Florida Department of
TRANSPORTATION

Evaluation of Pozzolanic Materials for Replacement of Fly Ash in FDOT Concrete

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Current and Planned Research

- **Completed Project:**
  - **"The Structural and Durability Performance of Glass Modified Concrete."**
- **Ongoing Project:**
  - **"Evaluation of Alternative Pozzolanic Materials for Partial Replacement of Portland Cement in Concrete."**
- **Scheduled Project:**
  - **"Development of Calcined Clays as Pozzolanic Additions in Portland Cement Concrete Mixes."**
- **Planned Project:**
  - **"Development of Ground Glass Pozzolanic Replacement for Fly Ash in Portland Cement Concrete Mixes."**

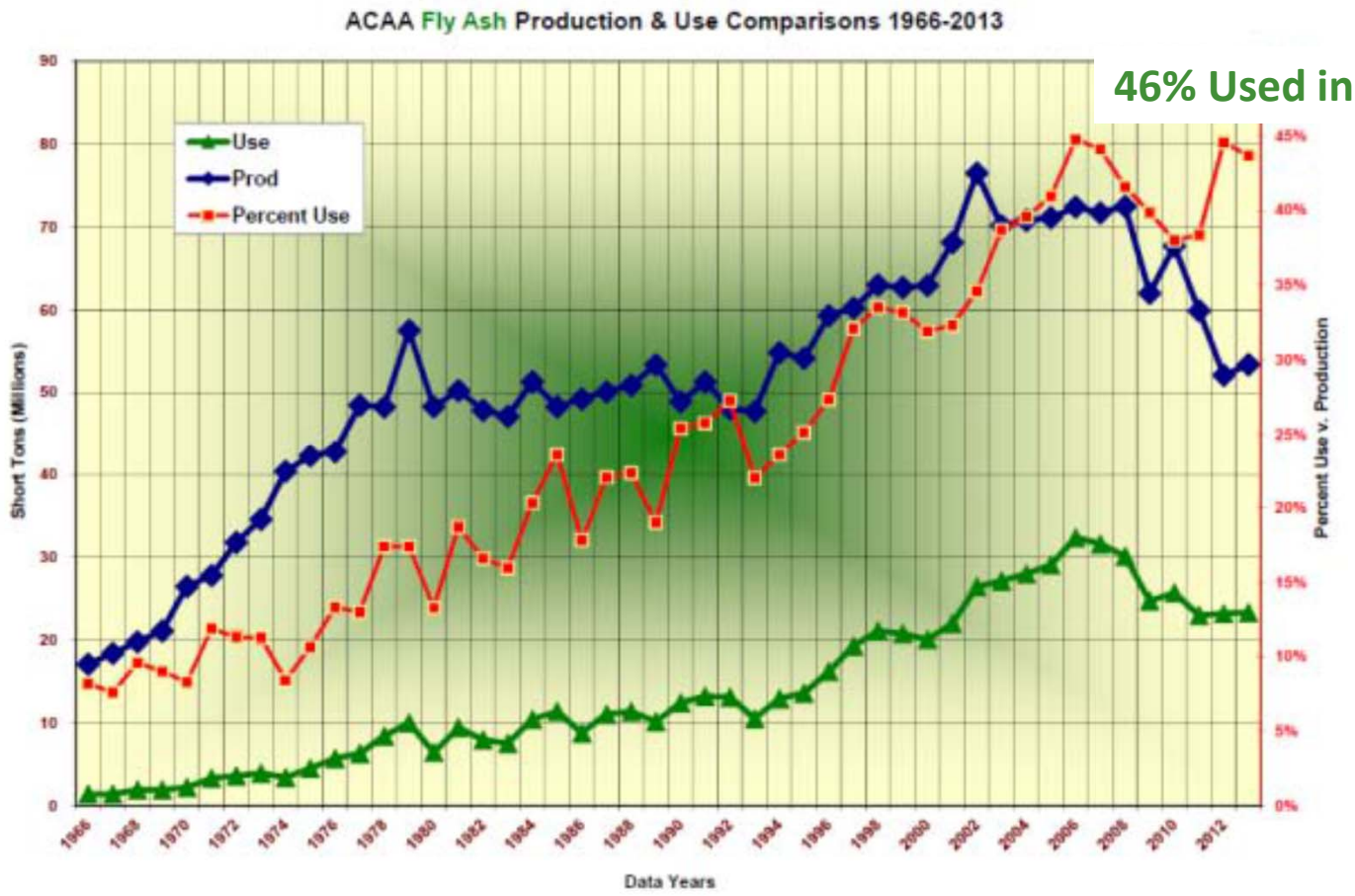
Acknowledgments

The Data Presented Here are from the Following FDOT-Sponsored Research Project with the University of Florida:

- **Project: "Evaluation of Alternative Pozzolanic Materials for Partial Replacement of Portland Cement in Concrete,"** BDV31-977-06.
- **Principal Investigator:** Chris Ferraro, Ph.D., P.E.
- **PhD Student Researcher:** Jerry Paris

