# Concrete Sustainability: A Vision for Sustainable Construction With Concrete in North America


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*Materials in Sustainable Transportation Infrastructure*

Michigan Tech, Houghton MI


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# Michigan Tech


- 6,758 Total Students
- 912 Graduate Students
- 55.1% College of Engineering
- 66.6% Michigan Residents
- 9.6% International
- 410 Faculty
- 1,218 Staff
- FY2007 - $57M in total research expenditures ($4.33M transportation related)
- FY2008 - projected $63M in total research expenditures (projected $5.9M transportation related)

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# University Transportation Center
## *Materials in Sustainable Transportation Infrastructure*

- **Goals**
  - **Conduct innovative materials research** to improve the sustainability of transportation infrastructure
  - **Deliver distinctive educational programs** and opportunities to prepare students to embrace sustainability in the construction, maintenance, and repair of transportation infrastructure
  - Advance the understanding of the role of materials in sustainable transportation infrastructure **(T2)**

# Background

- **Sustainable Development**
  - Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs
- **Alternate Definition**
  - Making decisions based upon the “triple bottom line” that includes social impacts, environmental impacts, economic impacts
    - **Social**: health, education, housing, security, population
    - **Environmental**: atmosphere, land, oceans, coasts, seas, fresh water, bio-diversity
    - **Economic**: economic structure, consumption and production patterns.

# Introduction

- ACI Strategic Development Council created the Sustainable Development Initiative about one year ago
- ***Charge***
  - Develop the guiding document leading to a road map to sustainability for the <u>concrete industry</u>
  - <u>Establish *Big Hairy Audacious Goals* (BHAGs) that stretch the industry</u>
- A series of 5 workshops were held where participants began discussing and shaping the document
- This is the *unofficial* observations of one participant…

# Approach

- Process was led by seven committees
  - Mobilization
  - Environmental Footprint/Metrics
  - Vision, Values, Principles
  - Communications
  - Codes & Standards
  - Education
  - Advocacy

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# Approach

- Process was led by seven committees
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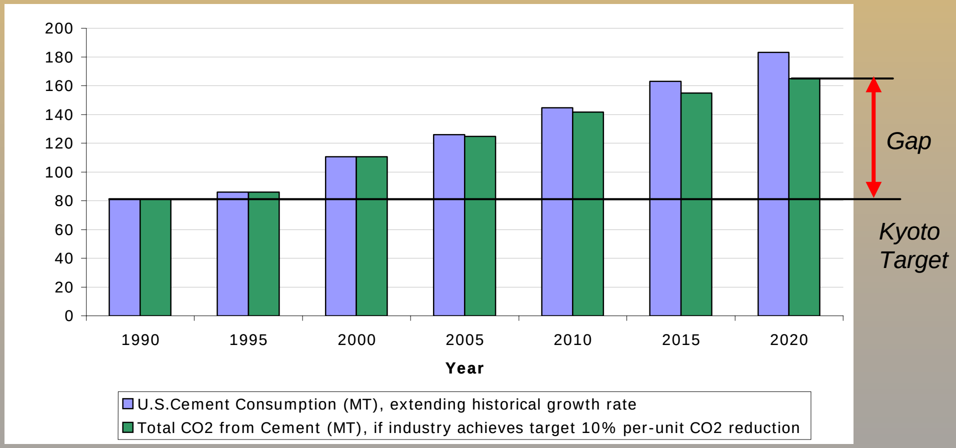
# Approach

- Document the improvements made in the past 50 years regarding GHG emission, embodied energy, and water use in the concrete industry
- Isolate the segments of the industry where the largest gains remain to be made
- Quantify the magnitude of those gains and the strategies/research/technology required to achieve them
- Set a target date to achieve milestones, which will dictate the rate of change needed

# Sources

- PCA - Portland Cement Association
- WBCSD - World Business Council for Sustainable Development
- IEA - International Energy Agency
- DOE / Energy Information Administration
- EPA - Environmental Protection Agency
- FHWA, Bureau of Transportation Statistics
- ACAA - American Coal Ash Association

- The U.S. concrete industry manufactured over 400M cubic yards of concrete in 2005
  - 75% Ready Mix, 5% Block, 4% Precast
- Through its life cycle, concrete is responsible for significant $CO_2$ emissions and energy use
  - 110 MMT of $CO_2$/year
  - 550 QBTUs energy/year
- The majority of the $CO_2$ and energy originates in the primary binder for concrete: cement
  - ~120MMT cement used in U.S. in 2005 including imports
  - ~2.3BMT worldwide in 2005




*Source: WBCSD Substudy 8, IEA data,* CalStar analysis, Tom Pounds

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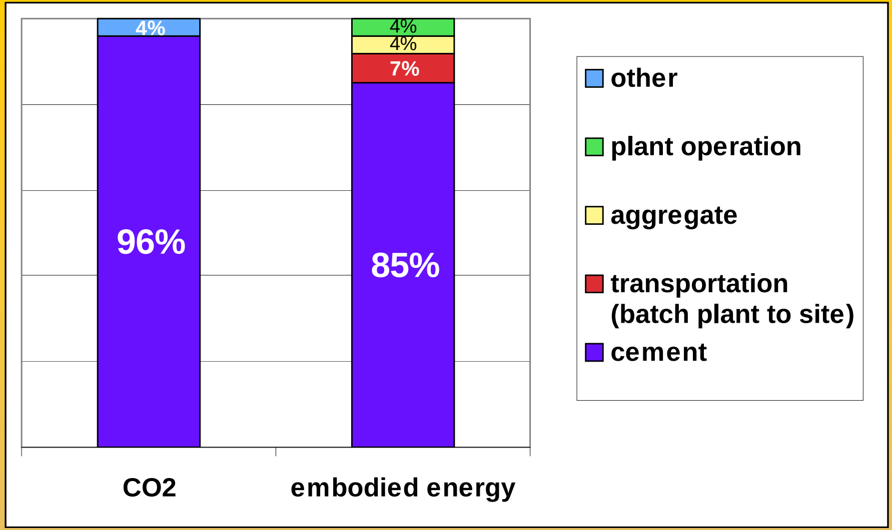
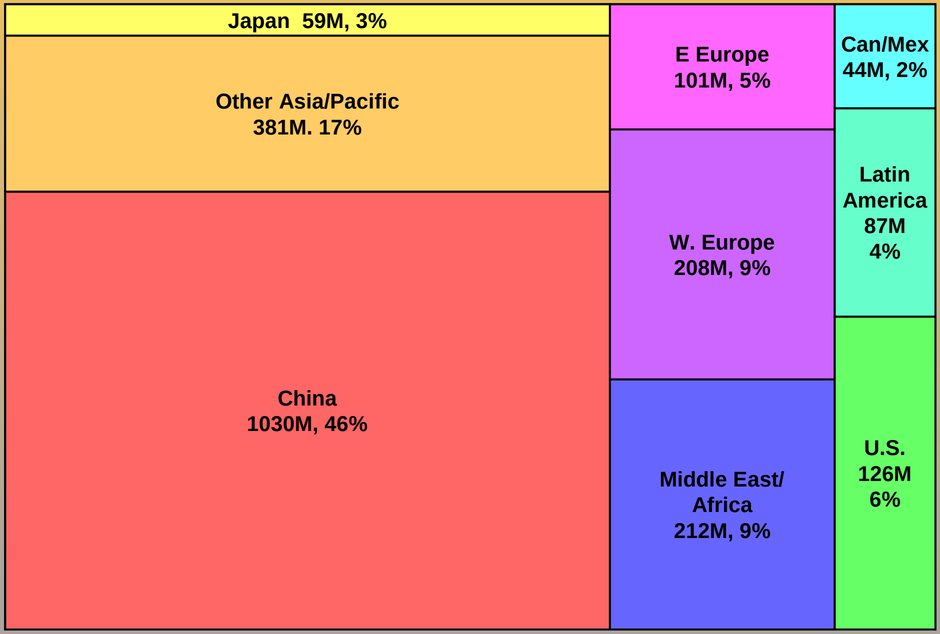


