# Industrial Symbiosis for Small and Medium Scale Enterprises: Case of Muzaffarnagar, India

**Elsa Olivetti, Shourjomoy Chattopadhyay, Nandini Kumar, Charles Fine**

*Natural Resources Department, TERI University & Institute for Industrial Productivity, India*

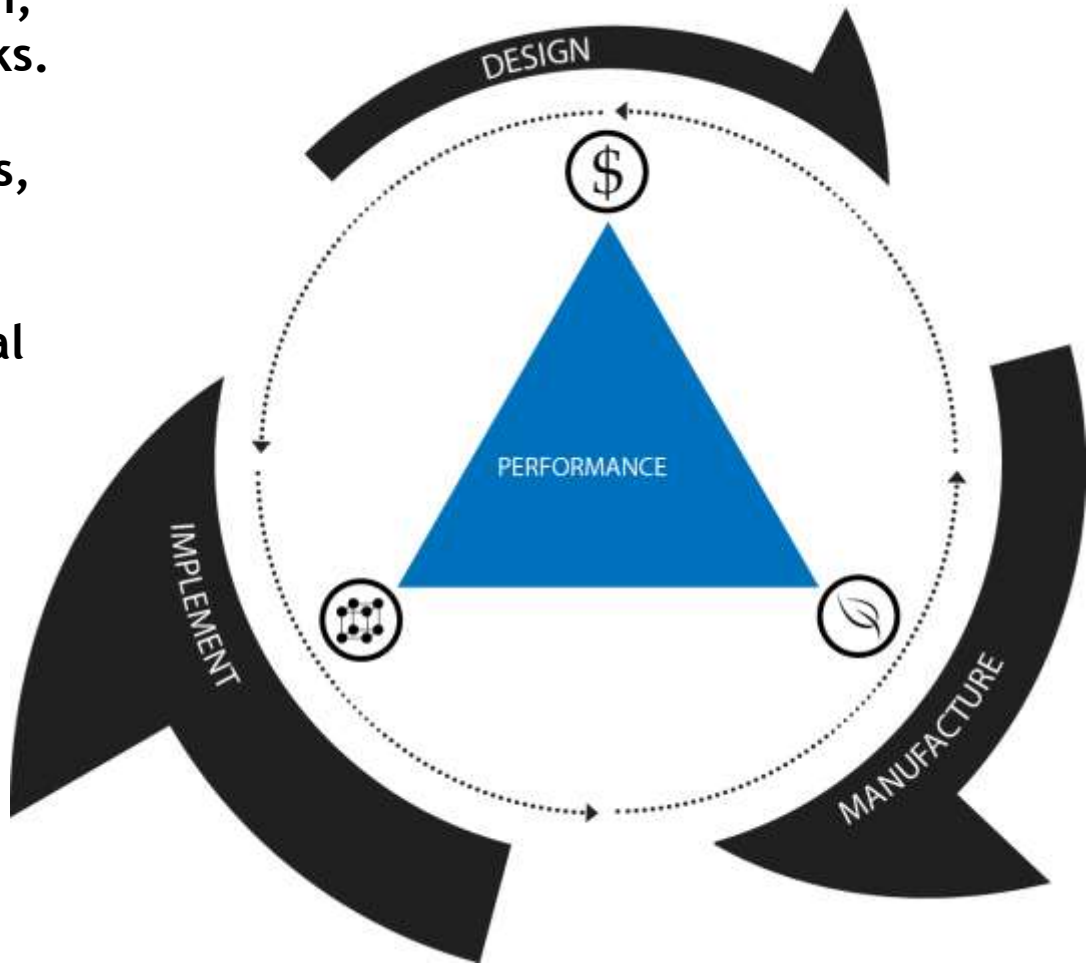
*Tata Center for Technology and Design*

*Department of Materials Science and Engineering, Sloan School of Management, MIT*