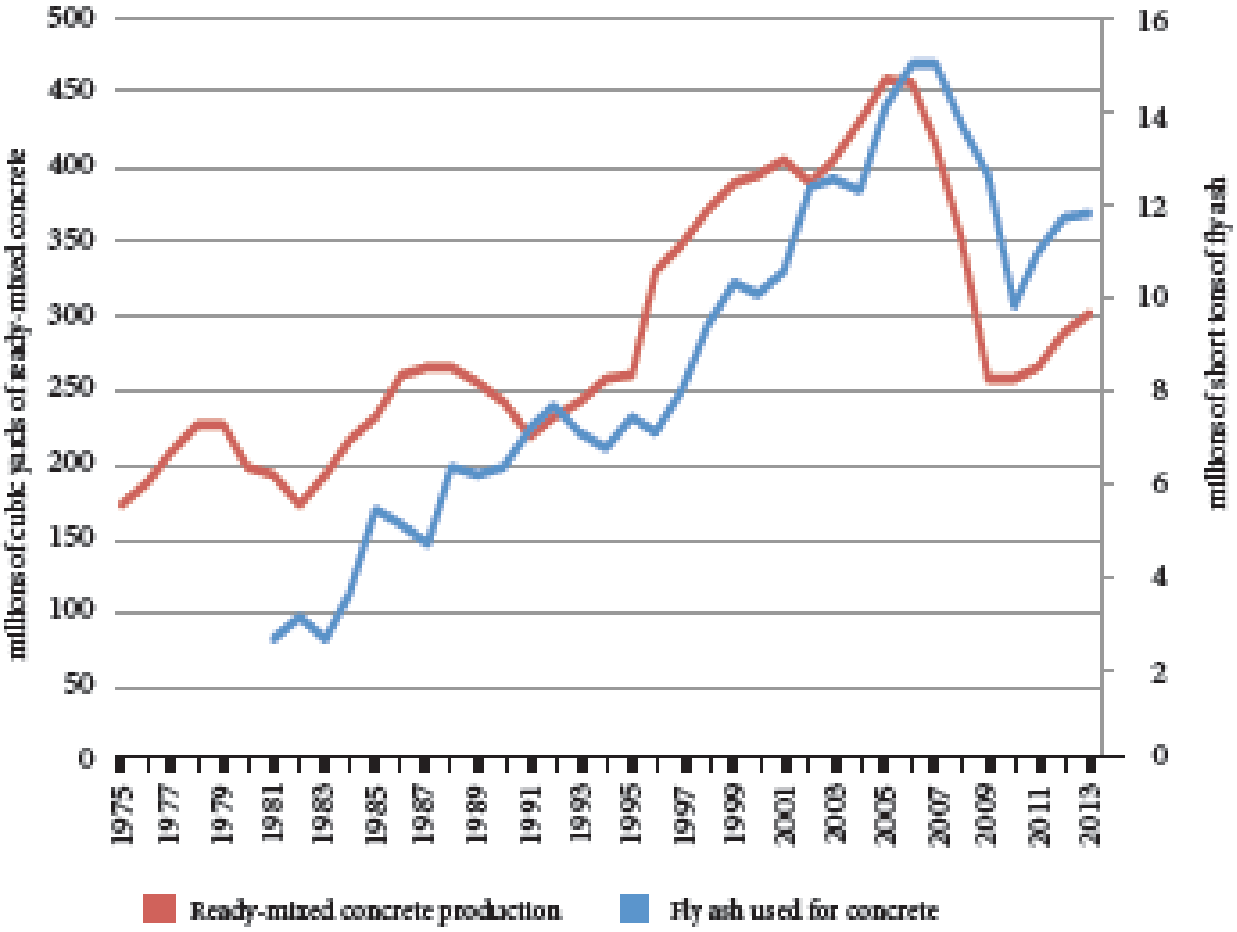
Production and Use of Fly Ash

Is There a Problem with the Supply of Fly Ash?



