Rapid Limestone Calcination using Microwave Assist Technology™

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ACEEE
American Council for an Energy-Efficient Economy

July 21st, 2011
Niagara Falls, New York

U.S. DEPARTMENT OF ENERGY

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Outline

- Background
- Experimental Results
- Energy Data
- Scale-up
- Summary

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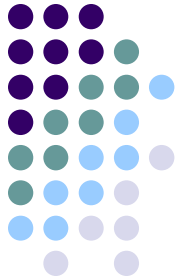
Background

Proposal Call from US Department of Energy



Problem: Lime & cement plants huge energy consumers

- Typical plants consume 4.5 Mil BTU/ton of material made
- 90% of energy used in calcining →485 Tril BTU/year

Solution: Use Microwave Assist Technology™ (MAT™)

- Reduce energy by 50%*
- Faster, more efficient calcining

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Background

- 18 million tons produced annually
- Lime- main applications:
  - **metallurgical** (35%)- iron and steel production as a flux to remove impurities
  - **environmental** (28%)- gas abatement, water treatment, agricultural stabilization
  - **chemical** (21%)- paper production, pharmaceuticals, food additives
  - **construction** (16%)- stabilize soils, stucco cladding, asphalt additive for strength increase in aggregate products

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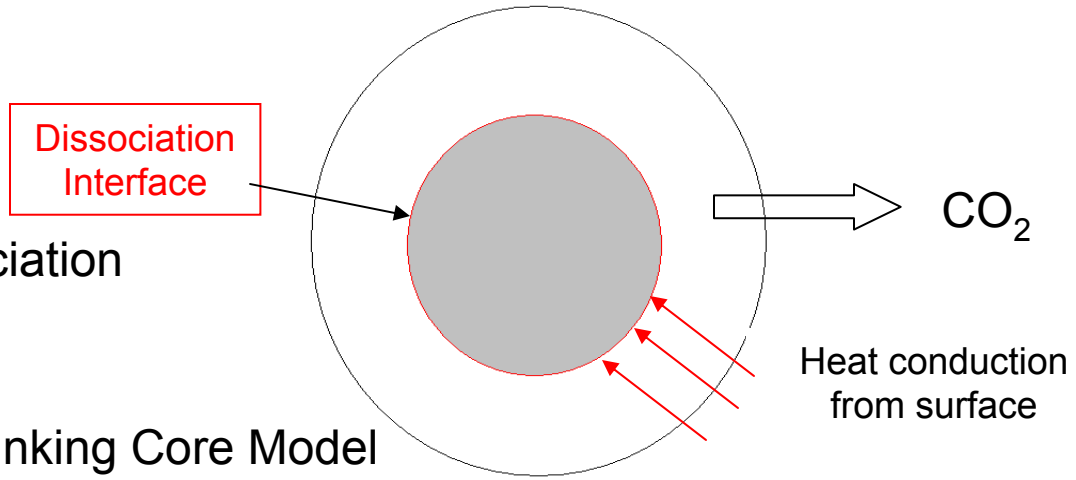
Lime Calcination

- Calcining reaction: $\underset{100g}{CaCO_3}$ + heat ⇒ $\underset{56g}{CaO}$ + $\underset{44g}{CO_2}\uparrow$
- Strong endothermic reaction (44.3 kcal/mole)
  - Endothermic cooling prevents heat diffusion at the reaction front
- Weight loss 44%, complete reaction
- Dissociation depends:
  - Temperature, time, pressure, particle size

Conventional Limitation:
- Slow conduction rate
- Only one interface for dissociation



Shrinking Core Model

Microwave Assist Technology (MAT)

Addition of microwaves to traditional kilns

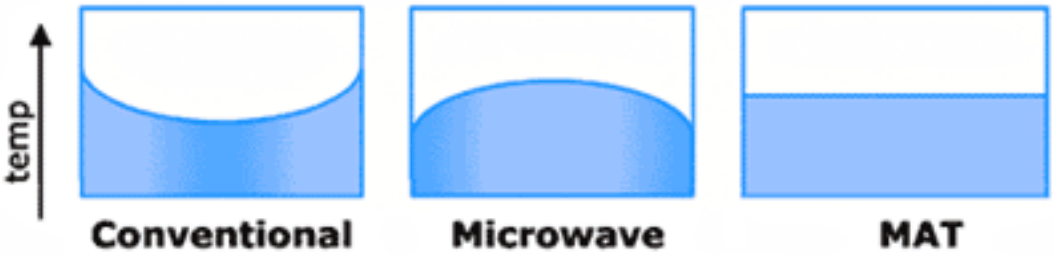
Limitations of Traditional Heating

Heat transfer by conduction → gradients → slow process → energy intensive
↳ grain growth