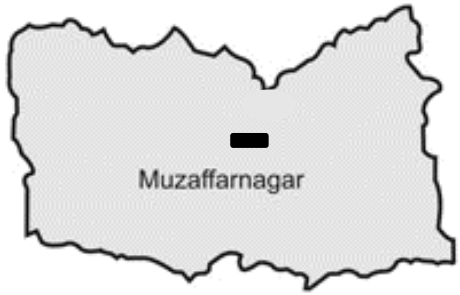
# Research strategy

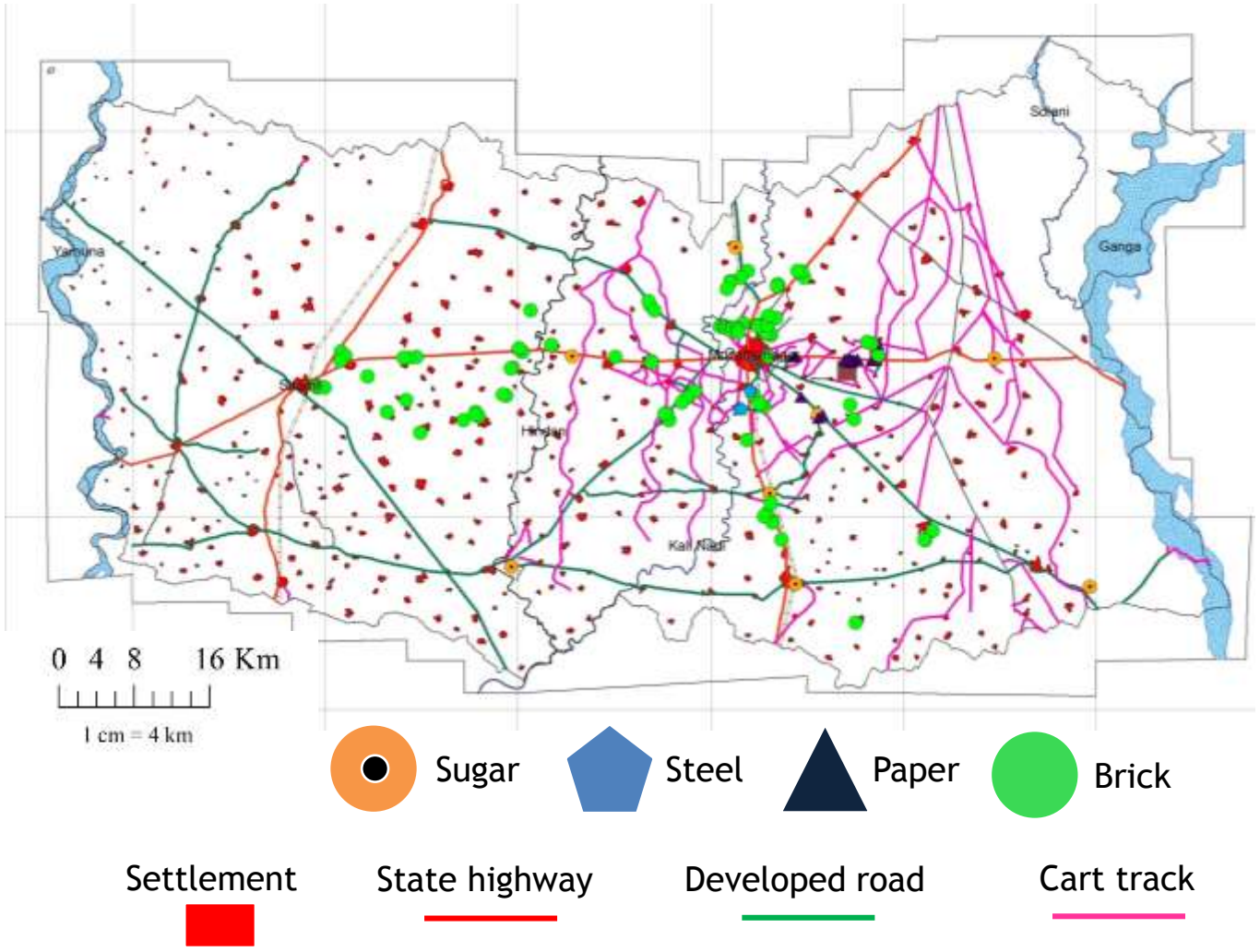
**Materials do not exist in isolation, they are part of complex networks.**