Minkara (2015), "Beneficial Use of Coal Ash in Concrete,"_Headwaters

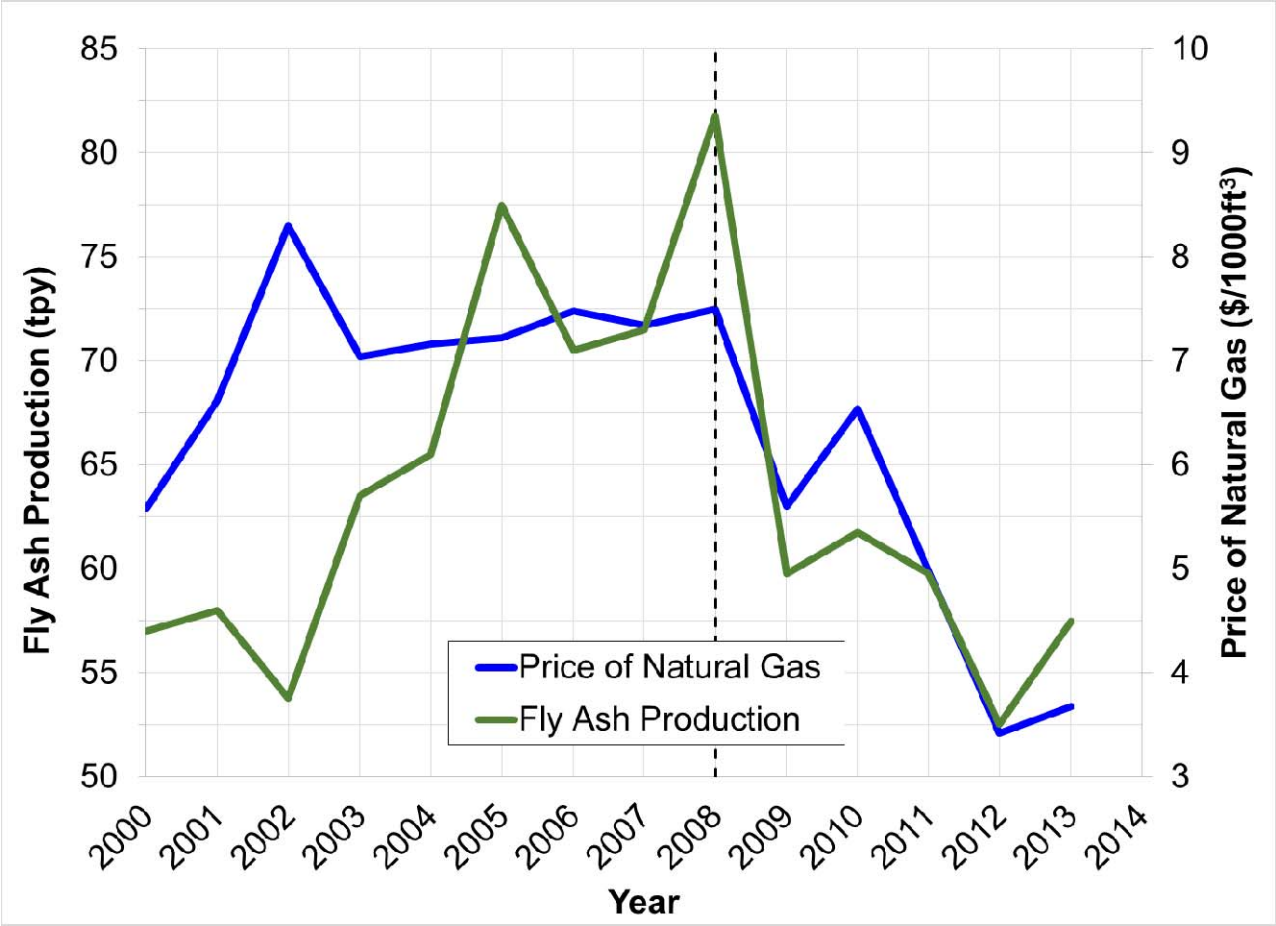
Ready-Mixed Production and Fly Ash Use



It looks like the recession had an affect, but was it the only cause?

ARTBA (2015), "Production and Use of CCP in the US"

Fly Ash Production and Price of Natural Gas



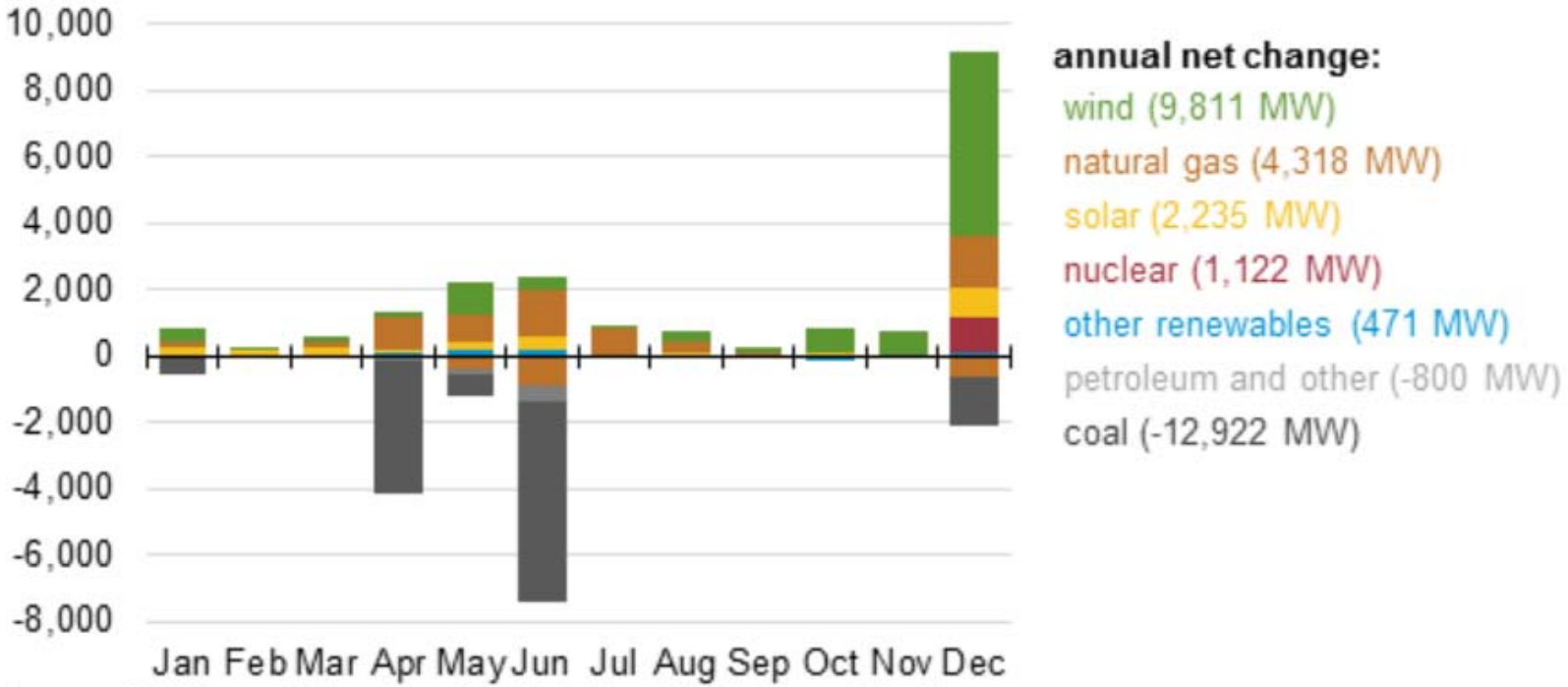
How much of an effect does the price of Natural Gas have?