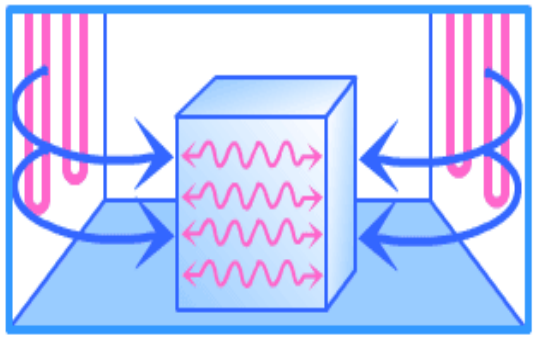
MAT Solution to Heating

Apply microwaves and radiant heat → uniformity → fast process → lower energy cost
↳ control grain growth

Lower temperature process → lower energy cost



Temperature profile across part thickness



MAT electric kiln

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Dielectric Importance

- Heating behavior determined by the loss tangent delta
- The loss tangent delta, Tan (δ), represents the efficiency of a material to convert absorbed energy into heat

Conductivity increasing →

Transparent to microwaves
Very Low
Dielectric loss
Tan D < 0.01

Absorb microwave (heats)
Dielectric loss
Tan D ~ 0.01-20

Reflects microwaves
Electrical conductor

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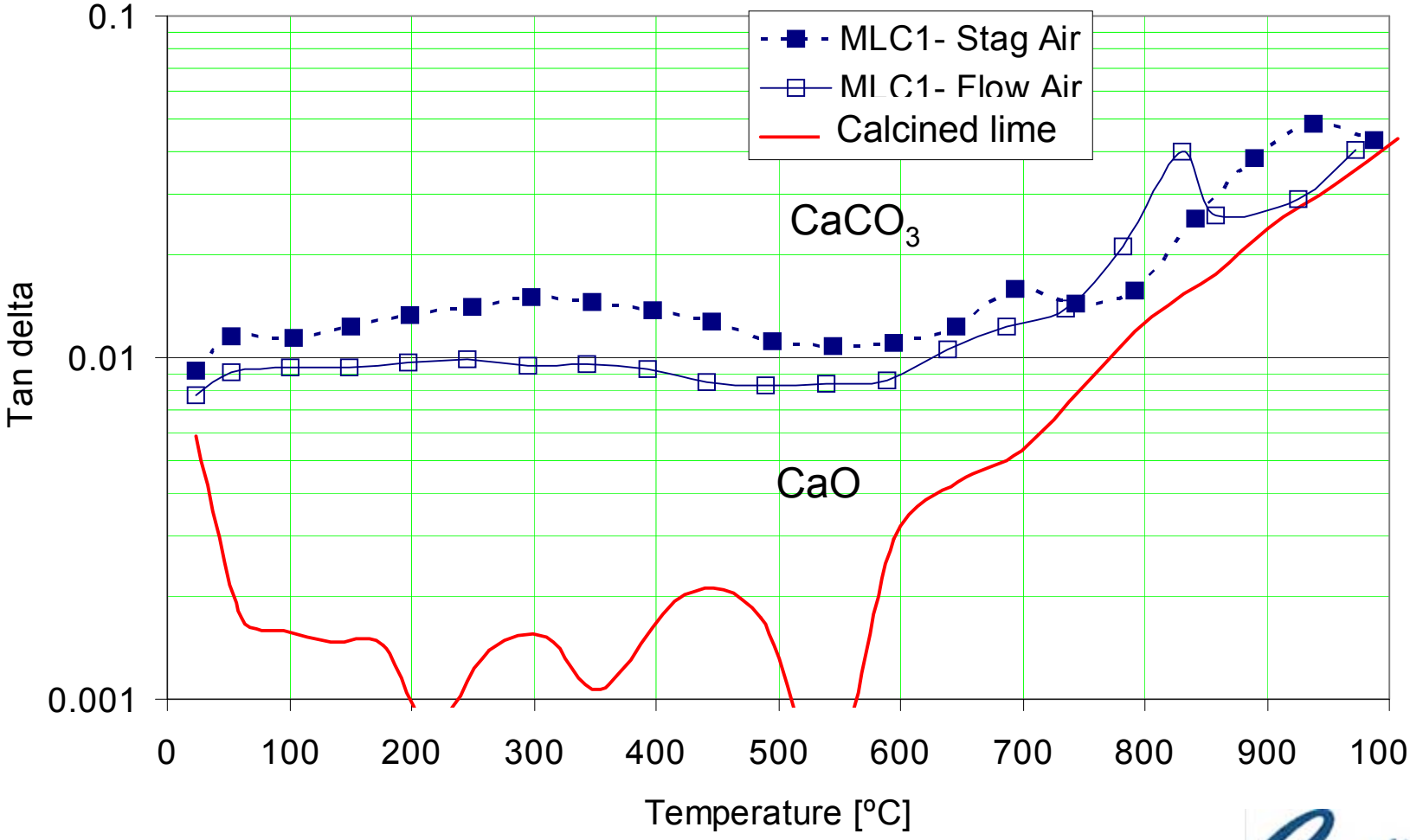
Dielectric Properties

