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Presentation To:

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MINES

Reducing Greenhouse Gas Intensity from Thermal Processing of Oil Shale Using the Alberta Taciuk Process (ATP) by Managing Carbonate Decomposition

Colorado School of Mines, 32nd Oil Shale Symposium

UMATAC Industrial Processes
A company of ThyssenKrupp Polysius

ThyssenKrupp

ThyssenKrupp Polysius

Agenda

- Introductions
- Carbonate Decomposition Research & Results
- Implementation into Commercial ATP Application
- Questions

Corporate Introduction

ThyssenKrupp AG – Plant Technology

Fördertechnik	Polysius AG		Uhde
Mining, Crushing, Stockpiling, Ash Handling	UMATAC, ATP System	Cement Production	EPC, Oil Refining and Upgrading

World Class Partners

Complete Project Integration from Mine to Barrel, and Beyond!

UMATAC Research & Development Facility

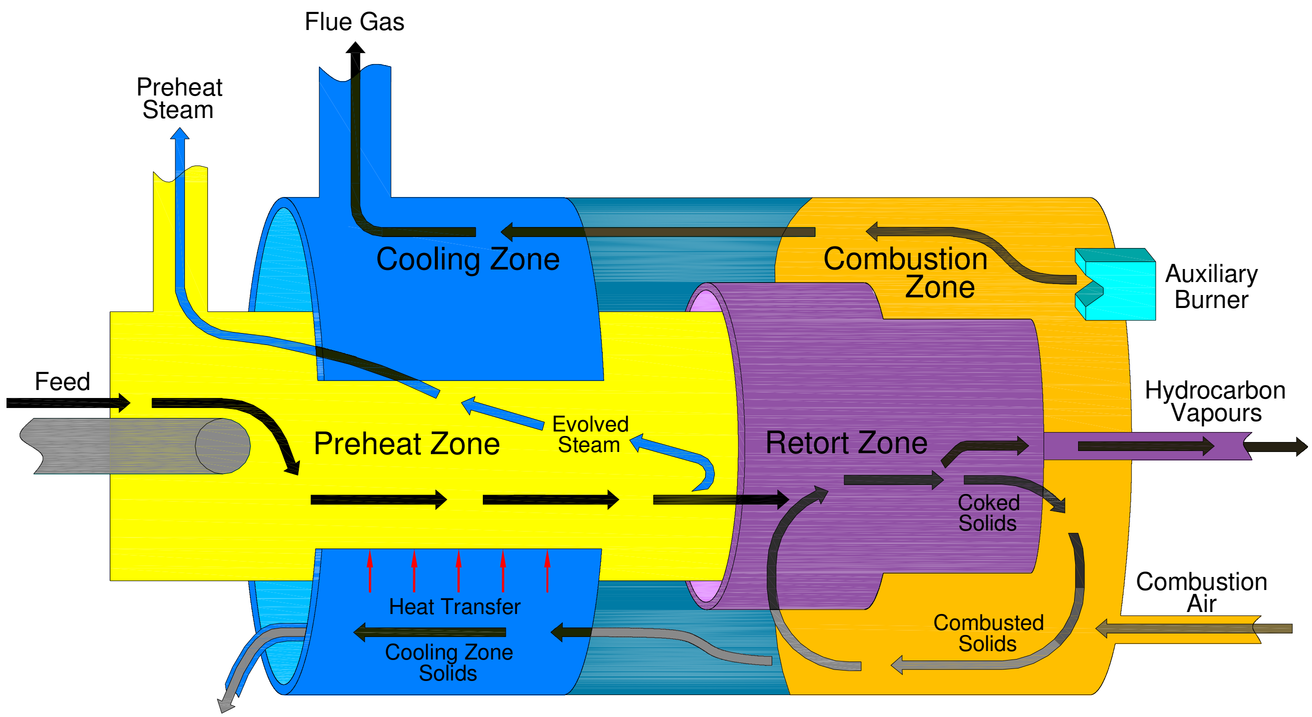
UMATAC Research & Development Center Capabilities

- **Feed Stock / Product Characterization:**
  - Basic Physical Properties
  - Modified Fisher Assay (MFA)
  - Batch Testing (Bulk Oil Sample Production)
  - Analysis of Solid / Liquid / Gaseous Products
- **ATP Technology:**
  - Bench Scale Test Units
  - Small Scale Units (Batch)
  - Continuous Flow Test Units
  - ATP60 Plant (5 t/h Demonstration Plant)
- **Other Services:**
  - Special Test Unit Development and Operation
  - Alternative Feed Stocks
  - Shale Ash Cementing Tests
  - Project Specific R&D