Data from ARTBA (2015), "Production and Use of CCP in the US"

Coal-Fired Power Generation is Declining

Scheduled 2015 capacity additions mostly wind and natural gas; retirements mostly coal

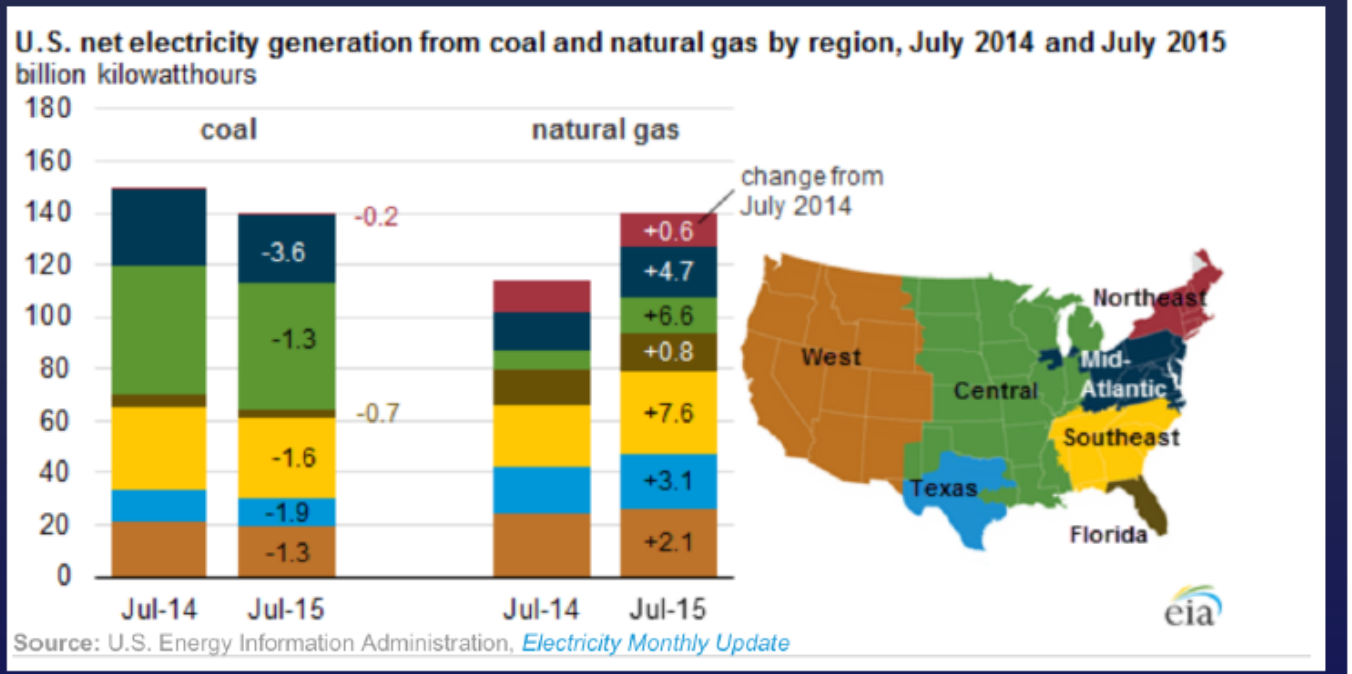
Scheduled electricity generation capacity additions and retirements in 2015
megawatts



Source: U.S. Energy Information Administration, *Electric Power Monthly*
Note: Other renewables include hydroelectric, biomass/wood, and geothermal.

Regional Natural Gas vs Coal

July 2015 – for the 2nd time ever natural gas surpassed coal in electricity generation