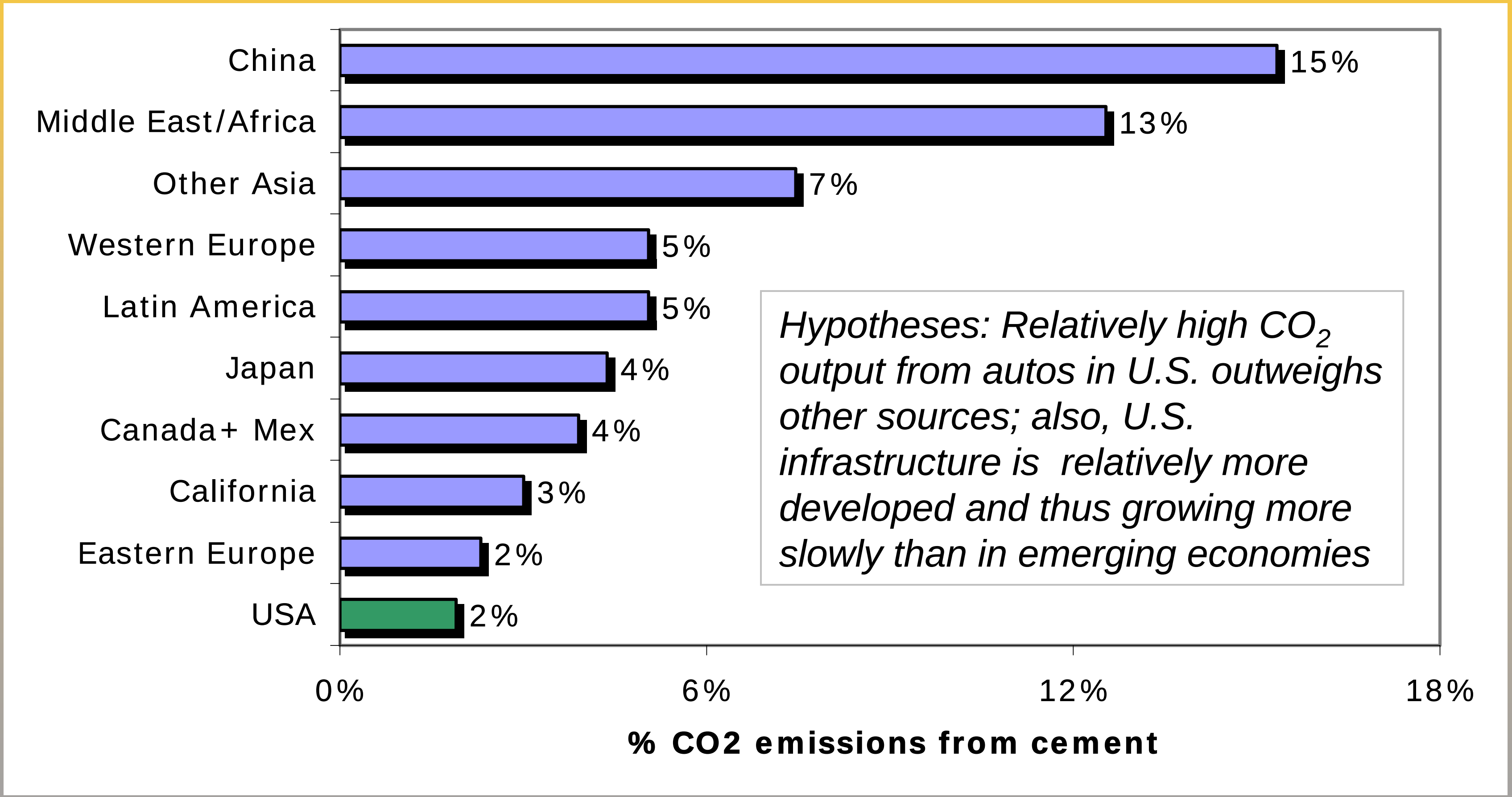




The U.S. cement industry has adopted a voluntary target of reducing $CO_2$ emissions by 10 percent (from a 1990 baseline) <u>per ton of cementitious product produced or sold by 2020</u>

# Estimated % of Regional $CO_2$ from Cement

## *Share in U.S. Less than Half of Global Average*

Cement manufacture is responsible for ~3% of total GHG emissions, and ~5% of $CO_2$ emissions worldwide

