Fill Fraction	-	0.09
% Carbonate Decomposition (CO_2)	-	3.5



Preliminary Commercial Design
Three Applications

- **6000 TPD Oil Shale Plant**
  - Three Kilns
- **6000 TPD with Onsite Oil Upgrading**
- **2000 TPD – Waste Fines**
  - Single Kiln

Common Conditions

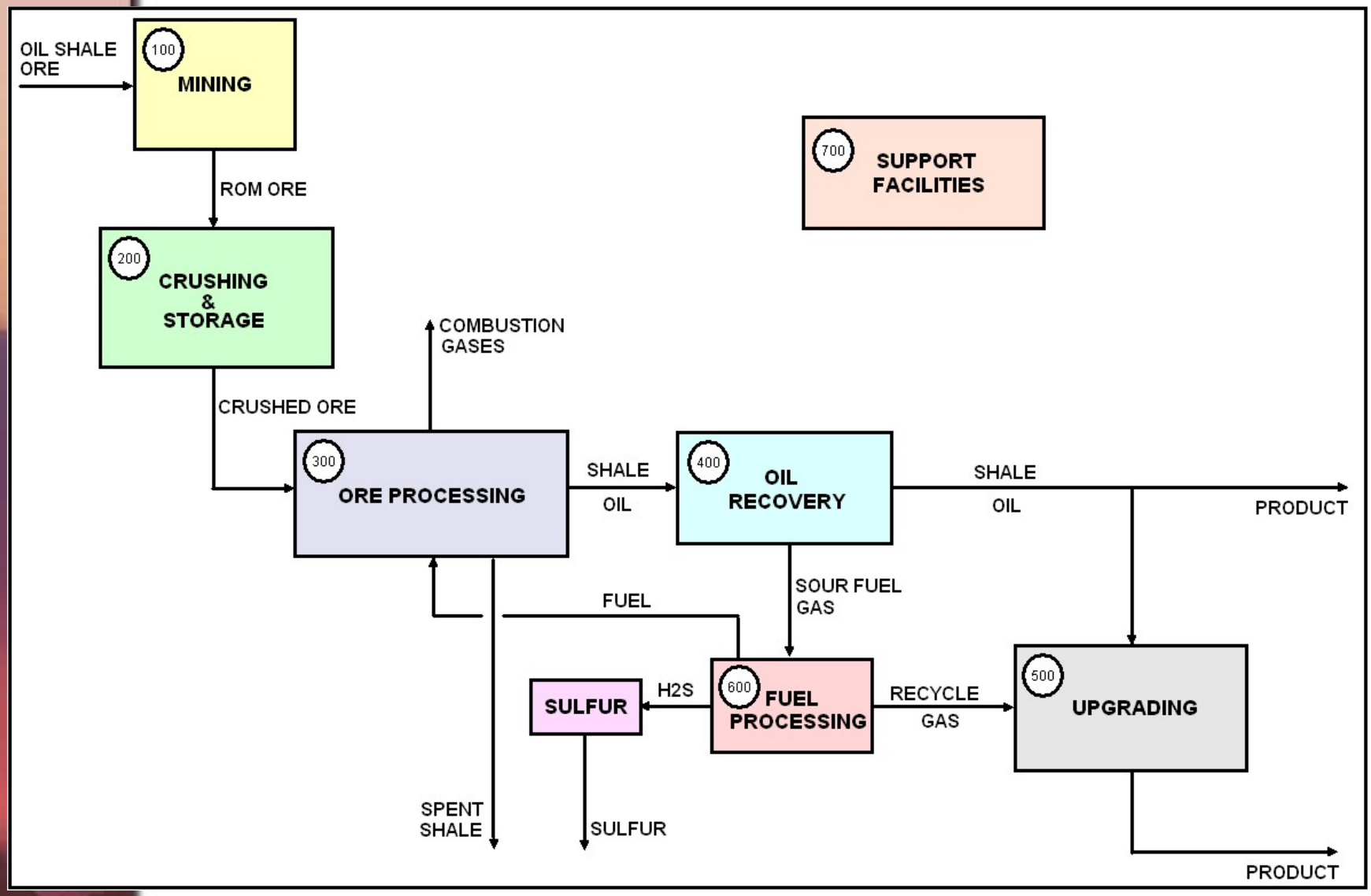
Shell:

12 ft shell diameter
127 ft heated shell length
2 rpm, 1^{o} slope
Residence time – 50 min

Shale:

1.9 mm diameter
36 gal/ton
Fuel gas/Natural gas
Total Oil Collection

Commercial Plant Cofiguration
Cost Centers



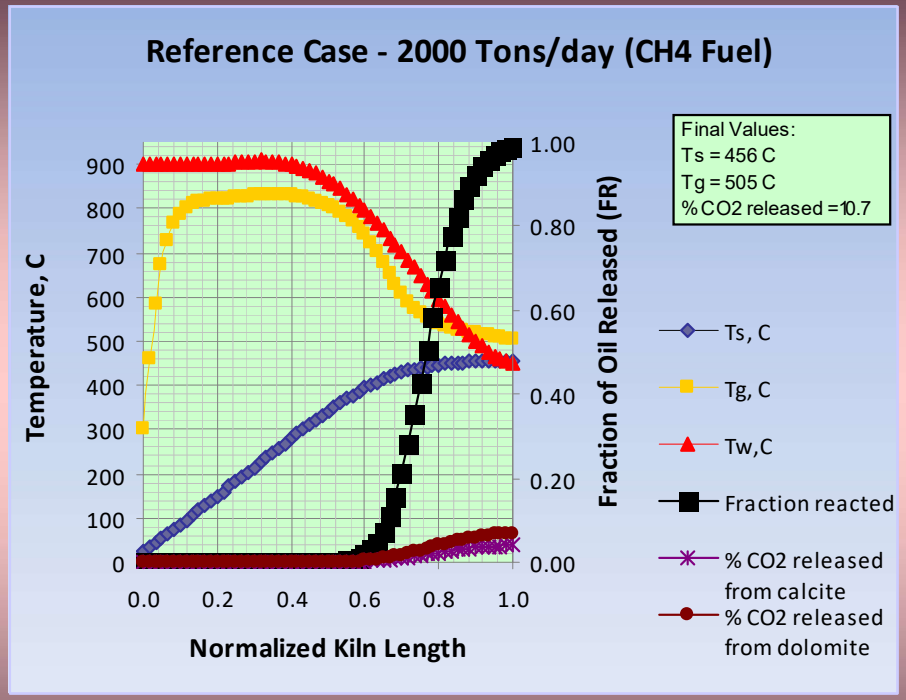
Commercial Indirect Fired Rotary Kiln

(3.5 ft diameter, 35.4 ft long, Photo Courtesy Heyl and Patterson, Inc.)

CR Kiln Code Predictions for Commercial Scale

- **Test Conditions Input**
  - **98 % F/A oil conversion**
  - **900 °C initial shell temp.**
  - **ca. 500°C solid exit temp.**
  - **2 rpm**
  - **3.5% steam, 400 °C**

	Kiln Code
Shale Feedrate, TPD	2000
Residence Time, min	52
Fill Fraction	0.13
% Carbonate Decomposition (CO_2)	10



Commercial Clean Shale Oil Surface (C-SOS) Process Design Cost Estimate

- **Indirect-Fired Rotary Kiln**

  Cross-fired burners

  12 ft diameter

  127 ft long

  HB 800 alloy

  900^{o}C peak shell temperature

  500^{o}C peak shale temperature

  36 gal/ton shale oil

  2 mm shale diameter

  3.5 % sweep steam

Estimated Commercial Costs - Standard Approach

Assumptions

- NREL guidelines
- Eastern Utah location
- Open pit mining
- Installed costs 2.7 x equip. cost
- 15 % project contingency
- 10 % process contingency
- 5 % construction interest
- 10 % owner costs/startup

- 330 days/year
- Current: wage rates, utilities, depreciation
- 20 year plant life
- 30 % discount, if no oil upgrade
- Fuel gas 60 % of kiln need
- Recovery of sulfur

Preliminary Commercial Cost Summary

	Opt. 1 Three kilns 6000 TPD crude oil	Opt. 2 Three kilns 6000 TPD upgrade oil	Opt. 3 One kiln 2000 TPD waste fines
Cap. Cost ($ millions)	198	254	48
Cap. Cost per (bbl/year)	116	135	85
Oil produced (1000 bbl/year)	1700	1885	566
Annual Operating Costs ($ millions)	57	86	11
Product price ($/bbl)	57	80	68
Annual Revenue ($ millions)	95	151	38
Net Annual Revenue (less op. cost)	38	65	27
% Net Annual revenue before taxes/cap. cost	20	26	32

Summary

- **Phase II DOE/SBIR nearly complete**
- **Pilot plant demonstrated process**
- **Kiln code/process code – vital tools**
- **Attractive Options**
  - Upgrading oil onsite
  - Process fines stockpile
- **Intermediate-Scale Testing Required**

DOE/SBIR Project Extension

- Improve Oil Recovery
- Verify discoveries for kiln capacity increase
- Increase fine particulate removal

THANK YOU

Doug Smoot, Kent Hatfield, Craig Eatough
Combustion Resources, Inc.

To Obtain Copy of

Preliminary Commercial Design/Cost Report

Give Business Card to

Doug Smoot or Craig Eatough or
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