Testing from Bench to Demonstration Scale to Suit Clients' Needs

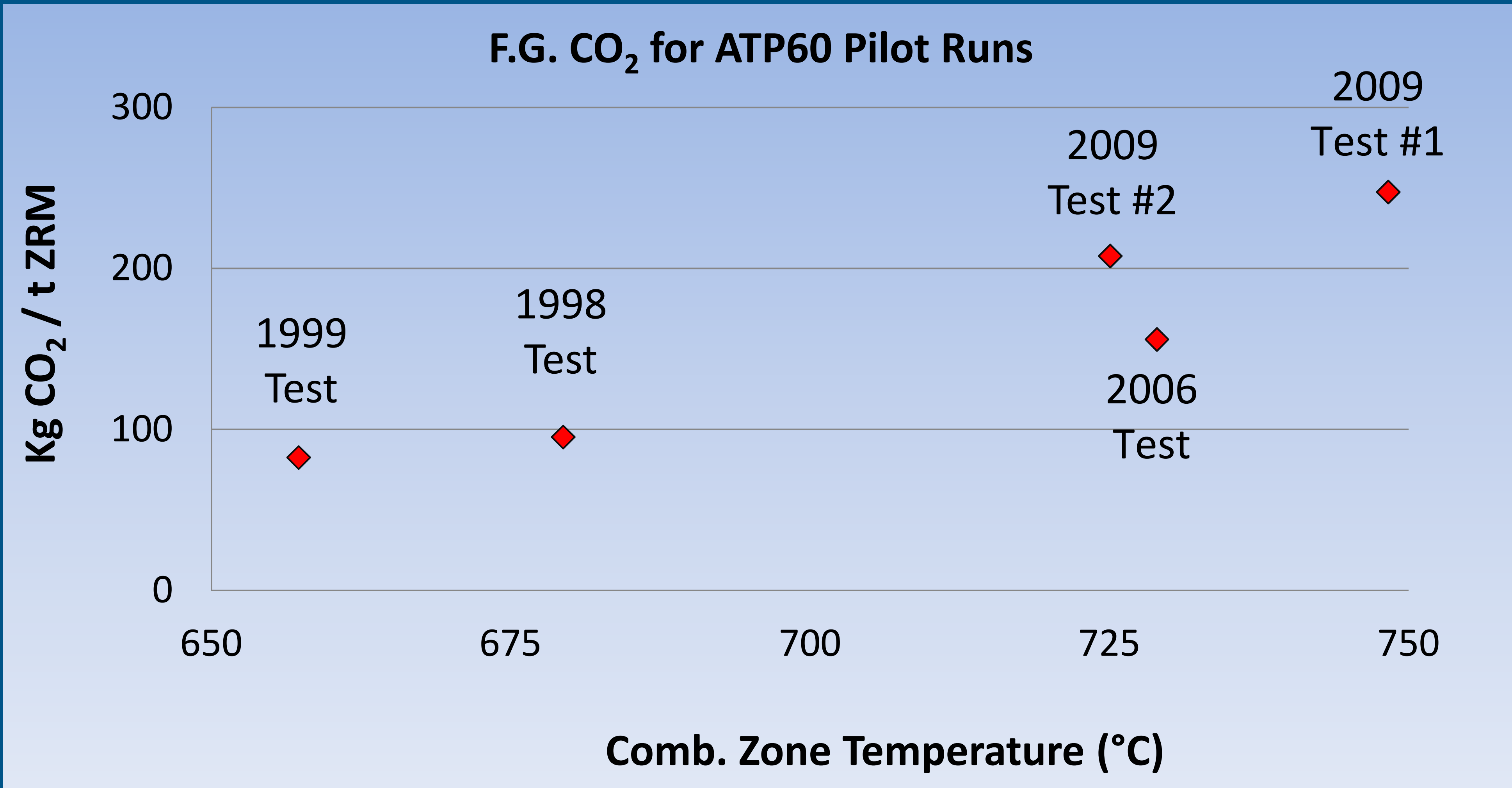
The ATP Processor

	Preheat	Retort	Combustion	Cooling
Residence Time/Cycle (min)	10-15	5-8	6-12	10-20 Coarse, <1 Fines
Temperature (°C)	Amb. – 250	500	680-750	650-350
Gas Phase	Steam	HC Vapors	Air/F.G./Dust	F.G./Dust
Pressure (mmWC)	-2	-40	-15	<-15
Carbonate Rxns Intensity	N/A	Low	High	Moderate - Diminished Rate



The ATP Processor

The Problem: Variation in Historical Data



Research Prompted by Large Deviation in Historical Data from ATP Pilot Runs on Al Lajjun Shale

Current CO_2 Accounting – Karak International Oil Project

KARAK INTERNATIONAL OIL | JORDAN ENERGY & MINING

CO_2 Intensity Estimate: Conservative & Comprehensive

145-185 kg/t ZRM

200-250 kg/bbl SCO

Offsets: CO_2 Difference between KIO Byproducts and Current Production/Transport of Byproducts

Potential Offsets:

A - Offset Imported Sulphur for Fertilizer

B - Low CO_2 Electricity Export

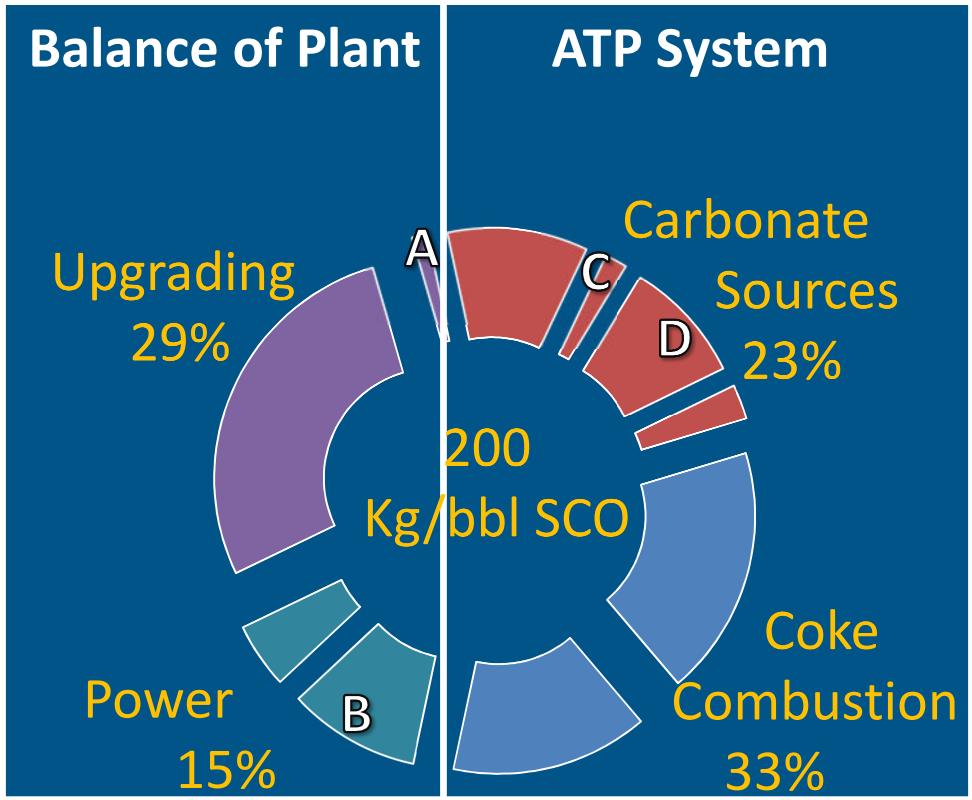
C - Phosphate Co-Mining

D - Shale Ash use in Cement Manufacture

Comparable to:

Alberta Oil Sands	233 kg/bbl SCO
OPEC Primary Recovery	167 kg/bbl
OPEC Tertiary Recovery	208 kg/bbl