- Preferential heating



Flow rate effect on dielectrics

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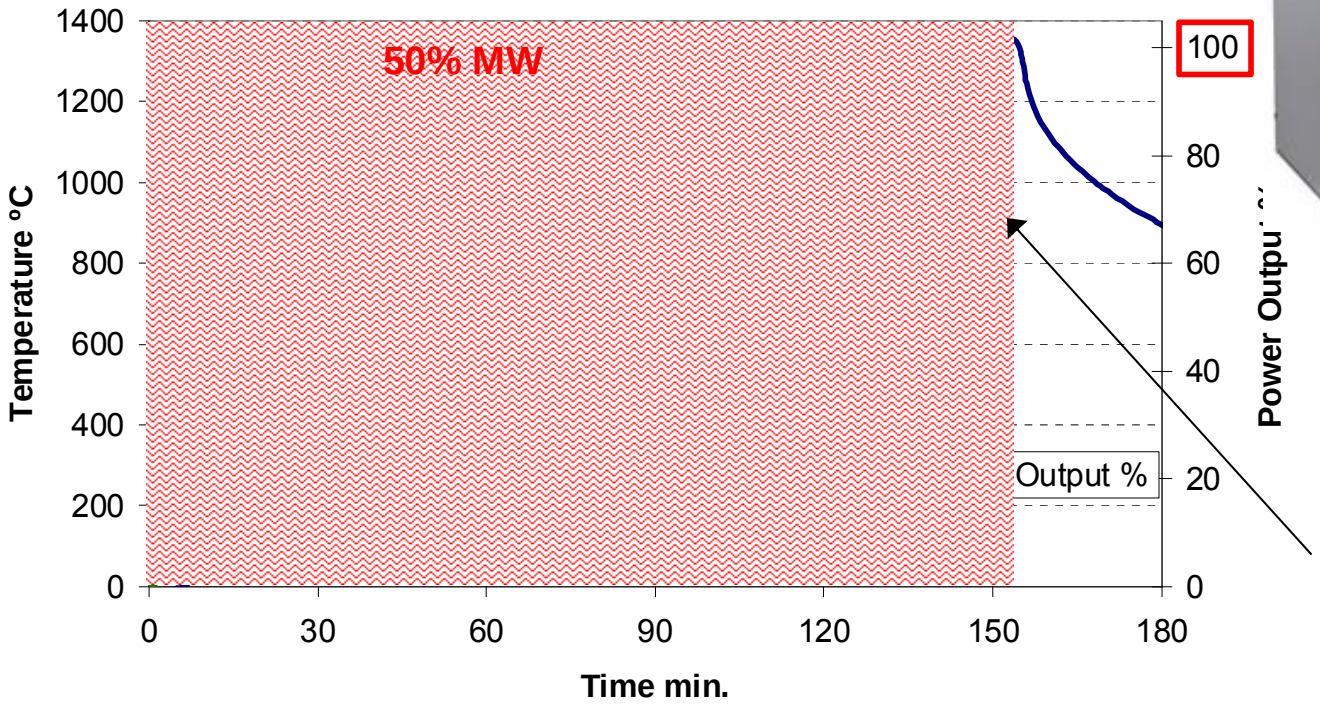
MAT™ Calcining Studies



Shows microwave heating

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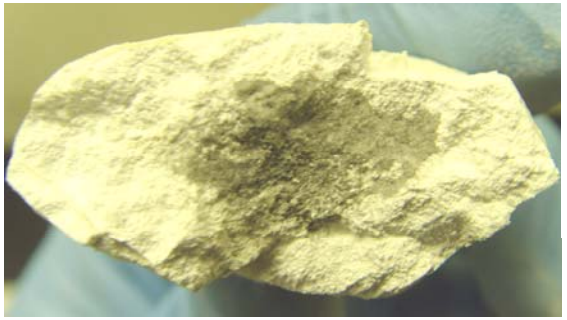
MLC 1