**To inform the design of materials, this research combines an understanding of underlying physical and chemical mechanisms with analysis of processes and systems.**



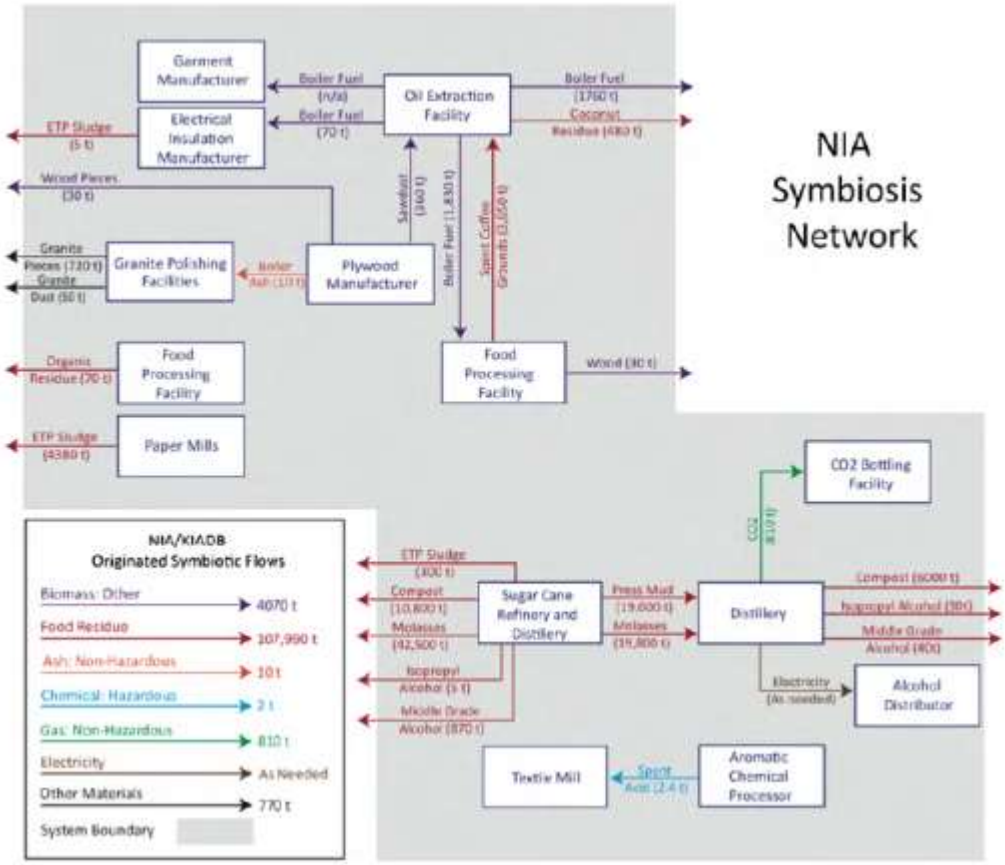
# Our region of study

# Previous work in India

- Explores the role of the informal sector
- Geographic extent of activity
- High degree of recovery