CO_2 Generation and Distribution

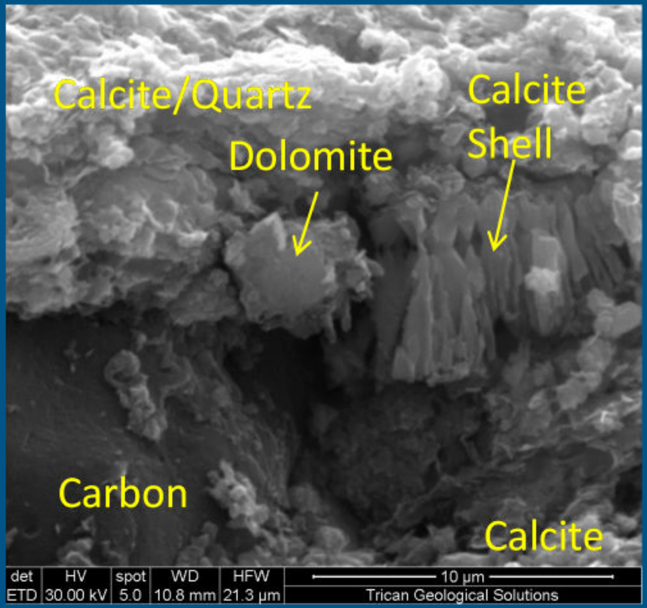


SCO Produced by ATP has Carbon Footprint Similar to Other Conventional & Non-Conventional oils

Al Lajjun Oil Shale – Mineralogy & Carbonate Decomposition

High Carbonate Content:

~ 27-40 wt%	Calcite	($CaCO_3$)
~ 5-7 wt%	Dolomite	($CaMg(CO_3)_2$)
~ 0-5 wt%	Magnesite	($MgCO_3$)
~ 0-2 wt%	Siderite	($FeCO_3$)

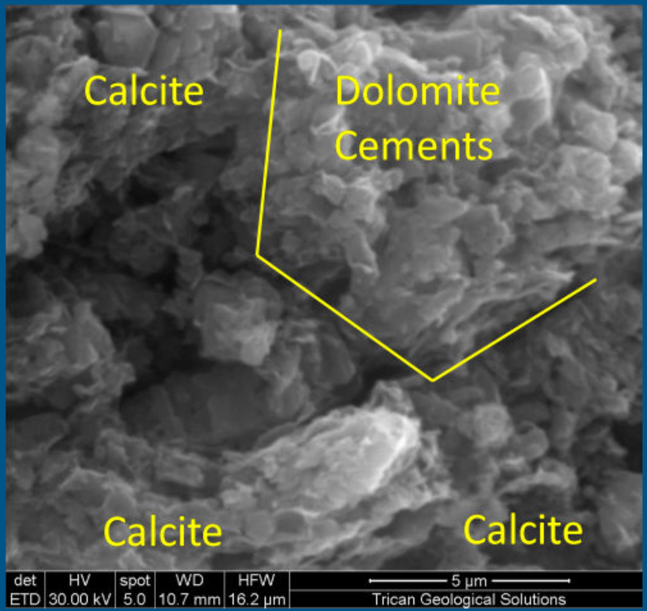


Thermal Decomposition of Calcium Carbonate:

$CaCO_3 \rightarrow CaO_{(s)} + CO_{2(g)}$

Temperature Range: 600°C to 1,000°C

Endothermic Reaction: ~1.8 MJ/kg



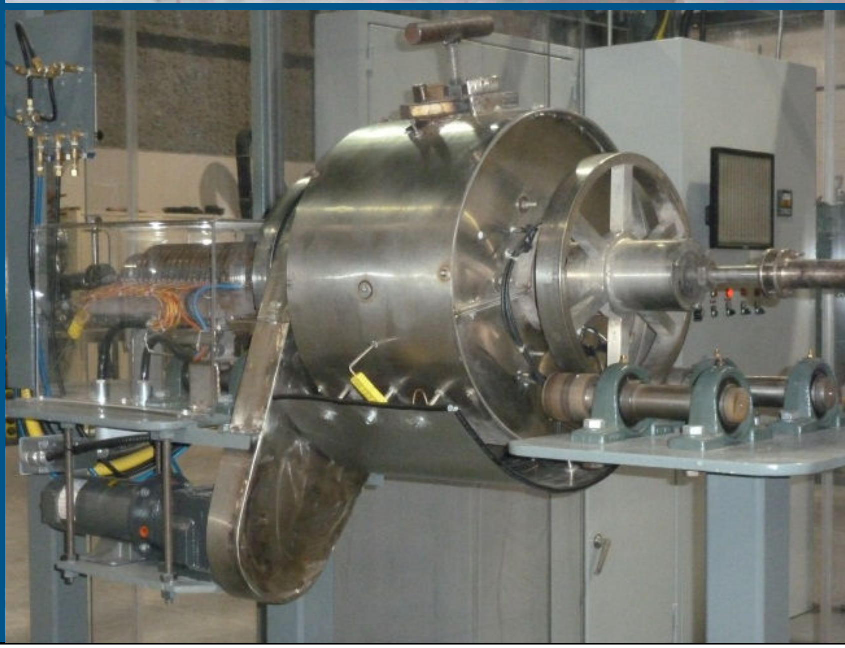
Al Lajjun Shale:
High Carbonate Content

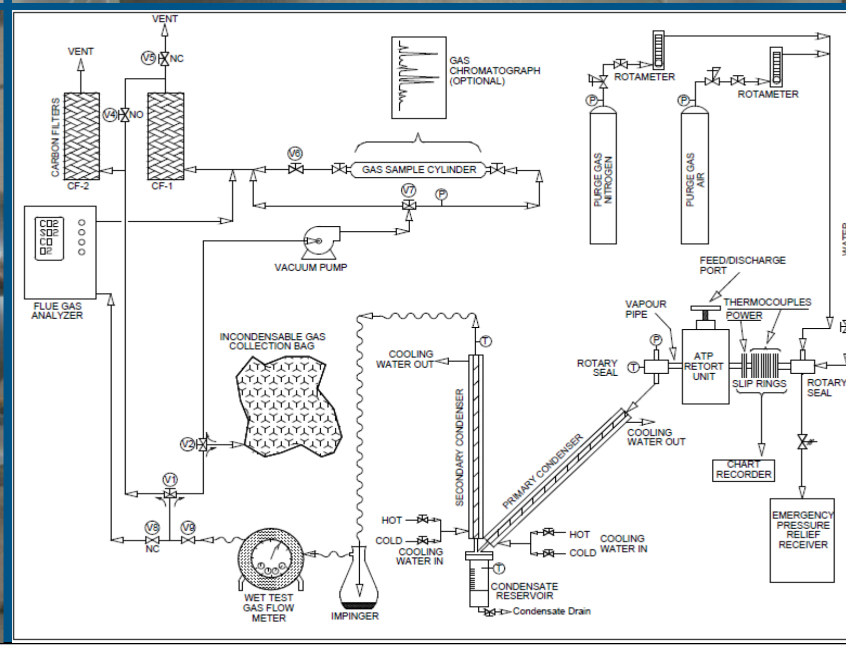
Literature Review

Many Sources Referencing Thermal Decomposition of Carbonates:

Laboratory/Academic Setting	Industrial/Commercial Setting
Pure Carbonate Species	Carbonate Species Embedded in Shale (Clays, Silica, Kerogen, Etc)
mg - g	Up to 500 t/h
Fixed Heating Rates	Variable Heating Rates
Inert Atmospheres	Different Atmospheres
High Vacuum/Pressure	Nearly Atmospheric Pressure
Effect of Temperature	
Effect of CO_2 Partial Pressure	

The Research Apparatus: ATP Batch Unit





The Research: Initial Approach

Isolate Carbonate Decomposition Reaction

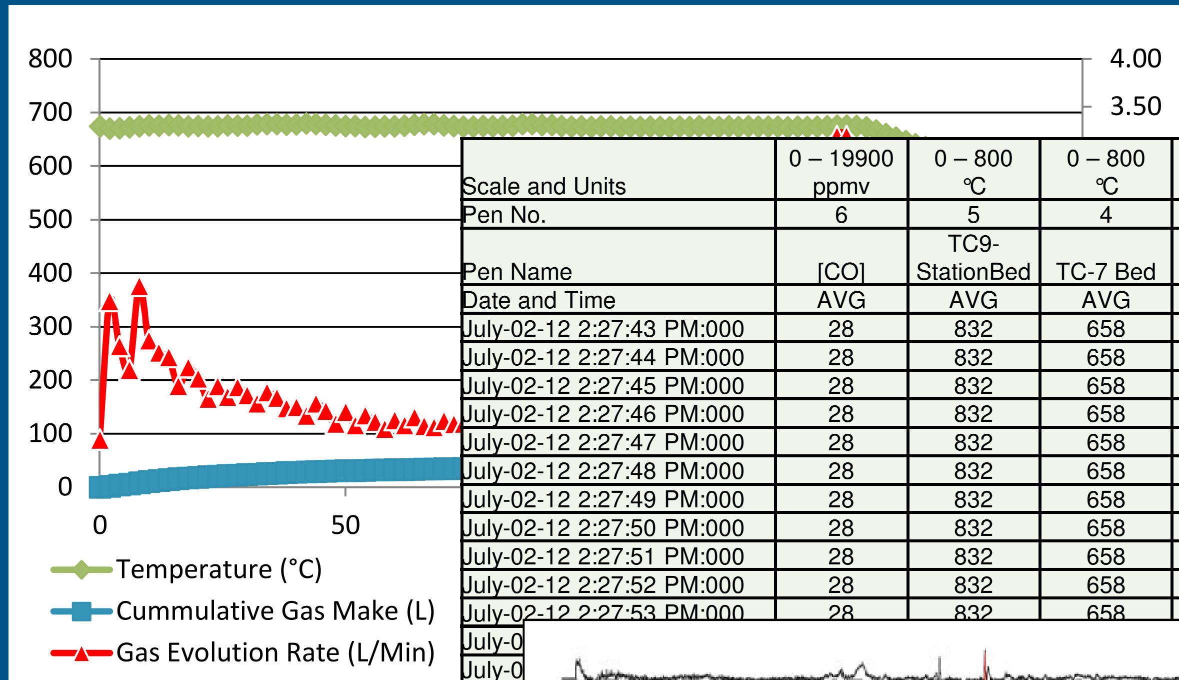
O_2-Free Environment to Prevent Combustion / Oxidation Reactions

Parallel Reactions:

$CO_2 + C_{(Coke)} \rightarrow 2CO_{(g)}$ $2CO_{(g)} \rightarrow CO_2 + C_{(Soot)}$ $Coke \rightarrow xC_{(s)} + yCH_4 + zH_2$

The Research: Comprehensive Approach

- 40 Batch Runs / Pyrolysis / High-Temperature Carbonate Decomposition / Combustion
- 360 GC Analyses
- LOI
- CEM CO_2 & CO
- XRD Analyses
- SEM
- Ultimate Analyses
- Calcite Equivalent by Acid Digestion