1 Kg at 1200 °C



Conv – 0 dwell

35.8%

Conv – 60 min

43.5%

MAT – 0 dwell

43.1%

Avg. limestone size 3.0 – 4.5cm

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Energy Calculations

- **Energy Consumption**

Electrical Energy + Microwave Energy = **Total Energy Consumption**

Electrical Energy = Sum { [(13000 watt/hr)*(working output % per interval / 100) * (Time (hours) per interval)] }

Microwave Energy = [(Microwave %)*(1800 watt/ hr)*(Time (hours))]

- **Weight Loss percentage**

Weight Loss % = (Mi-Mf / Mi) *100

Where (Mi) is the initial mass, and (Mf) is the final mass

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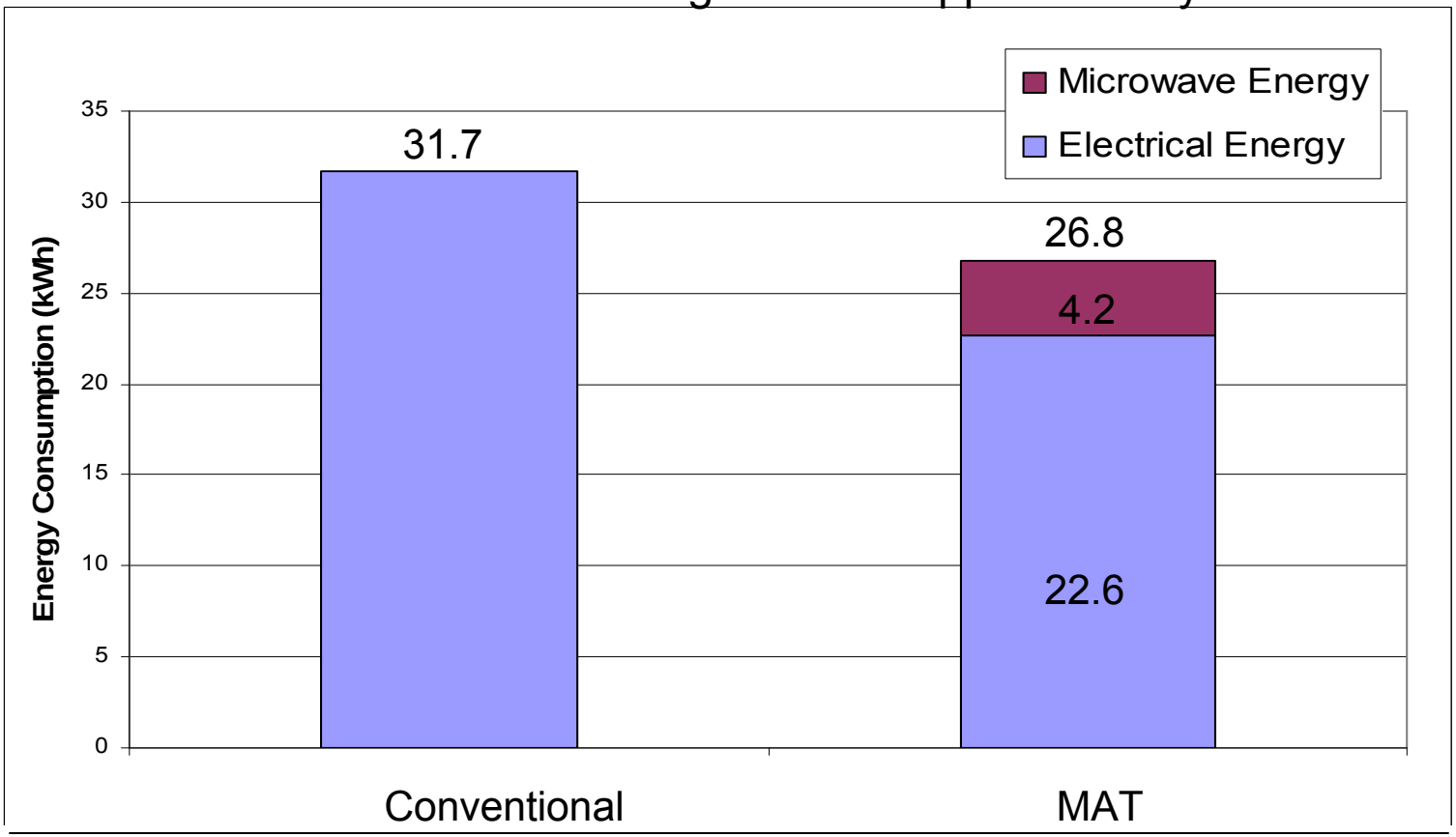
Energy Consumption