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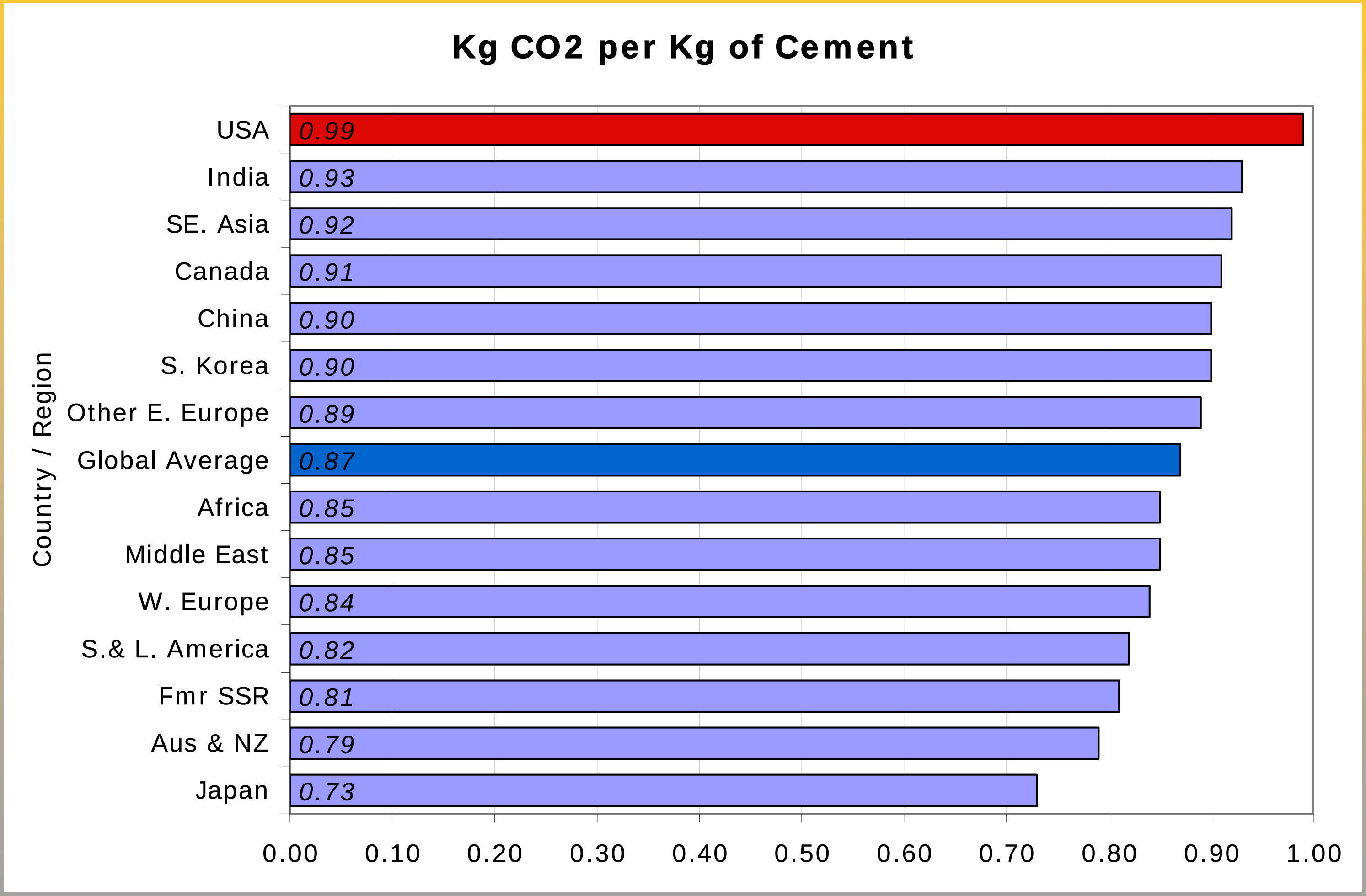
*Sources: Battelle WBCSD Studies; World Resources Institute; Lisa Hanle: US EPA, 2005; CalStar Analysis, Tom Pounds*

# $CO_2$ Output per Ton of Cement

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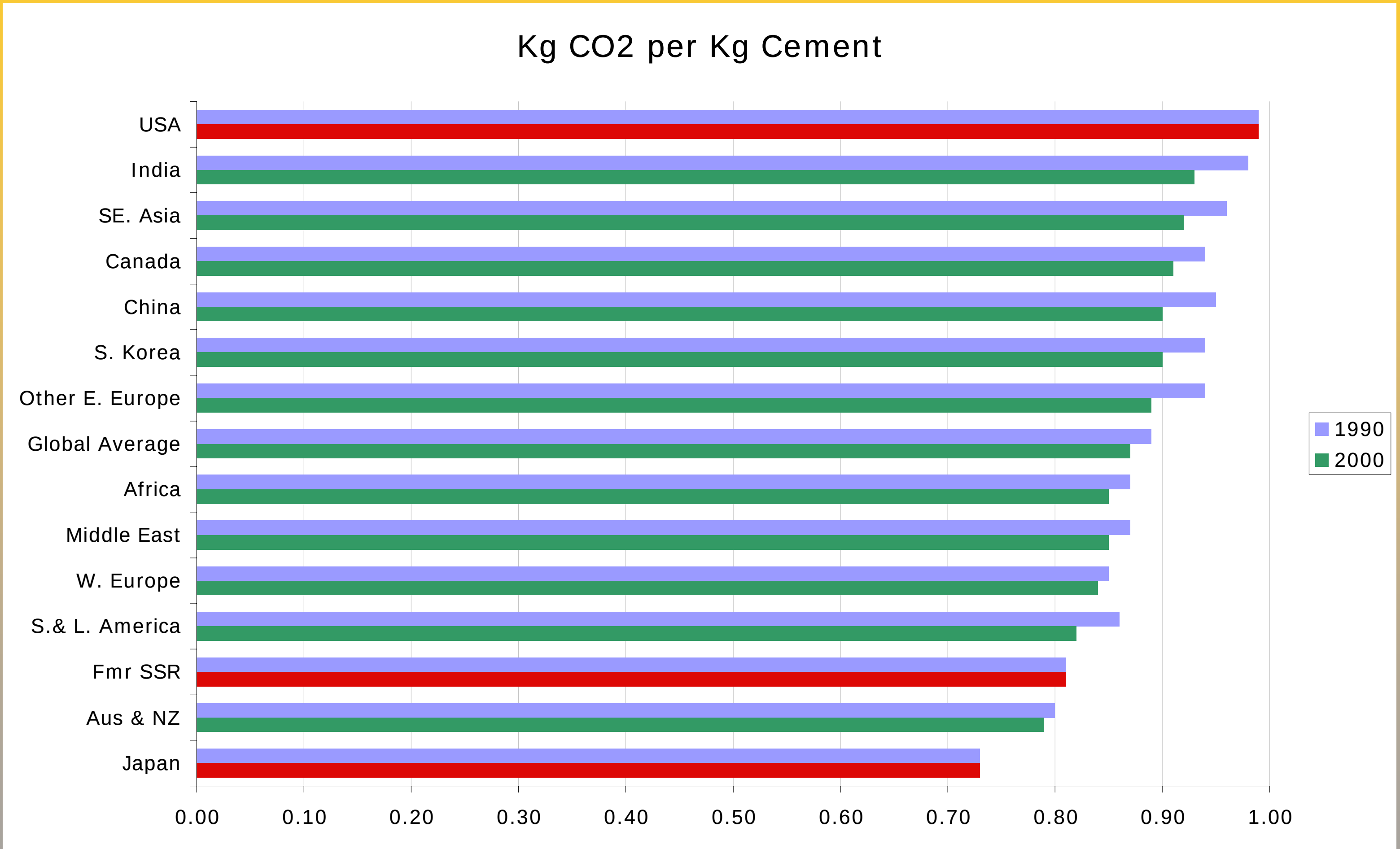
Sources: WBCSD Substudy #8 (IEA data); CalStar analysis, Tom Pounds

# Per-Unit $CO_2$ Output, 1990 to 2000




Sources: WBCSD Substudy #8 (IEA data); CalStar analysis, Tom Pounds

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# Why U.S. Cement is $CO_2$ Intensive
## *High Energy Intensity*

| Region Name | MJ/kg clinker 1990 | MJ/kg clinker 2000 | SubRegion Name | MJ/kg clinker 1990 | MJ/kg clinker 2000 |
|---|---|---|---|---|---|
| North America | 5.47 | 5.45 | | | |
| | | | USA | 5.5 | 5.5 |
| | | | Canada | 5.2 | 4.95 |
| Western Europe | 4.14 | 4.04 | | | |
| | | | W. Europe | 4.14 | 4.04 |
| Asia | 4.75 | 4.5 | | | |
| | | | Japan | 3.1 | 3.1 |
| | | | Australia & NZ | 4.28 | 4.08 |
| | | | China | 5.2 | 4.71 |
| | | | SE Asia | 5.14 | 4.65 |
| | | | Korea | 4.47 | 4.05 |
| | | | India | 5.2 | 4.71 |
| Eastern Europe | 5.58 | 5.42 | | | |
| | | | FSU | 5.52 | 5.52 |
| | | | Other E. Europe | 5.74 | 5.2 |
| Latin America | 4.95 | 4.48 | | | |
| | | | L America | 4.95 | 4.48 |
| Middle East & Africa | 5.08 | 4.83 | | | |
| | | | Africa | 5 | 4.75 |
| | | | Middle East | 5.17 | 4.92 |