Scale and Units	0 – 19900 ppmv	0 – 800 ℃	0 – 800 ℃	0 – 508 mmWC	0 – 20 vol%
Pen No.	6	5	4	3	2
Pen Name	[CO]	TC9-StationBed	TC-7 Bed	dP	[CO2]
Date and Time	AVG	AVG	AVG	Sample	Sample
July-02-12 2:27:43 PM:000	28	832	658	6.2	0.2
July-02-12 2:27:44 PM:000	28	832	658	6.2	0.2
July-02-12 2:27:45 PM:000	28	832	658	6.2	0.2
July-02-12 2:27:46 PM:000	28	832	658	6.2	0.2
July-02-12 2:27:47 PM:000	28	832	658	6.2	0.2
July-02-12 2:27:48 PM:000	28	832	658	6.2	0.2
July-02-12 2:27:49 PM:000	28	832	658	6.2	0.2
July-02-12 2:27:50 PM:000	28	832	658	6.2	0.2
July-02-12 2:27:51 PM:000	28	832	658	6.2	0.2
July-02-12 2:27:52 PM:000	28	832	658	6.2	0.2
July-02-12 2:27:53 PM:000	28	832	658	6.2	0.2
July-0					
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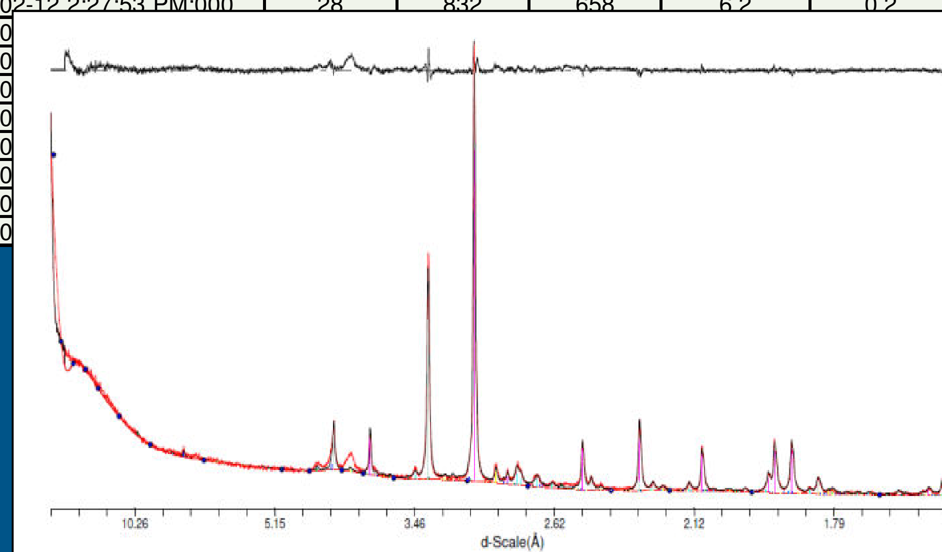
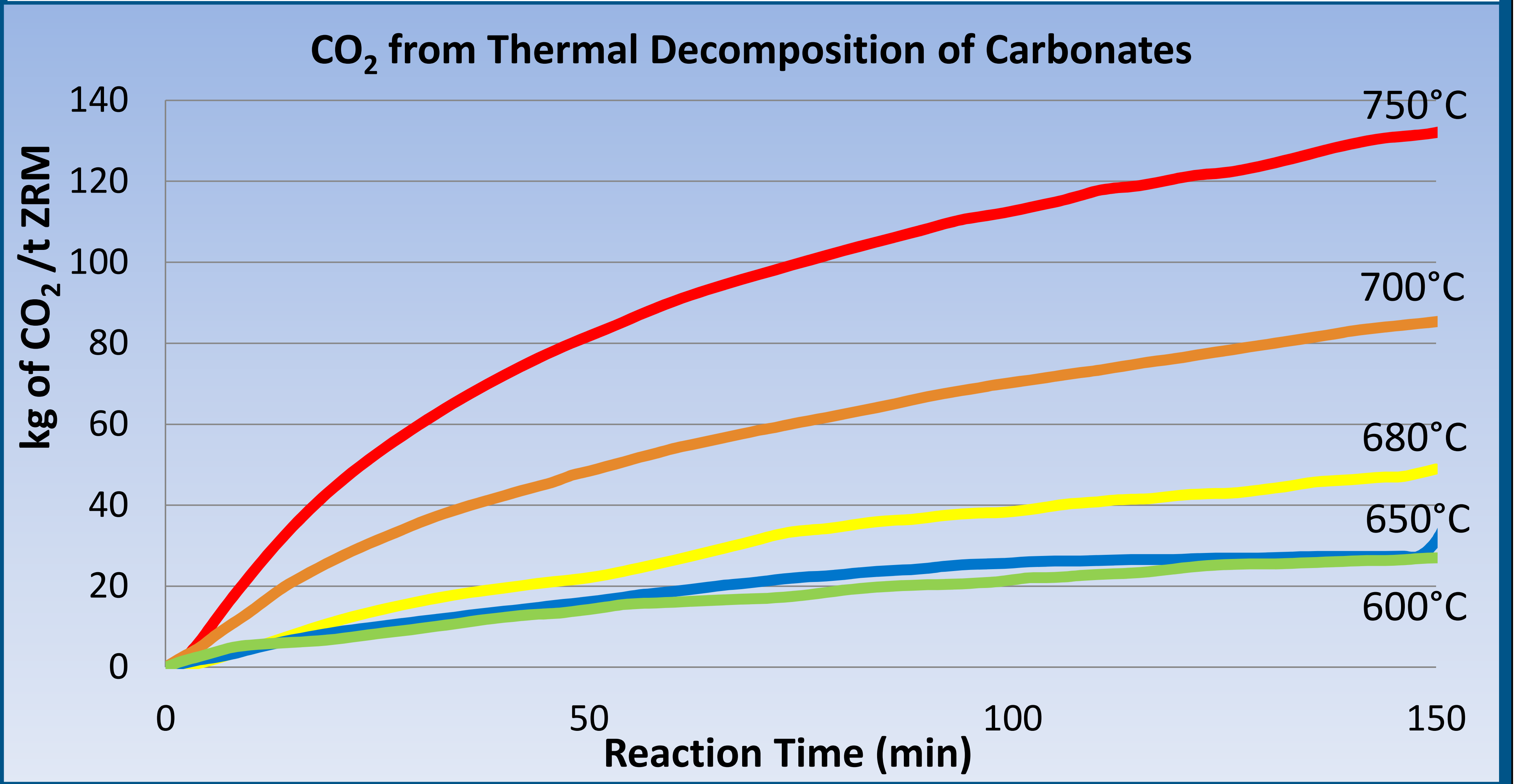


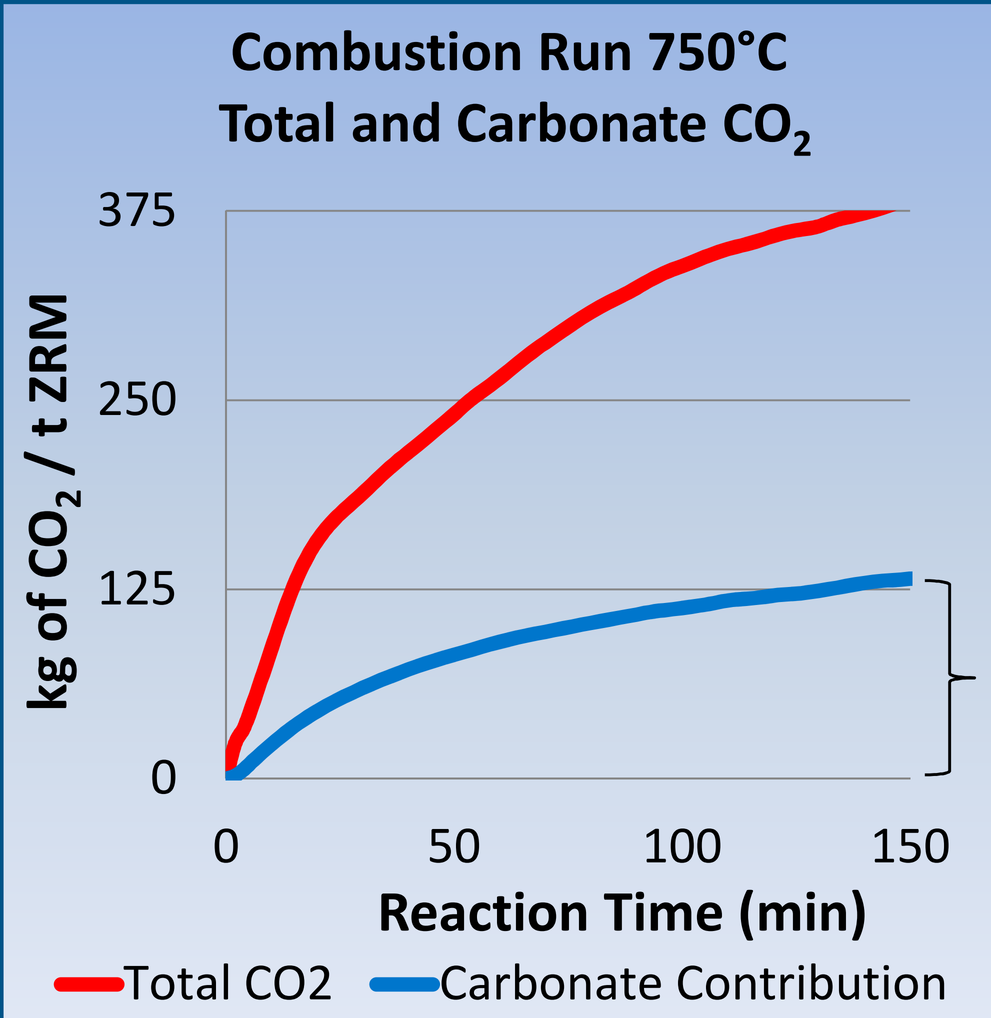
ULTIMATE ANALYSIS, as received basis									
LAB#	ID:	%MOIST.	%C	%H	%N	%S	%ASH	O b/d	Basis
121083	Raw Shale	0.94	20.59	2.00	0.37	3.27	62.37	10.46	arb
			20.79	2.01	0.37	3.30	62.96	10.56	db
121084	Pyrolyzed Solids	0.04	12.29	0.42	0.32	1.10	72.43	13.40	arb
			12.29	0.42	0.32	1.10	72.46	13.41	db
121085	Decarbonated Solids	0.10	10.41	0.17	0.20	1.21	80.03	7.88	arb
			10.42	0.17	0.20	1.21	80.11	7.89	db
121086	Combusted Solids	0.21	5.20	0.09	0.01	1.22	83.34	9.93	arb
			5.21	0.09	0.01	1.22	83.52	9.95	db