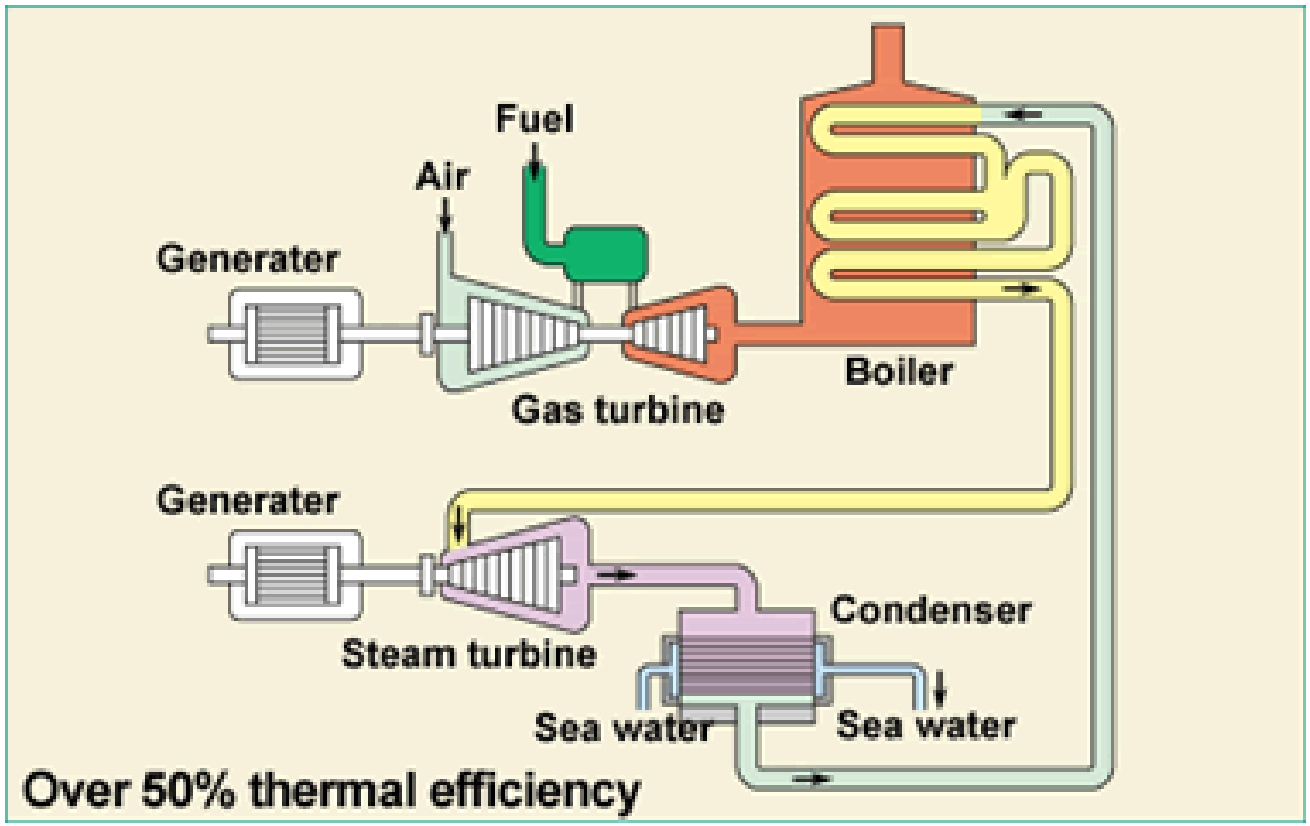
Barcelo et al. (2015), North American Fly Ash Supply: Is it Really at Risk?, Lafarge-Holcim

So – Why is Coal-Fired Power Generation Declining?

- **The number of coal-fired power plants is decreasing**
  - **Cheap natural gas** is leading some manufacturers to convert from coal to gas.
  - **Emissions requirements** are steadily becoming more stringent, making coal-fired plants more costly (due to investment in control technologies), leading to reduced operation or conversion to gas..

Combined Cycle Gas Power Generation

Waste heat from the gas turbine is used to create steam to drive a steam turbine



https://www.mhps.com/en/products/detail/ccpp_mechanism.html

Advantages of Combined Cycle Power Generation

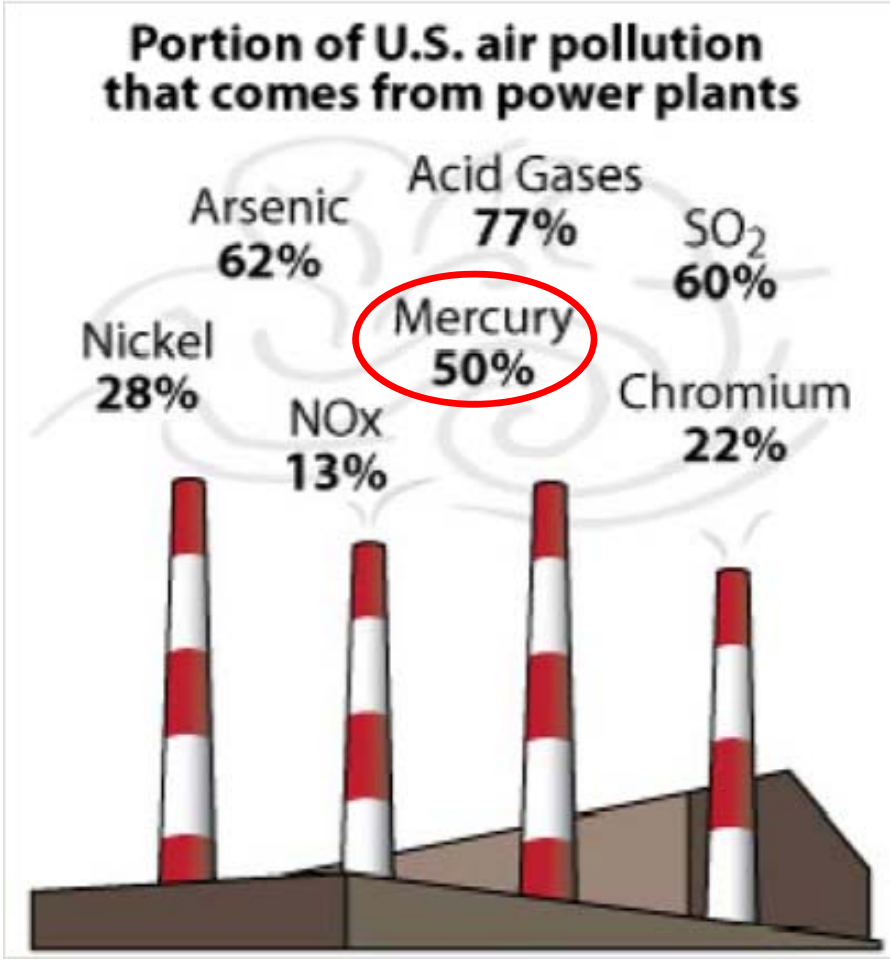
- **High Thermal Efficiency** – more than 50% combined
  - 40% for the gas turbine and
  - 43% for the steam turbine

  } **Reduced Fuel Consumption**
- **Reduced Air Pollution** – reduced emissions of
  - Carbon dioxide
  - Nitrogen oxides
  - Sulfur dioxide
- **Reduced Thermal Pollution**
  - lower temperatures of discharge water

https://www.mhps.com/en/products/detail/ccpp_mechanism.html

Emissions - Why the Push for Regulation?