*The U.S. uses more energy per unit of clinker production than other industrialized nations*

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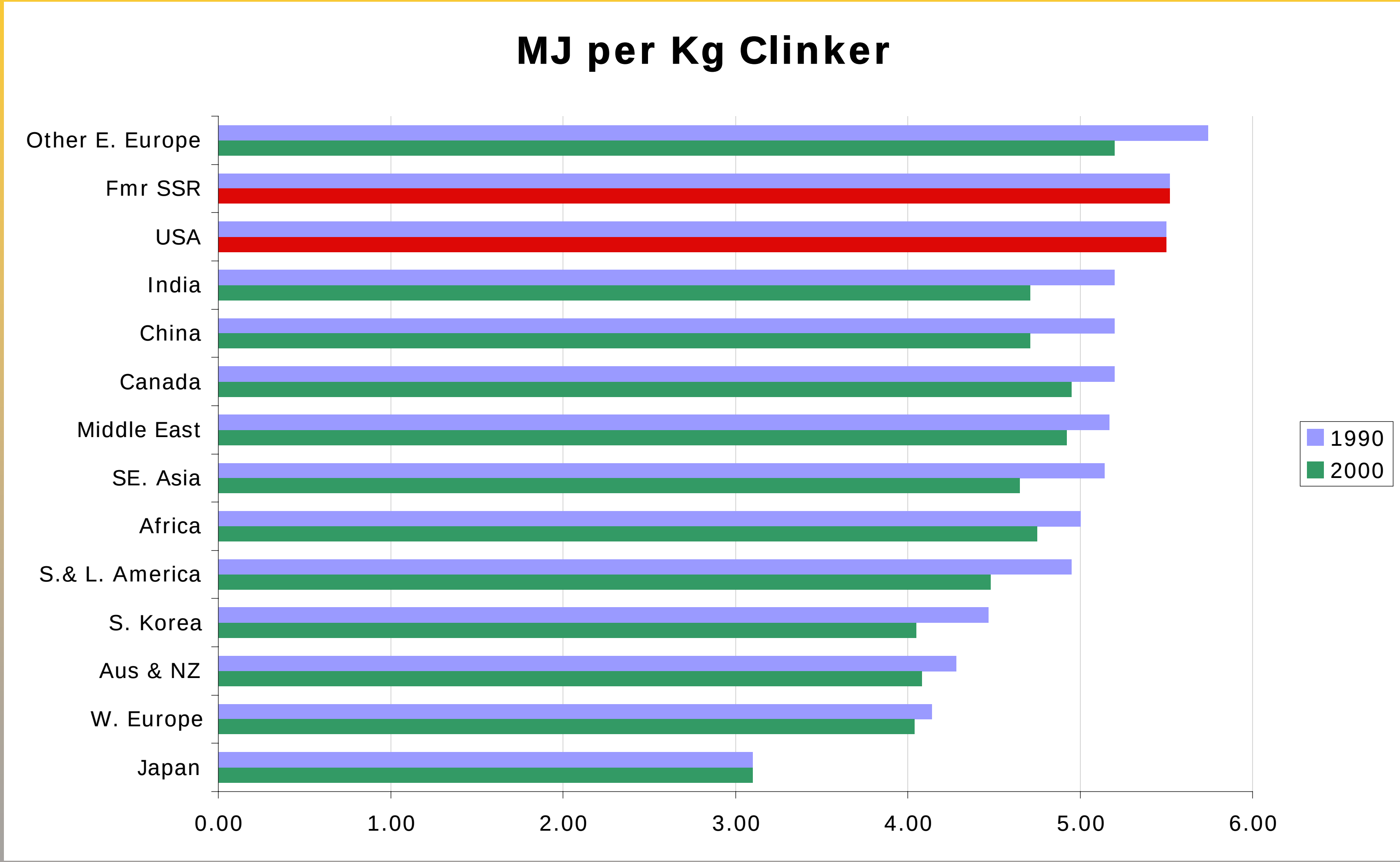
*Source: WBCSD Substudy 8, IEA data;* CalStar analysis, Tom Pounds

# Energy Intensity 1990 - 2000

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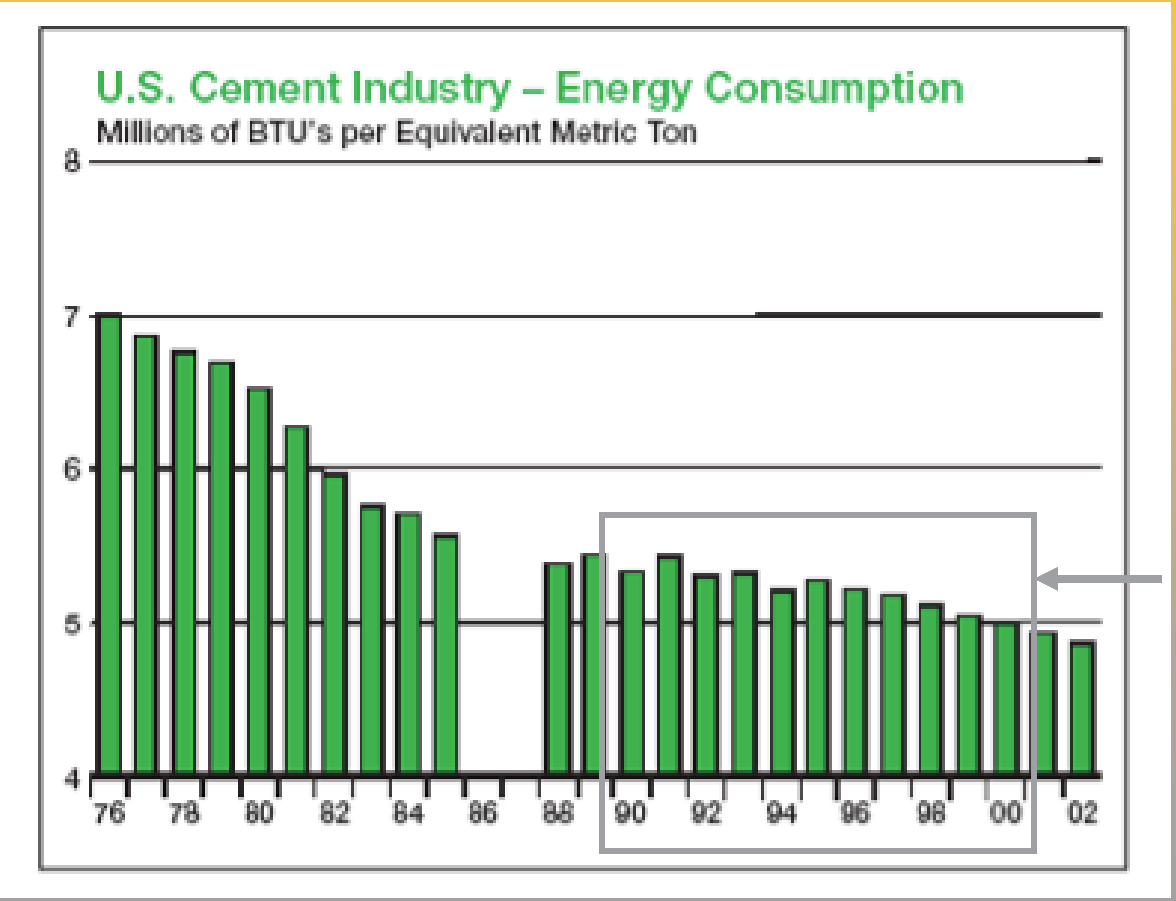
*Source: WBCSD Substudy 8, IEA data,* CalStar analysis, Tom Pounds