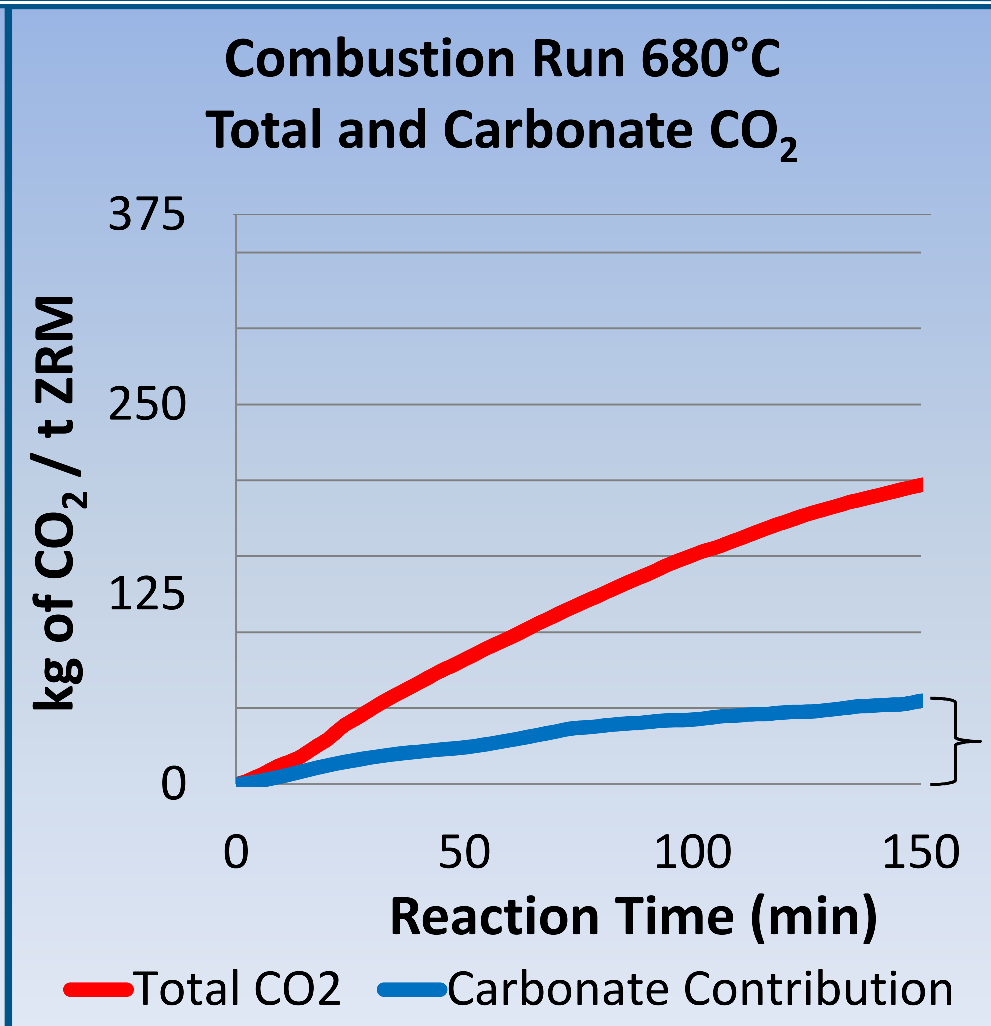
The Results: Temperature and Residence Time



Lower Temperature Reduces Carbonate Decomposition Significantly – and Also Reduces Overall Heat Demand!