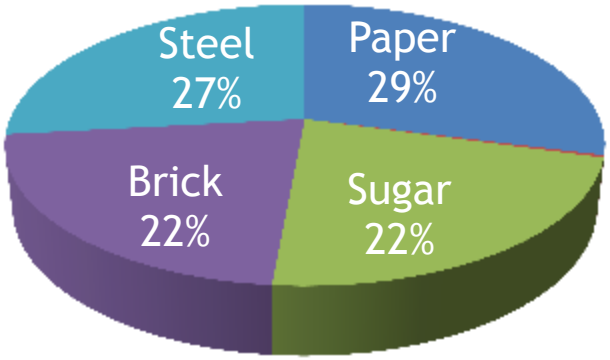


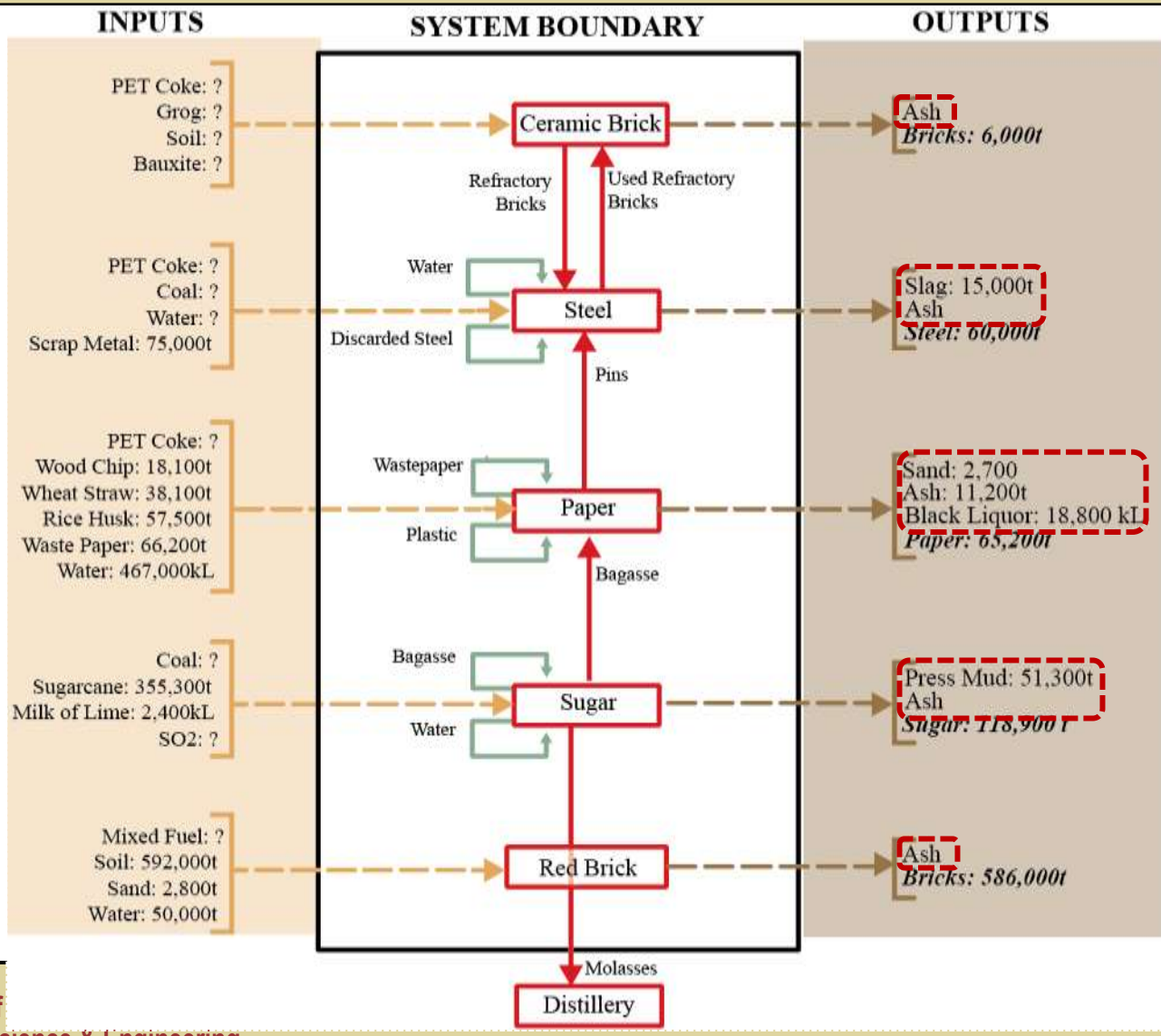

*Bain, Shenoy, Ashton, Chertow, Res. Cons. Recyc. 2010. 54(12)*

# Catalog flows of material in Muzaffarnagar

