DIMINISHING CARBON DIOXIDE EMISSIONS AND ENERGY USE IN FOUNDRIES VIA INNOVATIVE POLLUTION PREVENTION AND CLEVER CAPITALIZATION OF HEAT

FRED S. CANNON, PROFESSOR, PENN STATE
(Masters and Degree of Advanced Engineer from Stanford)

- PENN STATE: BOB VOIGT, SRIDHAR KOMARNENI, TIM CONSIDINE, FRANK CLEMENTE, ANDRE BOEHMAN
- MIT: TIM GUTOWSKI, LEON GLICKSMAN
- NEENAH FOUNDRY: FRANK HEADINGTON, STEVE LEWALLEN, JEFF GOUDZWAARD
- FURNESS NEWBURGE: JIM FURNESS
10-YEAR COLLABORATION: PENN STATE, NEENAH FOUNDRY, MIT, FURNESS-NEWBURGE

<table>
<thead>
<tr>
<th>Project Description</th>
<th>Funding ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neenah ‘98: Green Sand Pollutants and Molding Strength.</td>
<td>$25,000</td>
</tr>
<tr>
<td>DOE 98-01: Green Sand Non-Incineration treat. of VOCs.</td>
<td>$550,000</td>
</tr>
<tr>
<td>NSF ‘99: Advanced Oxidation Processes for Foundries.</td>
<td>$37,000</td>
</tr>
<tr>
<td>NSF 00-02: Improve Green Sand with Advanced Oxidation.</td>
<td>$250,000</td>
</tr>
<tr>
<td>DOE 01-05: Less Foundry Emissions and Waste with AO.</td>
<td>$525,000</td>
</tr>
<tr>
<td>EPA/NSF 02-05: Less Materials and Pollutants with AO.</td>
<td>$375,000</td>
</tr>
<tr>
<td>CA ARB ‘03: Non-Incineration removal of VOCs, Odors.</td>
<td>$300,000</td>
</tr>
<tr>
<td>DOE 05-06: Anthracite in Green Sand of Foundries.</td>
<td>$70,000</td>
</tr>
<tr>
<td>NSF 05-08: MUSES Materials Flow of Metal Casting.</td>
<td>$1,300,000</td>
</tr>
<tr>
<td>EPA 07-08: Reclaiming Waste Green Sand in Foundries.</td>
<td>$35,000</td>
</tr>
<tr>
<td>N. Iowa U 07-08: Characterize VOCs from Core Binders.</td>
<td>$20,000</td>
</tr>
<tr>
<td>NSF 08-09: Foundry Cores with UV-Toughened Collagen.</td>
<td>$50,000</td>
</tr>
<tr>
<td>DOE 08-09: Anthracite fines bindered with Collagen.</td>
<td>$95,000</td>
</tr>
</tbody>
</table>

Total $3,632,000
STRATEGIES FOR DIMINISHING ENERGY, CARBON DIOXIDE

- ULTIMATELY, USE ENERGY SOURCE THAT USES NO CARBON, IS SUSTAINABLE, NIMBY-FREE
- IN INTERIM, BE CLEVER TO DIMINISH ENERGY AND $CO_2$ WHILE USING CARBON-BASED ENERGY
- FOCUS ON CUPOLA FOUNDRY HEREIN
CARBON DIOXIDE EMISSIONS
CONVENTIONAL CUPOLA IRON FOUNDRY

<table>
<thead>
<tr>
<th>KG CARBON DIOXIDE / TON IRON POURED</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>295</strong> COKE</td>
</tr>
<tr>
<td><strong>25</strong> NATURAL GAS AND LIMESTONE</td>
</tr>
<tr>
<td><strong>75</strong> OFF-SITE COKING &amp; ELECTRIC POWER</td>
</tr>
<tr>
<td><strong>145</strong> HEATING: NATURAL GAS AND ELECTRIC</td>
</tr>
<tr>
<td><strong>30</strong> GREEN SAND, MOLD BINDER</td>
</tr>
<tr>
<td><strong>30</strong> SHIPPING: SCRAP, GREEN SAND, ETC.</td>
</tr>
<tr>
<td><strong>600</strong> TOTAL FOR CUPOLA FOUNDRY</td>
</tr>
</tbody>
</table>
STRATEGIES FOR LESS ENERGY, CO$_2$