1 Kg load at 1200 °C

- MLC1 runs with a similar weight loss of approximately 43.5%



Energy Reduction
18.3%

Time Reduction
50 min

Conventional: 60 min dwell at 1200°C 0% MW

MAT: 10 min dwell at 1200°C 100% MW

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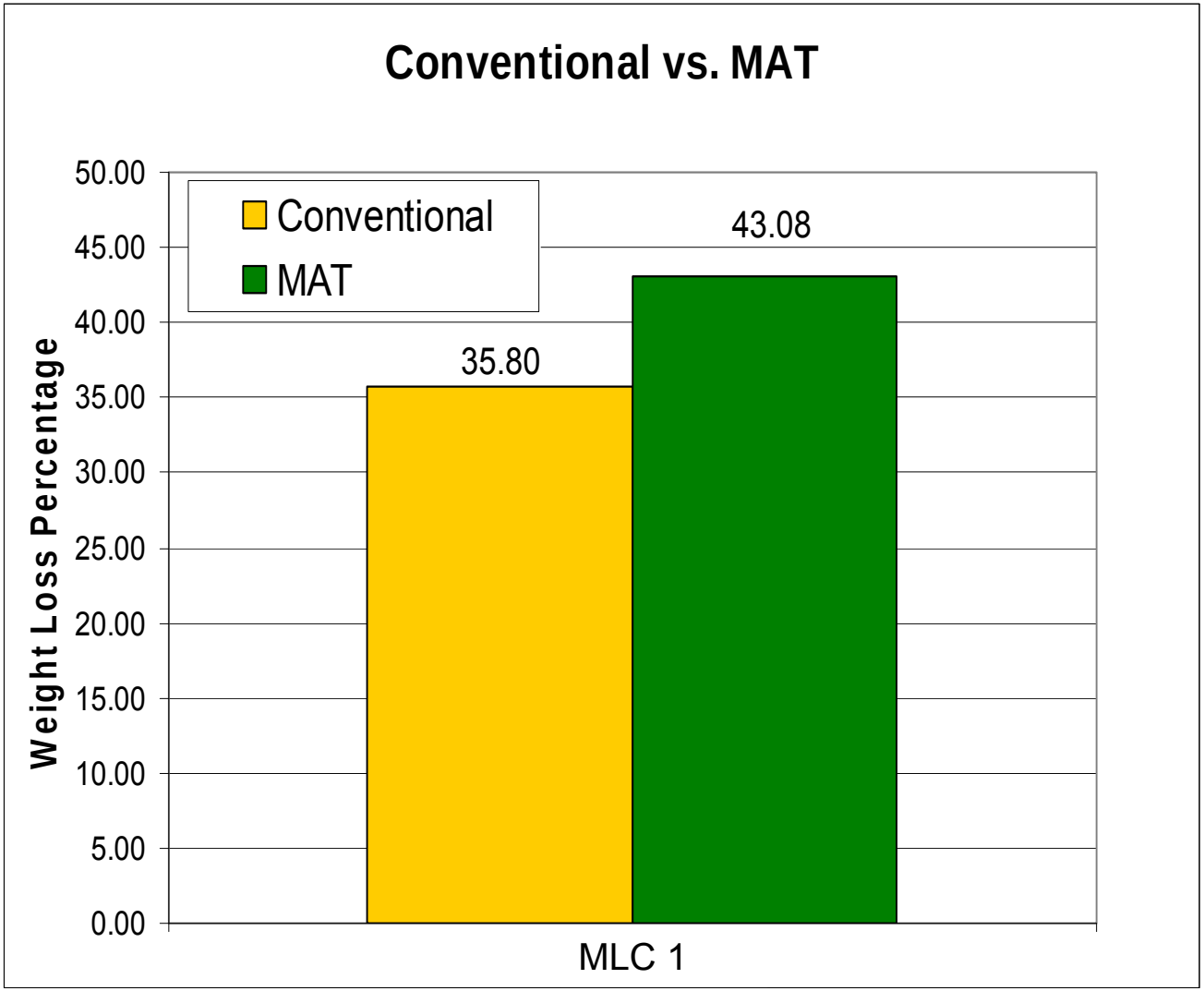
MAT™ vs. Conventional

1 Kg at 1200 °C with no dwell



MAT showed increased reactivity due to 20.3% higher weigh loss

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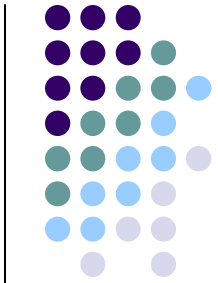
MAT™ vs. Conventional



Based on initial findings

- MAT appears to enhance dissociation reaction
- Larger dissociation interfaces
- Thermal or enhanced diffusion
  - E.g. “microwave effect”