# Need to reconcile IEA data with PCA data on energy intensity




*PCA data suggests ~10% reduction in U.S. per unit energy intensity from 1990-2000*

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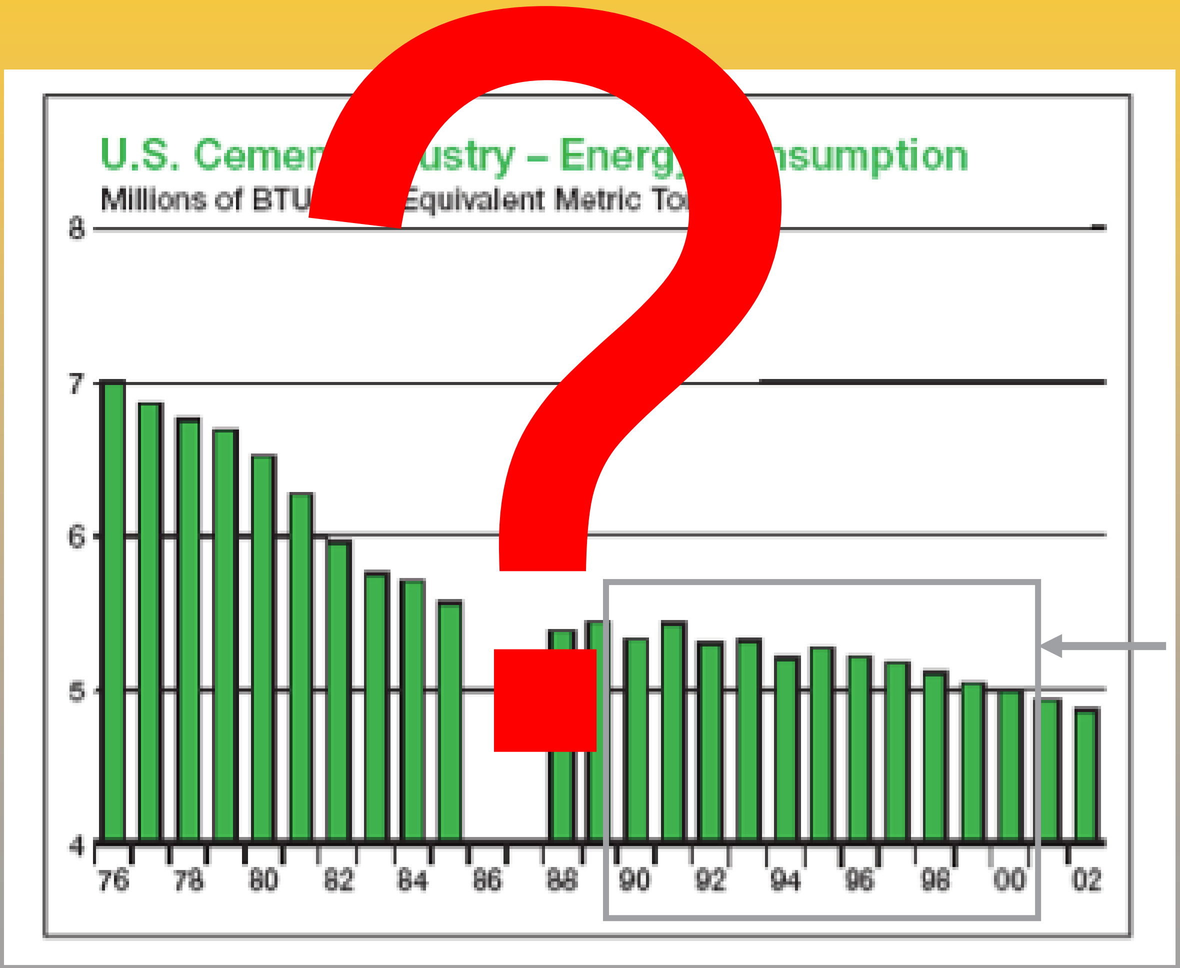


*PCA data suggests ~10% reduction in U.S. per unit energy intensity from 1990-2000*

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# Why U.S. Cement is $CO_2$ Intensive
## *Above Average Clinker Factor*

| Region Name | clinker factor, kg/kg | SubRegion Name | clinker factor, kg/kg |
|---|---|---|---|
| North America | 0.88 | | |
| | | USA | 0.88 |
| | | Canada | 0.88 |
| Western Europe | 0.81 | | |
| | | W. Europe | 0.81 |
| Asia | 0.85 | | |
| | | Japan | 0.8 |
| | | Australia & NZ | 0.84 |
| | | China | 0.83 |
| | | SE Asia | 0.91 |
| | | Korea | 0.96 |
| | | India | 0.89 |
| Eastern Europe | 0.83 | | |
| | | FSU | 0.83 |
| | | Other E. Europe | 0.83 |
| Latin America | 0.84 | | |
| | | L America | 0.84 |
| Middle East & Africa | 0.89 | | |
| | | Africa | 0.87 |
| | | Middle East | 0.89 |