- 15 RECIRCULATE H$_2$ AND CO FROM CUPOLA
- 5 REPLACE SOME COKE WITH ANTHRACITE
- 13 REPLACE SOME COKE WITH NATURAL GAS
- 12 IMPROVE CASTING YIELD VIA HOLLOW RISERS
- 5 RECLAIM GREEN SAND VIA HYDROACOUSTIC CLEANING
- 4 LESS VOCS, SCRAP: ADVANCE OXIDATION, CLEAN BINDERS
- 20 INDOORS: RE-USE LOW-VOC AIR, SO DON’T HEAT NEW AIR
- 5 CAPTURE CO$_2$ ON POROUS CARBONS, ASH, ETC

60-80% TOTALS (CUMULATIVE SUM)

45-60% TOTALS (COMPOUNDED SUM)
Figure 1: Existing foundry cupola and exhaust air system (in thin lines and font); and coal-using adaptations and in-situ activated carbon (in bold lines and font)
REPLACE COKE WITH 10-20% NATURAL GAS PLUS OXYGEN; AND 10-20% ANTHRACITE

- ONLY 2 US SUPPLIERS OF COKE
- WHEN USING COKE, MUST HEAT TWICE WITH NATURAL GAS:
- $\text{CH}_4$ (-IV VALENCE) TO $\text{CO}_2$ (+IV VAL)
- MORE ENERGY / $\text{CO}_2$ THAN WITH COKE:
- C (0 VAL) TO $\text{CO}_2$ (+IV VAL)
- WHEN USE $\text{CH}_4 + \text{O}_2$, LESS GAS FLOW UPWARD THROUGH CUPOLA THAN WITH COKE PLUS AIR; SO BURN MORE $\text{H}_2$ AND CO DEEP IN CUPOLA
CONVENTIONALLY, 35% OF COKE ENERGY IN EXHAUST H₂ AND CO

- **OPTION A:** CONVERT H₂ AND CO TO POWER VIA OFF-GAS GENERATOR
- **B:** RECLAIM HEAT DURING AFTERBURNING FOR INDOOR AIR, MAKING IN-SITU POROUS CARBONS
- **C:** RECIRCULATE OFF-GAS BACK THROUGH CUPOLA TUYERES
GREEN SAND MOLD, METAL POURING ENHANCED BY ADVANCED OXIDATION
METAL POURING: 40-60% OF MELTED METAL SOLIDIFIES IN ACCESS-WAY RISERS, ETC.

- INCREASE PRODUCT YIELD BY EMPLOYING HOLLOW RISERS, ETC.
- 10-25% LESS ENERGY, CARBON DIOXIDE
- ULTRASONICS ALSO CREATES STRONGER IRON
LESS IMPORT OF COLD AIR FROM OUTSIDE BY RECIRCULATING TREATED INDOOR AIR

- ALLOW 15-20% LESS ENERGY AND CO₂
- DURING NORTHERN WINTERS, INDOOR AIR HEATING ACCOUNTS FOR 35-45% OF ENERGY AND CO₂
- TO RECIRCULATE AIR, MUST REMOVE VOCs AND CO, SO WORKERS CAN BREATHE THE AIR
- POLLUTION PREVENTION BY ADVANCED OXIDATION, LOW-EMISSION BINDERS, REUSED GREEN SAND
ADVANCED OXIDATION TREATMENT OF BAG HOUSE DUST / WATER SLURRY

- BLACKWATER MIXED WITH GREEN SAND. GREEN SAND MAKES THE MOLD THAT MOLTEN METAL IS POURED INTO.
- GREENSAND: 85% SILICA SAND, 8% MB CLAY, 4-5% LOI COAL, 2% WATER.
- NEED CARBON IN MOLD TO DRIVE C INTO IRON, AND PREVENT OXIDATION.
- AO DIMINISHES VOCS BY 30-70%, CLAY AND COAL USE BY 25-35%, AND SCRAP BY 30-50%.
Clear view of iron being poured ~370 feet from camera

Greensand molds being pushed into shakeout

YOU CAN SEE THE LIGHT AT THE END OF THE TUNNEL
Dust mixer and acoustic system

Dust feed from new baghouses

5000 gallon system retained from replaced wet dust collecting system
EMISSIONS AT NEENAH: WITH AO (SOLID) VS. NO AO (HOLLOW)
EFFECT OF ADVANCED OXIDATION:
Real Time Test Results Pouring, Cooling & Shakeout in Production Foundry