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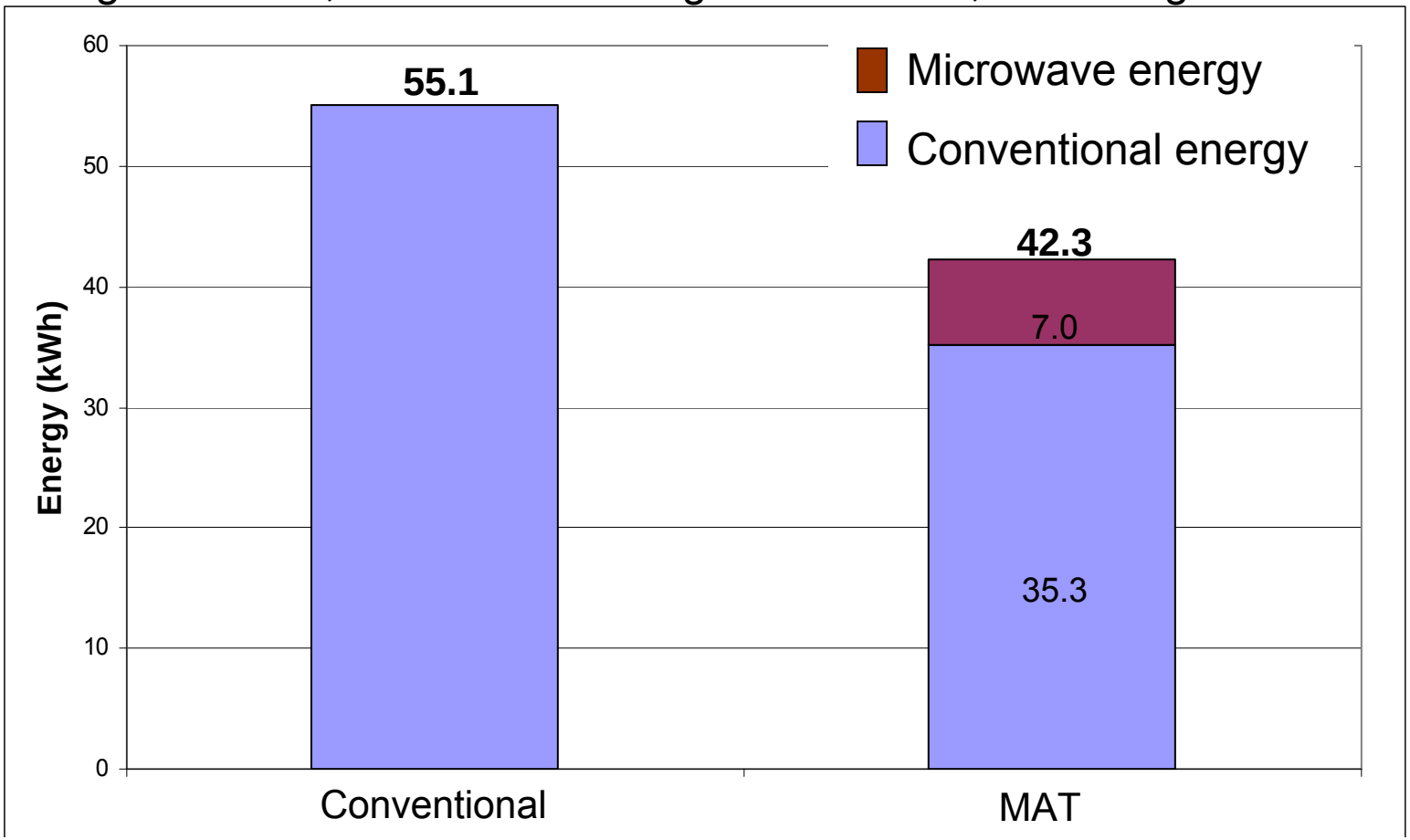
MAT vs. Conventional