*U.S. uses a higher ratio of clinker in each unit of cement*

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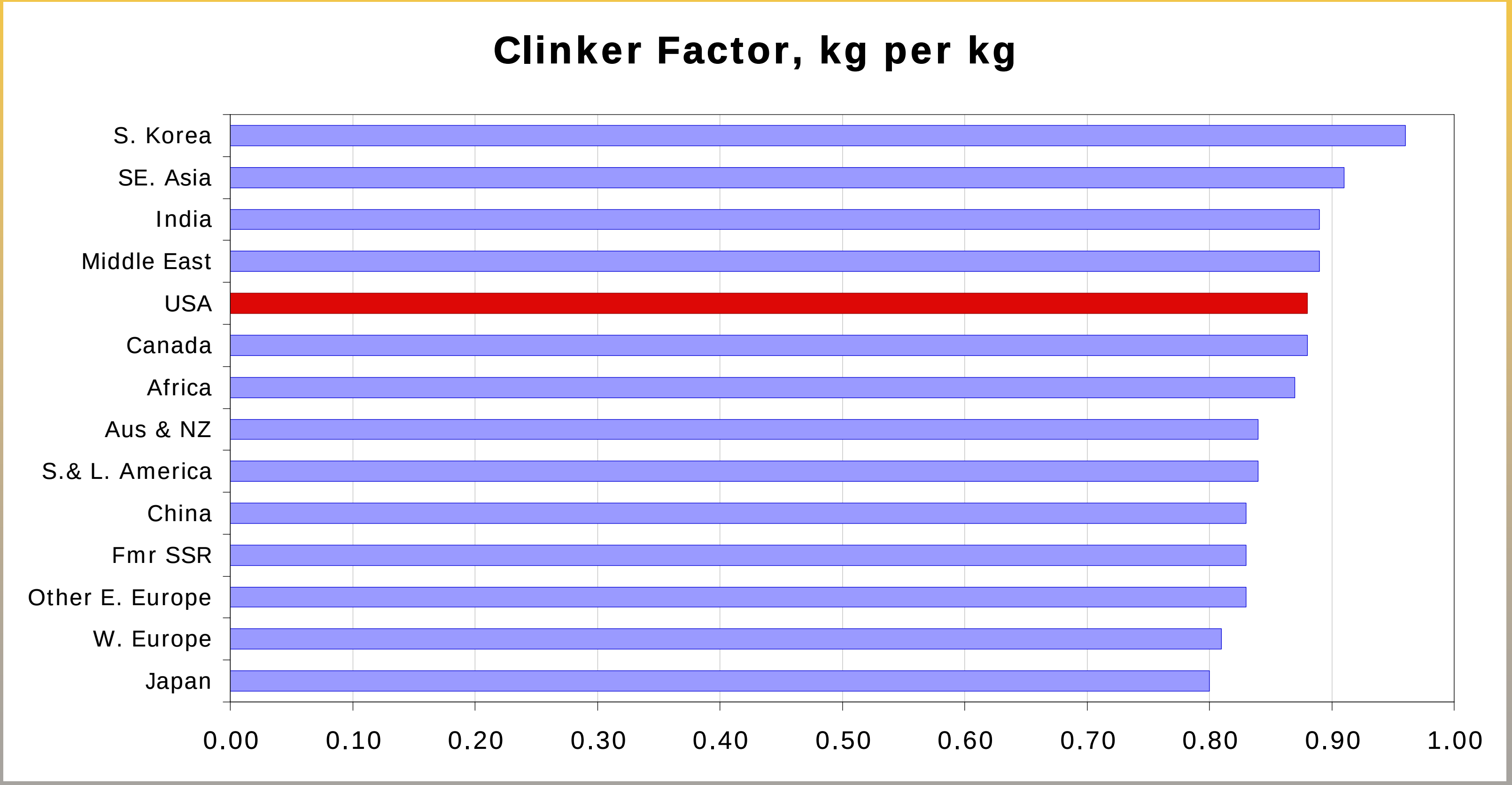
*Source: WBCSD Substudy 8, IEA data,* CalStar analysis, Tom Pounds

# Clinker Factor by Sub-Region Mid-1990s

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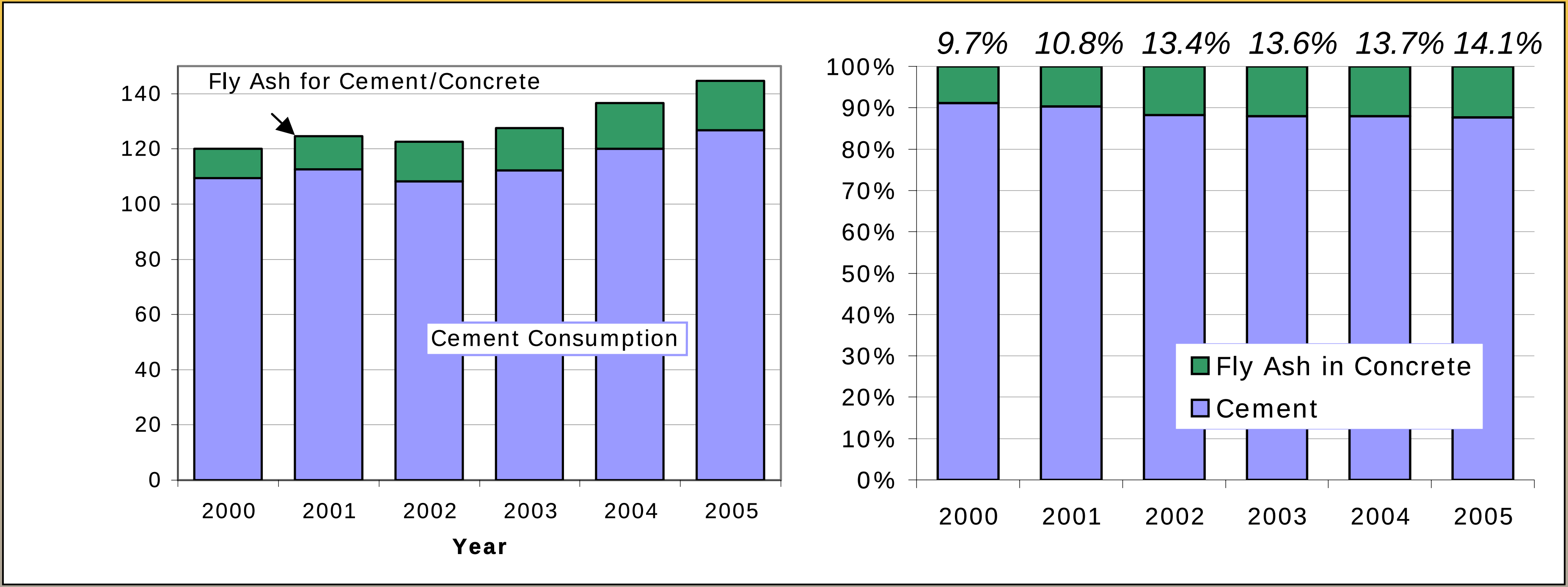
*Source: WBCSD Substudy 8, IEA data,* CalStar analysis, Tom Pounds

# Other Issues

- IEA data consider cement only, not concrete
  - Reflects increased use of blended cements outside U.S.
  - Doesn't capture impact of increased use of SCMs in concrete in the U.S.
  - Structure of the U.S.cement and concrete industry is different from most major benchmark markets in the world - less vertically integrated, making it difficult for cement companies to lead
  - U.S. concrete industry may be uniquely positioned to have a larger direct role in (and responsibility for) $CO_2$ reduction, vs global benchmarks where cement industry drives progress