The exposure of the superstructure of a bridge within 2500 ft of a coal-burning industrial facility is classified as Moderately Aggressive



http://www3.epa.gov/airquality/powerplanttoxics/powerplants.html

Why the Push for Regulation?

In 1990, about two-thirds of total U.S. mercury emissions came from medical waste incinerators, municipal waste combustors, and power plants

Industrial Category	1990 Emissions (tpy)	2005 Emissions (tpy)	Percent Reduction
Power Plants	59	53	10%
Municipal Waste Combustors	57	2	96%
Medical Waste Incinerators	51	1	98%

Power plants have not complied as much as other industries

http://www3.epa.gov/airquality/powerplanttoxics/powerplants.html

Reduction of F Ash – Coal Source

- **Coal switching** from eastern bituminous to Powder River Basin coal results in lower availability of low CaO (Class F) ash and higher availability of high CaO (Class C) ash.
  - Class C ash is more reactive than Class F ash
  - Class F ash is more effective at mitigating ASR at low cement replacement levels (<25%).
  - Higher replacement levels (>35%) are needed for ASR mitigation by class C ash.
  - Class F fly ash is typically preferred.

Minkara (2015), "Fly Ash is Still in Your Future," Headwaters

Objective of Current Research

Develop Sources of Pozzolanic Materials That Can Meet the Demands for Pozzolans in Future FDOT Concrete Mixes

- Evaluate candidate materials not in use by FDOT
  - Need to be available in large-scale quantities
  - Require minimal processing to make suitable for use
- Evaluate use of highly reactive pozzolans (SF, MK, UFFA) in amounts sufficient to produce properties similar to those obtained with Class F Fly Ash
- Evaluate both binary and ternary combinations

Methodology

Approach

- Determine suitability of any highly siliceous materials with particle size < 45 μm (passing 325-mesh)
- Preference given based on availability and sustainability
- Testing of portland cement-pozzolan samples
  - Elemental and mineralogical composition (XRF and XRD)
  - Particle size distribution
  - Heat of Hydration
  - Compressive strength
  - Modulus of elasticity
  - Splitting tensile strength
  - Length change
  - Flexural strength
  - Coefficient of thermal expansion
  - Surface resistivity

Replacements for Fly Ash

Nothing can replace fly ash based on price.

Raw Material	Price per Ton	Price per Pound
Silica Sand Fine Aggregate	$20	$0.010
Coarse Limerock Aggregate	$30	$0.015
Class F Fly Ash	$35	$0.018
Slag Cement	$115	$0.058
Type I/II Portland Cement	$130	$0.065
Kaolin	$150	$0.075
Micron 3 (bags)	$500	$0.250
Metakaolin (bags)	$800	$0.400
Silica Fume (bags)	$1,100	$0.550

Findings

Materials Chosen for Evaluation

- Class C fly ash
- Pulverized waste glass
- Recycled zeolite catalyst
- Rice husk ash
- Sugarcane bagasse ash
- Wood ash

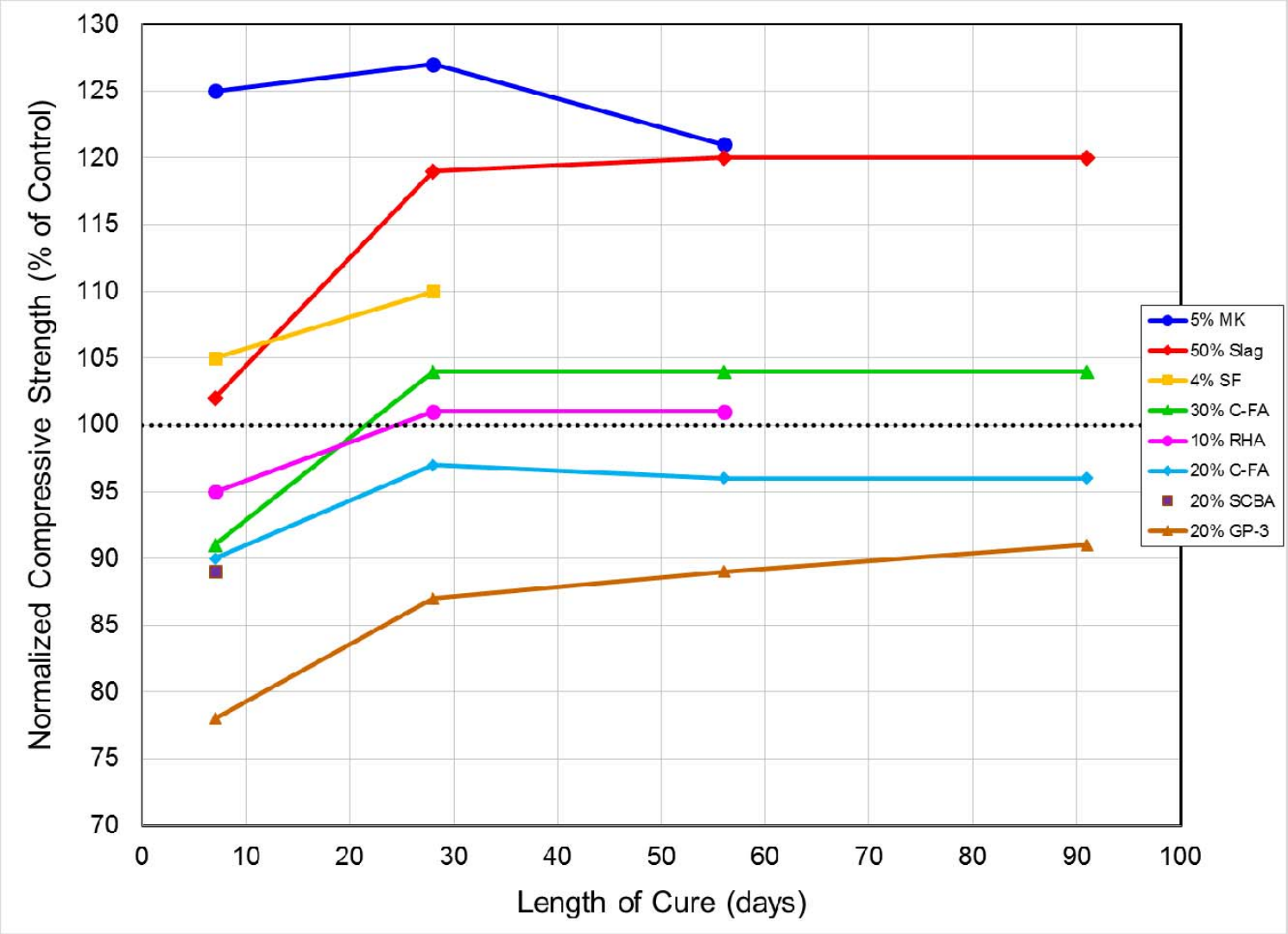
Class C fly ash is commercially available and is in common use in other parts of the country. Quick implementation.