Comparison

- 5kg MLC1 run, Conventional weight loss 41.0%, MAT weight loss 42.3%



Energy Reduction
23.23%

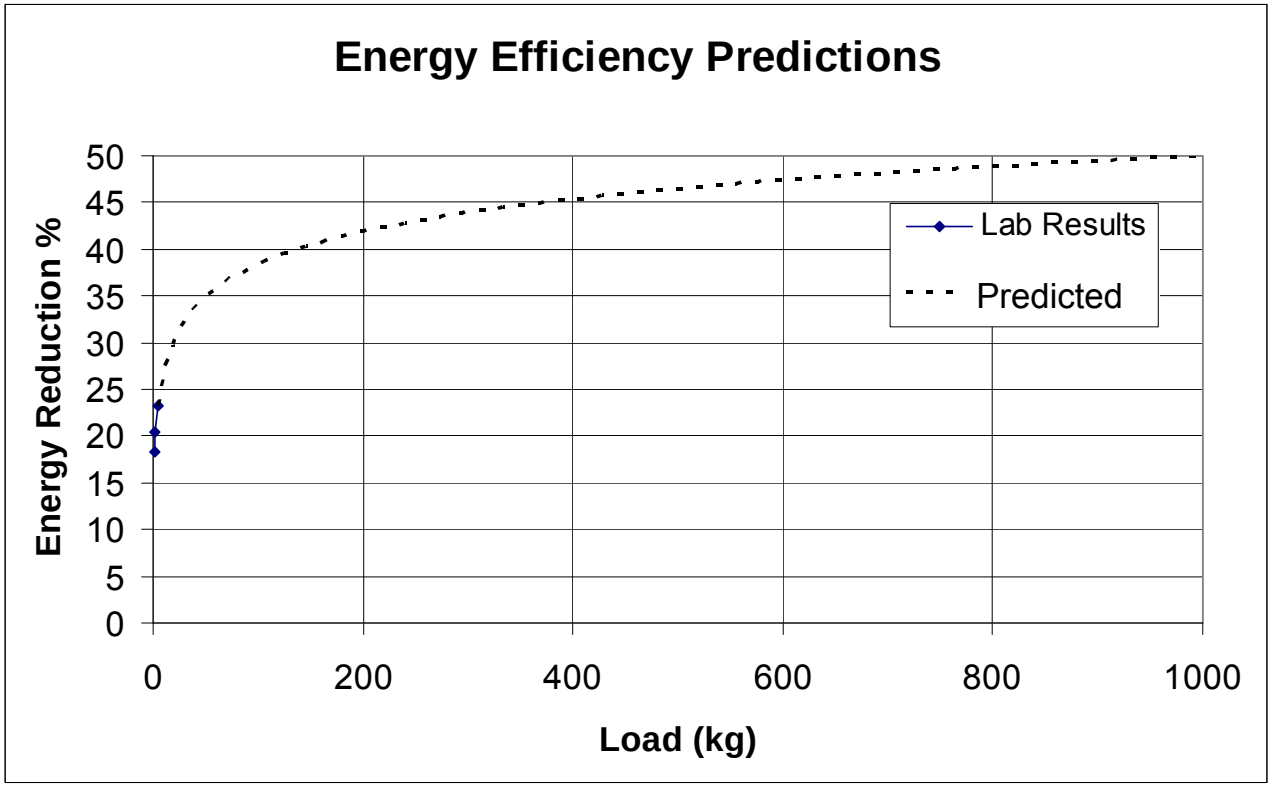
Time Reduction
120 min

Conventional: 240 min dwell at 1200°C 0% MW

MAT: 120 min dwell at 1200°C 100% MW

Scale – Up Projections

- MAT Calcining Scale-up: 1 kg to 5 kg
  - 27% increase in energy efficiency
  - 140% increase in time savings vs. conventional
- Larger energy and time reductions for larger kiln loads
- Due to the limitations of conventional heating