Stars Pattern - Tap vs A/O

Time, sec

ppm

Tap
A/O
WITH AO (WGS), CONDITION GREEN SAND CARBON SO IT HOSTS LESS HAPS, BUT RETAINS CASTING QUALITY
WITH AO (WGS), MAINTAIN CO$_2$ AND CO BLANKETS BETWEEN METAL AND MOLD, WHICH IS NEEDED
TGA-MS / FLASH PYROLYSIS: CELLULOSE BIOMASS RELEASE FEWER VOCS, CO$_2$ IN MOLD (FIRST GENERATION CO$_2$)

The diagram shows the comparative distribution of HCV (%) between different components (Anthracite, Sea Coal, Lignite, and Cellulose) for two different ranges, C1-C5 and C6-C16.
WITH COLLAGEN BINDER RATHER THAN PHENOLIC URETHANE BINDER; GENERATE FAR LESS VOCs, CO₂; BUT NEED ENHANCED STRENGTH WITH UV
RECLAIMING GREEN SAND BY HYDROACOUSTIC CAVITATION, ULTRASONICS-AO

- Conventionally, sand grains accumulate “raincoat” of recondensed carbon.
- With hydroacoustics, blast this carbon off, then the sand grains can be reused.
- Also, released carbon can be reused; and this carbon source releases less HAPS, while maintaining casting quality.
- 5-10 fewer truckloads / day sand in and out.
- Also, clean heat exchange tube with AO.
HYDROACOUSTIC ULTRASONICS-AO SAND RECLAMATION
REMOVE CARBON COAT

BEFORE TMT       AFTER
RECLAIMED SAND: QUALITY CASTING; RETAIN TENSILE STRENGTH

With Anti-Veining Additive

Percent Reclaimed Sand

Percent Reclaimed Sand

Tensile Strength (psi)
WITH WASTE HEAT FROM CUPOLA, PRODUCE IN-SITU POROUS CARBON (FOR NO COST)

- ADSORB VOCS SO AIR CAN BE RECIRCULATED
- FULL-SCALE TRIAL: PAC REMOVED 1/3 OF VOCS WITH <0.5 SEC RETENTION TIME BEFORE BAG HOUSE CLOTH
- AMINATED POROUS CARBON TO CAPTURE CO$_2$, CO (?)
IN-SITU POROUS CARBONS MADE VIA PYROLYSIS, SO ROBUST OVER BROAD RANGE OF TIME, TEMP (KISS)
SORB CO\textsubscript{2} IN-SITU INTO AMINATED POROUS CARBONS

- WITH AMINE FUNCTIONALITY ON POROUS CARBON, WET CO\textsubscript{2} SORBS TO 10-30% MASS RATIO; PUFF OFF AT HIGHER PARTIAL PRESSURES, THEN
- SORB CO\textsubscript{2} ONTO FLY ASH, CUPOLA EXHAUST PARTICLES, MAGNESIUM SILICATES
- USE CARBONATED INORGANICS FOR BUILDING AGGREGATE
## SUMMARY LOWER ENERGY AND CARBON DIOXIDE

<table>
<thead>
<tr>
<th>% Δ</th>
<th>STRATEGY</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>RECIRCULATE H₂ AND CO FROM CUPOLA</td>
</tr>
<tr>
<td>5</td>
<td>REPLACE SOME COKE WITH ANTHRACITE</td>
</tr>
<tr>
<td>13</td>
<td>REPLACE SOME COKE WITH NATURAL GAS</td>
</tr>
<tr>
<td>12</td>
<td>IMPROVE CASTING YIELD VIA HOLLOW RISERS</td>
</tr>
<tr>
<td>5</td>
<td>RECLAIM GREEN SAND VIA HYDROACOUSTIC CLEANING</td>
</tr>
<tr>
<td>4</td>
<td>LESS VOCS, SCRAP: ADVANCE OXIDATION, CLEAN BINDERS</td>
</tr>
<tr>
<td>20</td>
<td>INDOORS: RE-USE LOW-VOC AIR, SO DON’T HEAT NEW AIR</td>
</tr>
<tr>
<td>5</td>
<td>CAPTURE CO₂ ON POROUS CARBONS, ASH, ETC</td>
</tr>
</tbody>
</table>

60-80% TOTALS (CUMULATIVE SUM)

45-60% TOTALS (COMPOUNDED SUM)