# Fly Ash Represents a Growing Share of U.S. Concrete




*From <10% in 2000 to >14% in 2005*

*What limits future growth?*

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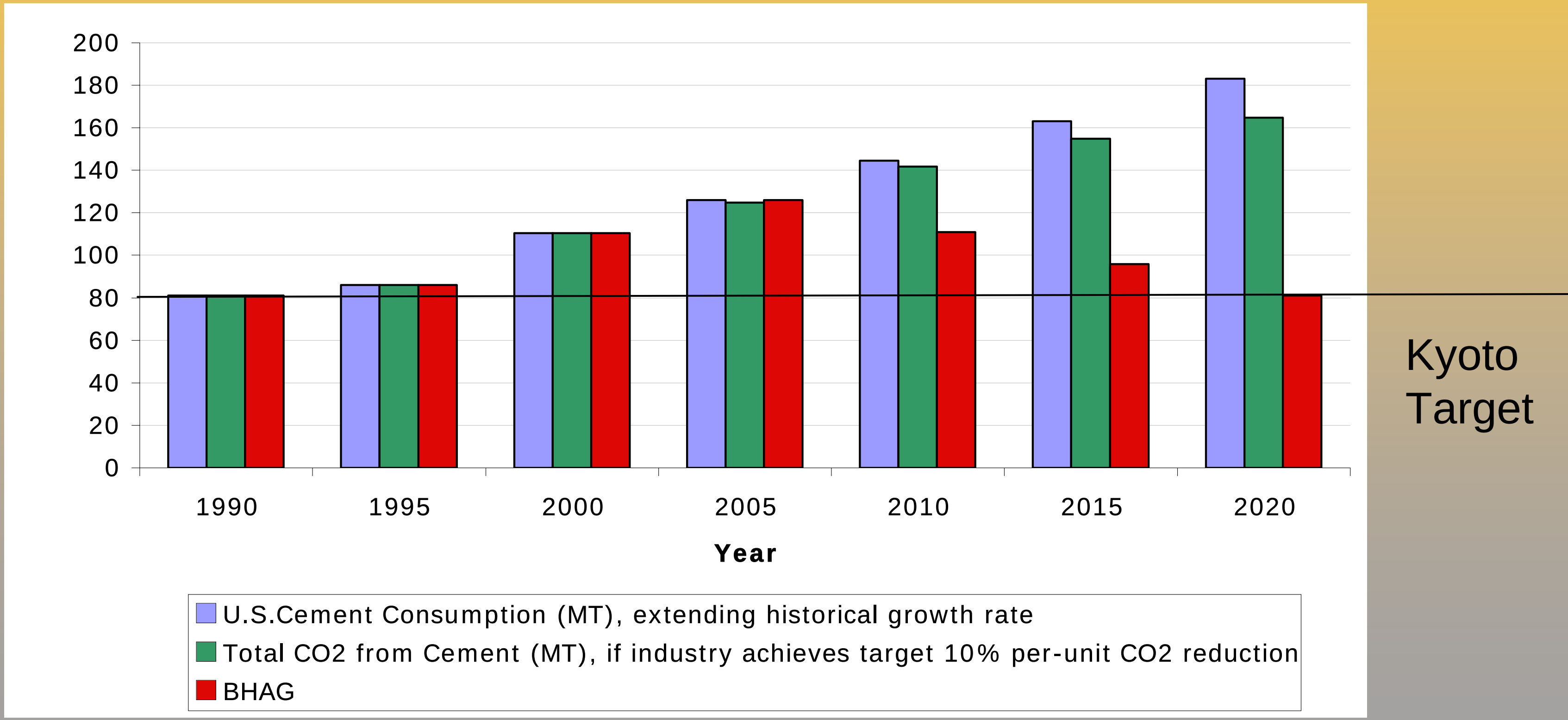
*Sources: American Coal Ash Association*

# Levers

- SCMs
- Other strategies to reduce cement consumption
- New cement production technologies
- New cements
- Increased use of recycled concrete
  - Role of Carbonation?
- *Significant research required…*

# BHAGs

- Baseline 2005 - Absolute Reductions
  - $CO_2$ Reduction of 35% by 2020, 50% by 2050

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# BHAGs

- Embodied Energy
  - Reduce by 20% by 2020
- Water Use
  - Reduce by 50% by 2020
  - Zero Discharge by 2050

# What is obtainable?

| | 1990 | 2005 | % Change |
| --- | --- | --- | --- |
| MT $CO_2$/MT cement | 0.99 | 0.94 | -5% |
| % SCM replacement | 4% | 12% | 200% |
| lbs cement/$yd^3$ concrete | 600 | 550 | -8% |
| MT $CO_2$/ $yd^3$ concrete | 0.26 | 0.21 | -19% |
| Total MT $CO_2$ Annually | 77 | 115 | 49% |

CalStar analysis, Tom Pounds

# What is obtainable?

| | 2005 | 2020 Trend | 2020 Aggressive | 2020 Stretch |
|---|---|---|---|---|
| MT $CO_2$/MT cement | 0.94 | 0.90 | 0.85 | 0.83 |
| % SCM replacement | 12% | 15% | 20% | 23% |
| lbs cement/$yd^3$ concrete | 550 | 530 | 500 | 500 |
| MT $CO_2$/ $yd^3$ concrete | 0.21 | 0.18 | 0.14 | 0.13 |
| Total MT $CO_2$ Annually | 115 | 143 | 114 | 107 |
| Percent Change Total | - | 24% | -1% | -7% |

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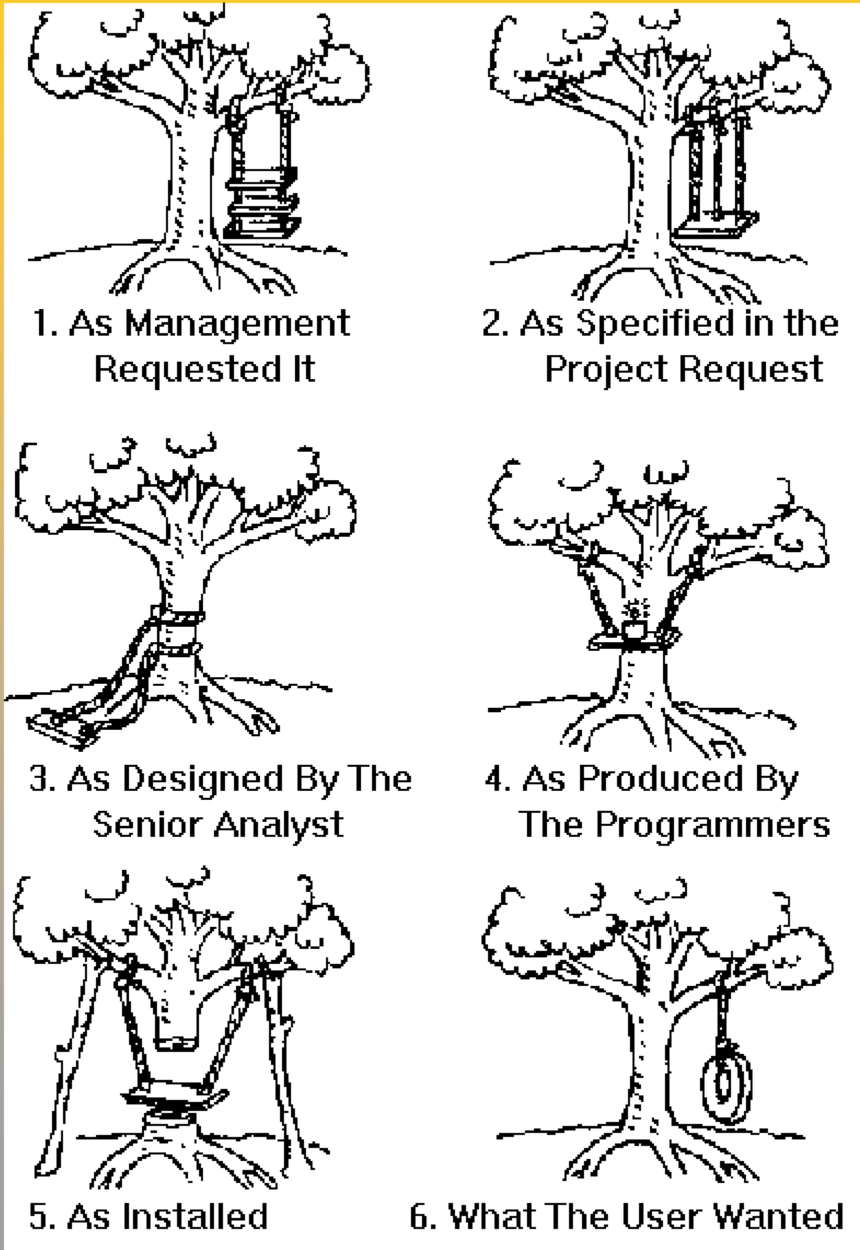
CalStar analysis, Tom Pounds