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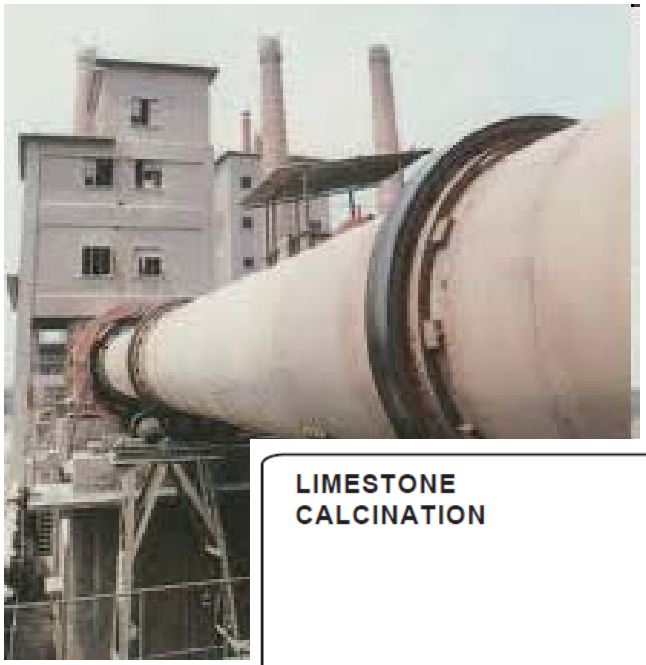
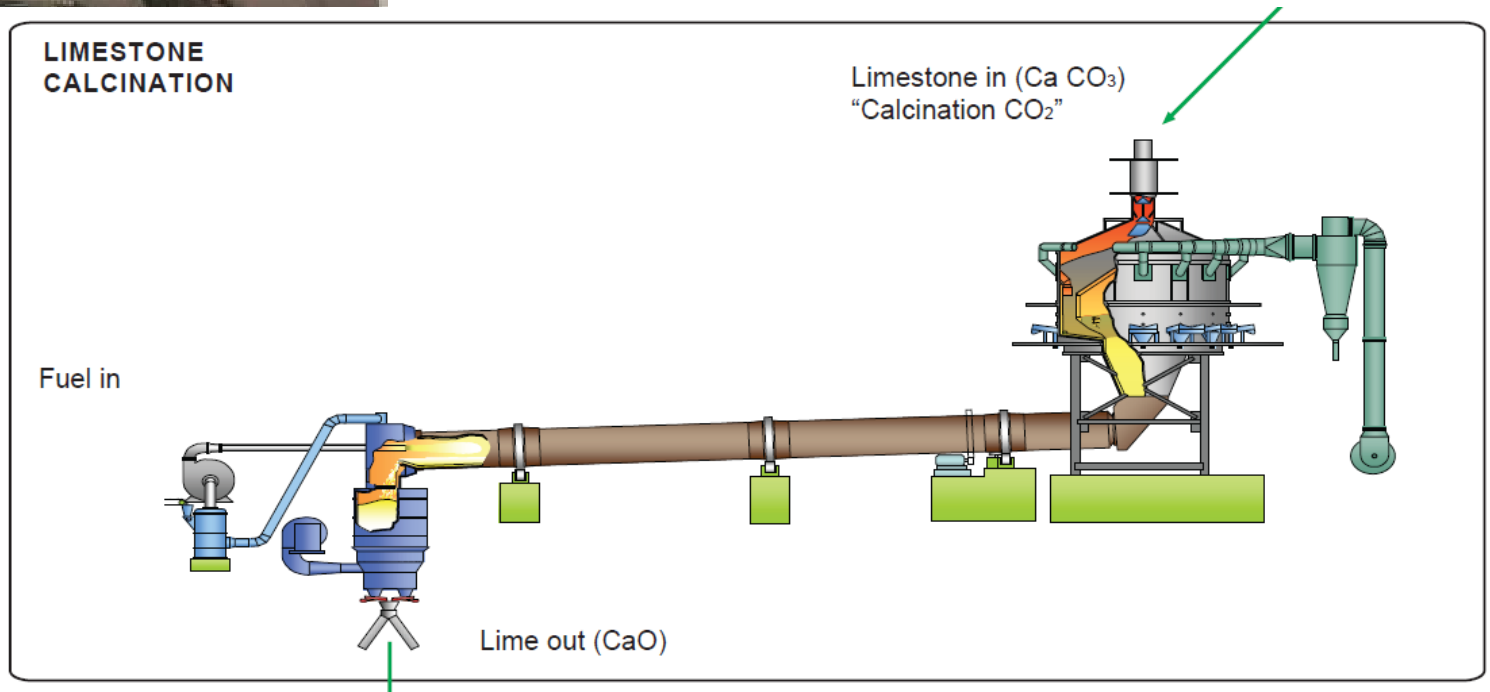
Scale-up Plans





Scale – Up Projections

- 10% industry implementation by 2020
  - Microwave pre-heater integration

Year	Energy (Tril BTU/yr)	Environmental Benefit CO_2 (Mlb)	Economic Benefit ($/yr)
2020	24.3	896	$19 Mil

Projected Annual Energy and CO_2 Savings for MAT Implementation year 2020.

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US Market Benefits

- MAT is adaptable for similar energy intensive rotary calciner industries - metal ores, structural and electroceramic powders, and catalysts

- MAT applications in various high temperature processing products – refractories, insulators, metal casting molds, and filters

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Summary / Future Work

- Microwave energy couples directly with limestone
- Preferentially heats uncalcined limestone.
- Conventional comparison confirmed enhanced disassociation
- Energy and time reduced using MAT for similar weight loss %
- Energy and time reduction increase confirmed with scale up

- Develop design for large scale microwave pre-heater
- Work with industrial partner to implement

- Follow on project – proposal this fall

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Acknowledgments

This work is supported by the Department of Energy's Industrial Grand Challenge Award # DE-EE0003472, project titled:

"Energy Efficient Microwave Hybrid Processing of Lime for Cement, Steel, and Glass Industries".

Additional thanks to:

Mississippi Lime

Microwave Properties North

MPN