Waste glass is abundantly available - requires considerably more research and development. Implementation will require development of supply chain and grinding facilities.

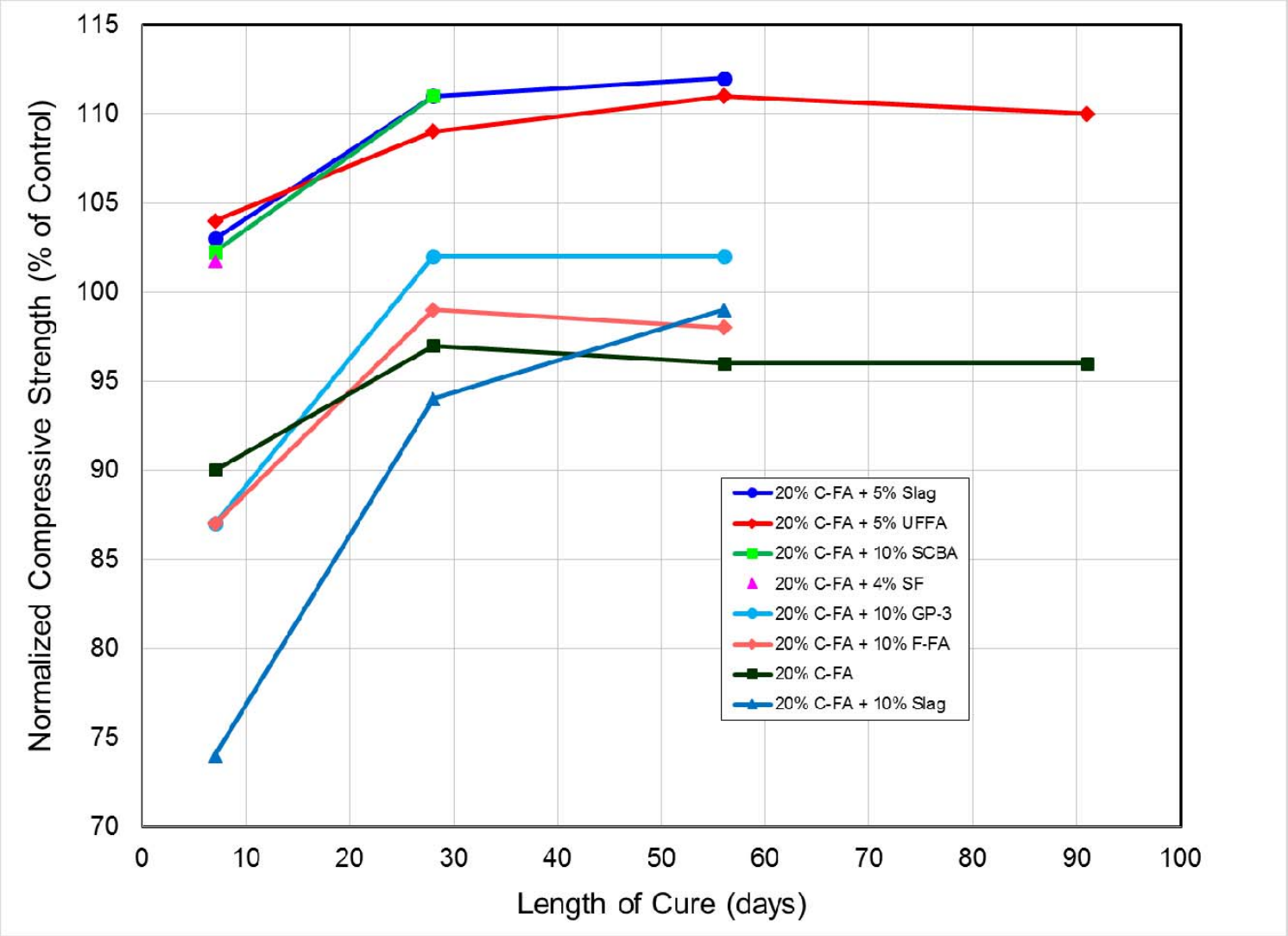
Testing

Underway, but results are not complete.