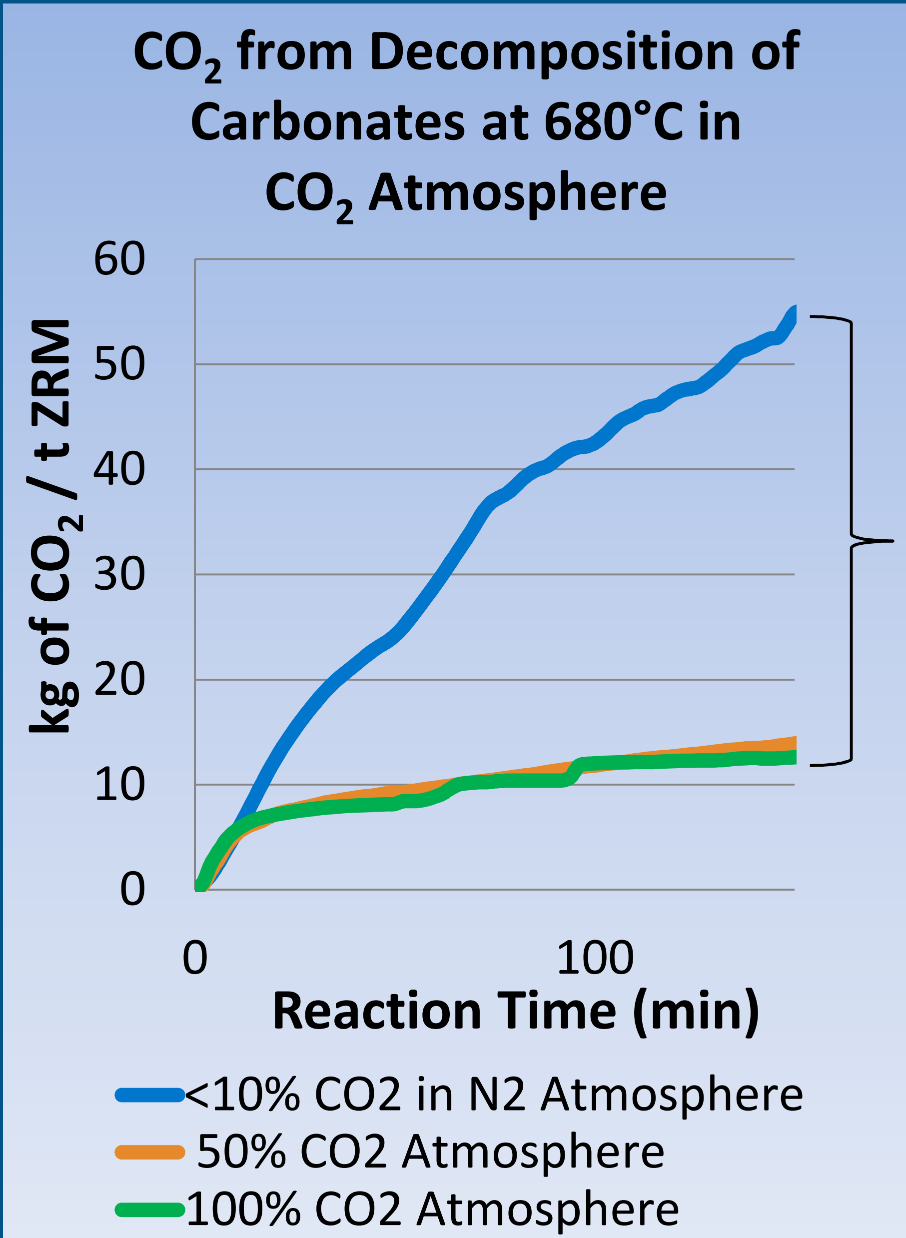
The Results: Carbonate CO_2





Lower Temperature:
Lower Overall Emissions
Lower Contribution from Carbonates

The Results: CO_2 Partial Pressure



Some Evidence Supporting Carbonization of Spent Shale Hypothesis:

$$CaCO_3 \rightarrow CaO_{(s)} + CO_{2(g)}$$

$$CaO_{(s)} + CO_{2(g)} \rightarrow CaCO_3$$

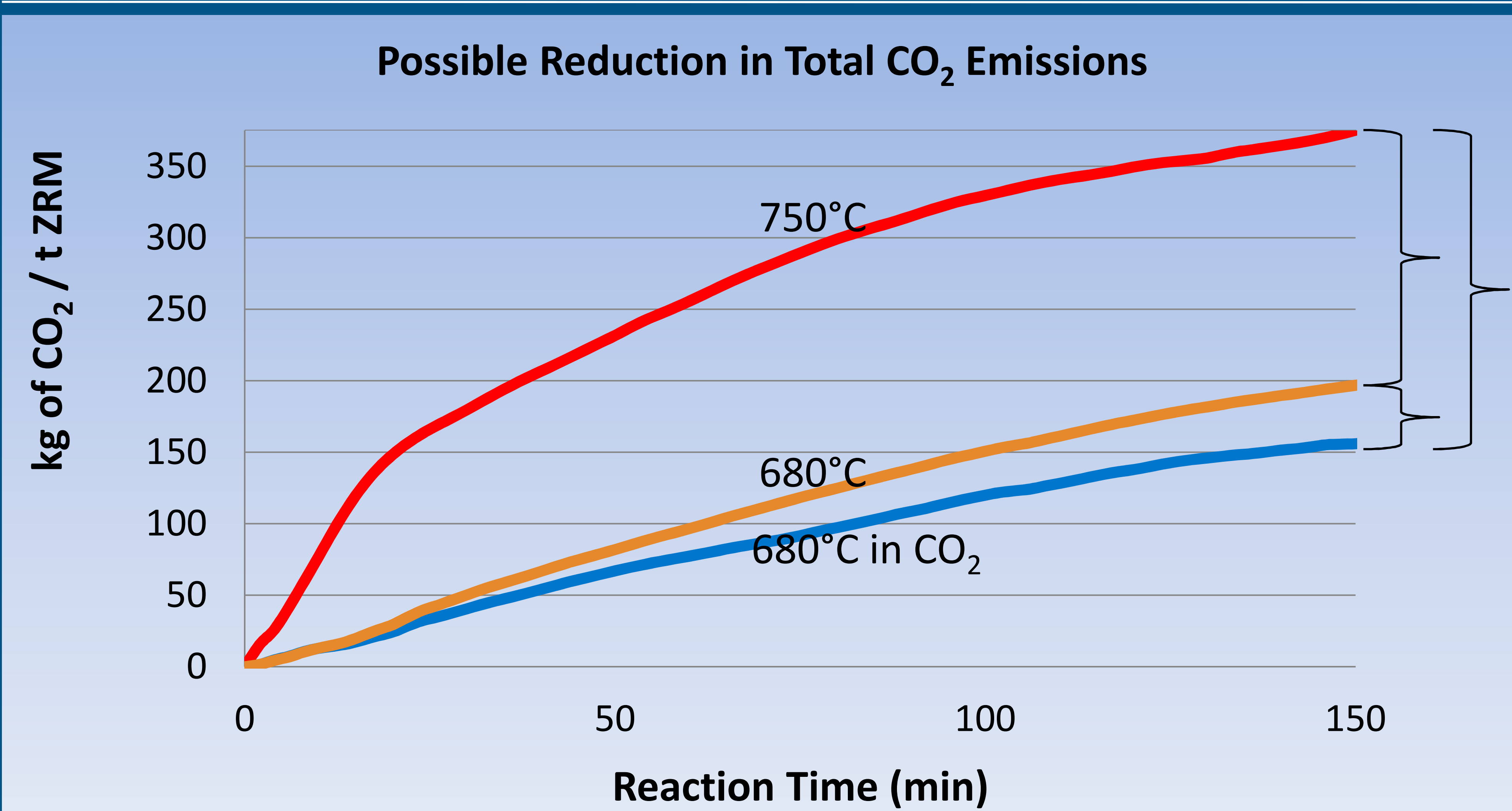
XRD Analysis:

Spent Al Lajjun Shale:
~500°C in Retorting Atmosphere
55.0 wt% Calcite
3.1 wt% Dolomite

680°C in N_2
32.3 wt% Calcite
0.1 wt% Dolomite

680°C in CO_2
56.4 wt% Calcite
4.0 wt% Dolomite

The Results: Combined Temperature & CO_2 Partial Pressure



Potential for Significant Reduction in CO_2 Emissions
By Simply Changing Operating Parameters of ATP

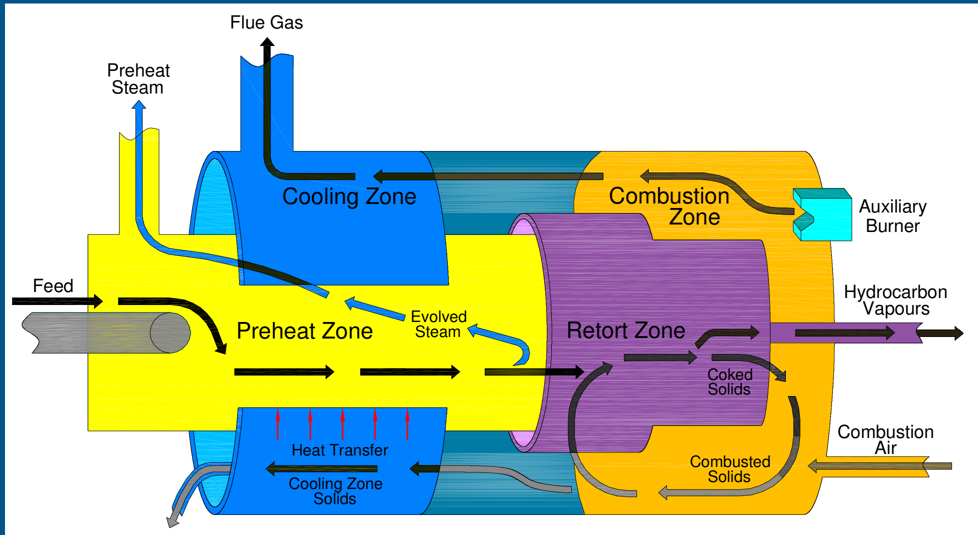
Implementation into Commercial ATP Application

Temperature Reduction?

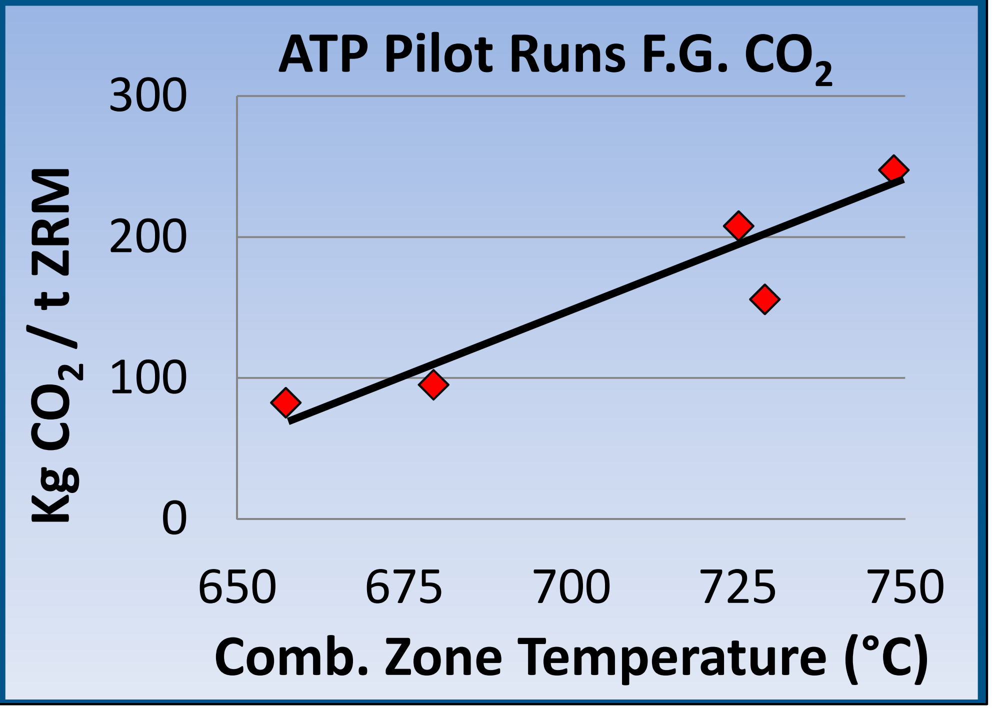
- ATP has the Flexibility (without Sacrificing Performance)
- Combustion Temperature can be Reduced:
  "Jordanian oil shale can be burned continuously & efficiently with an average bed temperature of 647°C.",
  M.A. Hararah, A. Sakhrieh, M. Hamdan
- Already Tested - More than 500 t

CO_2 Enriched Atmosphere?

- ATP has the Flexibility (without Sacrificing Performance)
- Best when Coupled with CO_2 Sequestration
- Economical Viability?



The ATP Processor



Questions?

Gracias 谢谢 Thank You

Obrigado Спасибі

Vielen Dank شكرا Merci

Definitions / Legend

ATP	Alberta Taciuk Processor
ATP60	UMATAC's 5 t/h Pilot ATP Unit (60 bbl/d on Oil Sands)
bbl	Barrel of Oil (~159 L)
CEM	Continuous Emission Monitoring
FG	Flue Gas
HC	Hydrocarbons
LOI	Loss on Ignition
mg	Milligram(s) (Unit of Mass)
mmWC	Millimeter(s) of Water Column (Unit of Pressure)
SCO	Synthetic Crude Oil
SEM	Scanning Electron Microscopy
t ZRM	Metric Tons of Zero Moisture Shale (No Free & No Retort Water)
wt%	Weight per Cent
XRD	X-Ray Diffraction

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