# The Consensus

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# The Consensus

- By 2010: set targets to reduce by 2030 the carbon footprint per unit of concrete and concrete product produced
- By 2010: set targets to reduce by 2030 the total annual carbon footprint for all concrete and concrete put in place
- By 2010: set targets to substantially improve by 2030 the environmental footprint of concrete with regards to embodied energy, water conservation, water quality, air quality, recycling and reuse

# The Consensus

- By 2010: set targets to substantially improve by 2030 the sustainable characteristics of new structures through the efficient and effective use of concrete in construction to take full advantage of concrete's attributes, and adopting specifications that facilitate innovation in product design.

- By 2010: establish education and outreach goals by market segment, with funded work plans for 75% of industry sectors.

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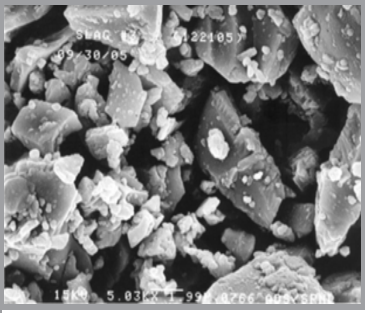
# How Do We Get There?

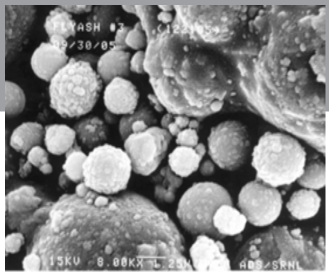
- Industry is not willing to take on the task by themselves - they need stakeholder support - *Demand Driven Change*
- Federal and State Highway Agencies need to lead the issue of sustainability
- Unilateral changes to affect sustainability
  - – Decrease the use of portland cement
  - – Increase use of SCMs
  - – More recycled materials
  - – Development of new sustainable-design tools

# How Do We Get There?

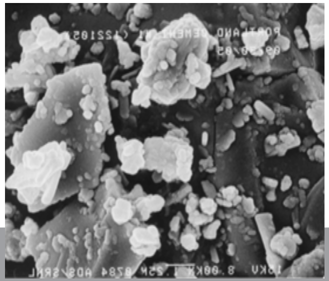
- New Design Tools Needed
  - What is the $CO_2$/embodied energy in a mile of pavement? How is it measured?
    - Asphalt?
    - Concrete?
  - What are the $CO_2$/embodied energy in different design/materials options?
  - How can the $CO_2$/embodied energy be lowered through design/materials choices?
  - Eventually "triple bottom line" engineering cost estimates?

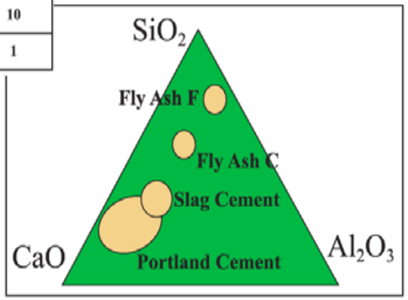
## Supplementary Cementitious Materials (SCMs)

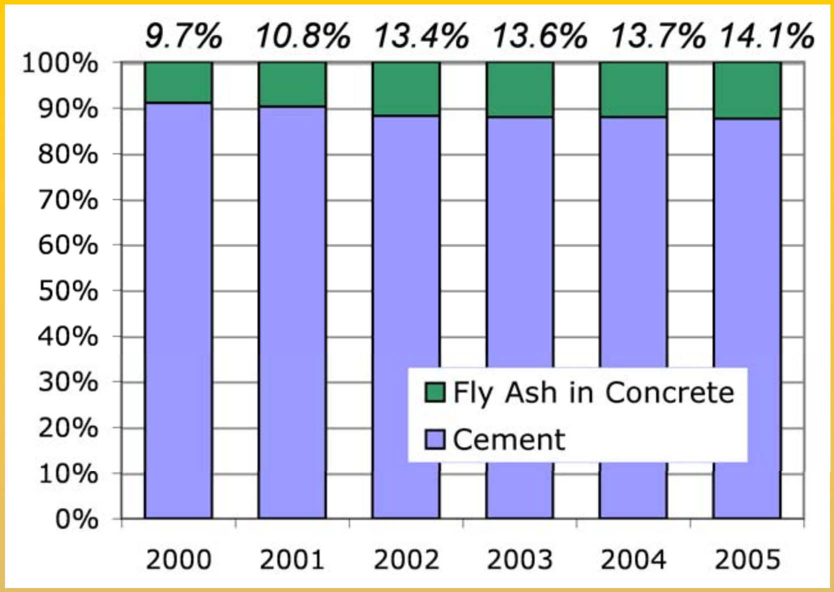




| | Portland Cement | Slag Cement | Fly Ash C | Fly Ash F |
|---|---|---|---|---|
| CaO | 65 | 45 | 25 | 3 |
| $SiO_2$ | 20 | 33 | 37 | 58 |
| $Al_2O_3$ | 4 | 10 | 16 | 20 |
| $Fe_2O_3$ | 3 | 1 | 7 | 10 |
| MgO | 3 | 6 | 7 | 1 |






Class C fly ash

Calcined clay

Silica fume

Class F fly ash

Slag

Calcined shale

- Need to decrease portland cement consumption to impact sustainability
- Steady increase in concrete/cement consumption requires use of SCMs
- Alternative cement binders and portland cement technologies

*Research*

- Standards & specifications
- New technologies for clean SCMs - Mercury Issue
- New cementitious systems such as *geopolymer cements*

*Education / Outreach*

- *Need Engineers / Architects / Technicians that can design and build using maximum SCMs*
- *Stakeholder education*

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Thanks for your attention!

Questions?

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