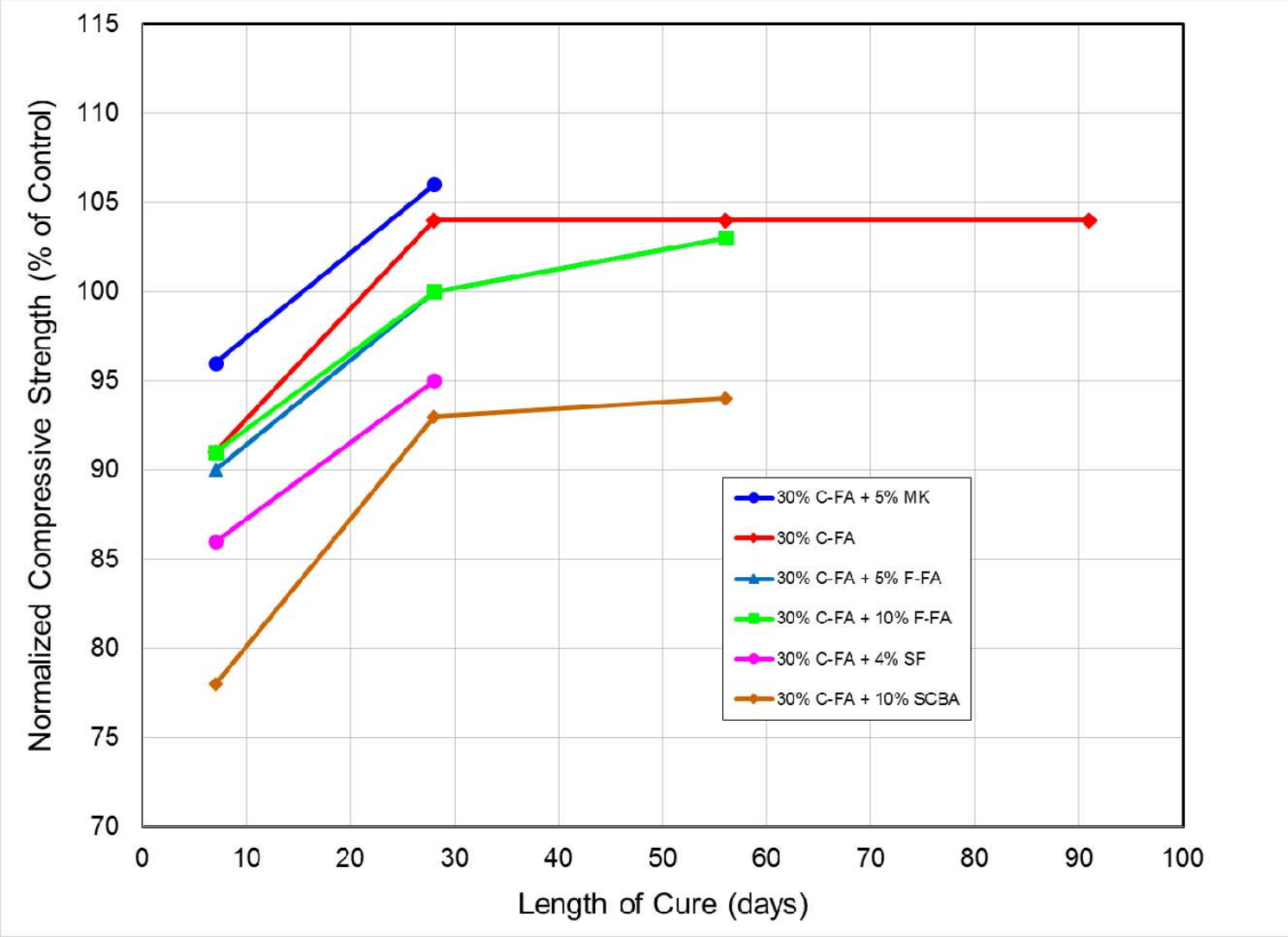
Selected Binary Pozzolan Mixes



Selected Ternary 20% C-FA Mixes



Selected Ternary 30% C-FA Mixes



Summary

Fly Ash is Hard to Replace, But it is Necessary

- Increased demand for fly ash, especially during periods of increased construction activity, is expected to exceed the supply from current producers
- Changes in the electric utility industry brought about by environmental regulations and the low cost of natural gas (retirement of coal plants, retrofitting with pollution control equipment, fuel switching, etc.) will continue to reduce the supply of quality ash.
- There are a limited number of alternative supplemental cementitious materials for concrete, and they are all considerably more expensive.

Summary

- The highly reactive pozzolans (SF, MK, and UFFA) show good potential in both binary and ternary mixes when added in relatively low amounts (< 5% replacement of cement by weight.
- Class C fly ash performs well as a total replacement for Class F fly ash at 20% cement replacement, and at both 20% and 30% replacements of cement in some ternary blends.
- Pozzolans that performed well in ternary blends with 20% Class C fly ash were 5% slag, 5% UFFA, 10% SCBA, 4% SF, and 10% GP-3.

Questions?