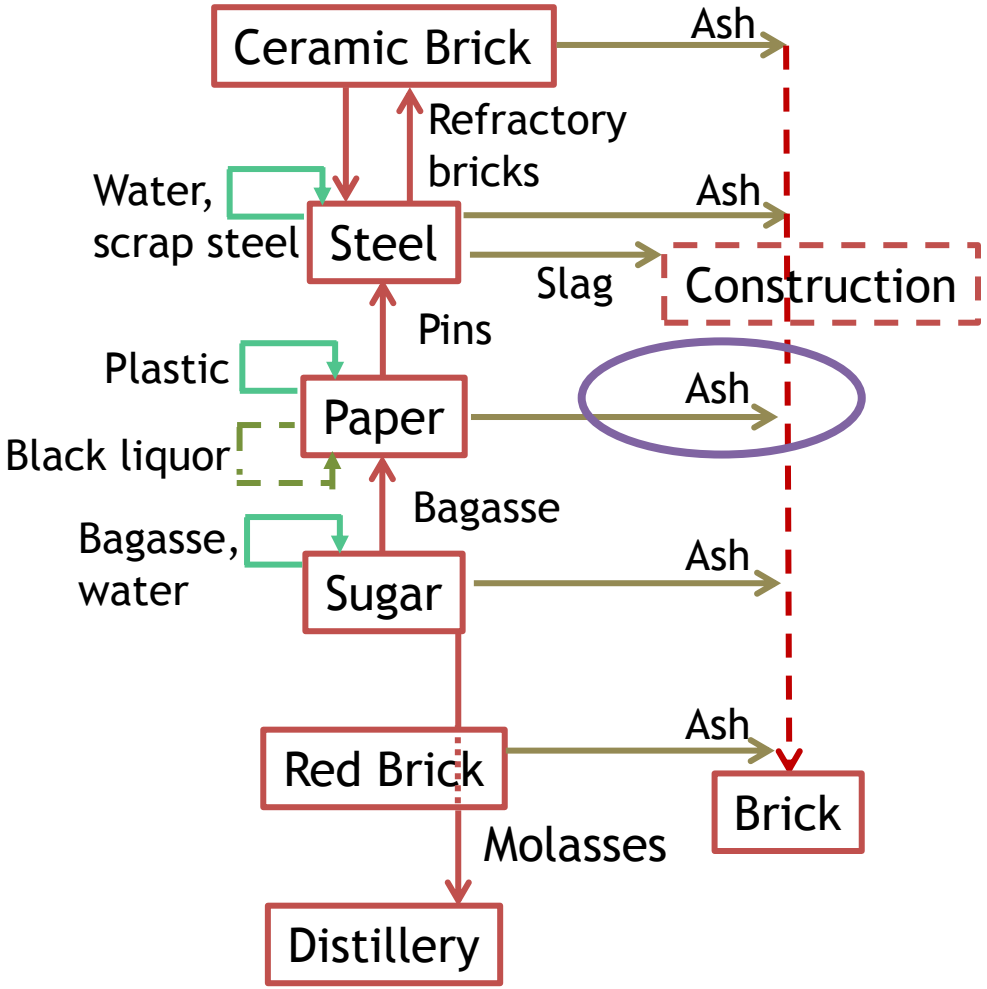
2.6 million tonnes of products annually

Industry breakdown in the region by mass



# Identify additional symbiosis exchanges within Muzaffarnagar

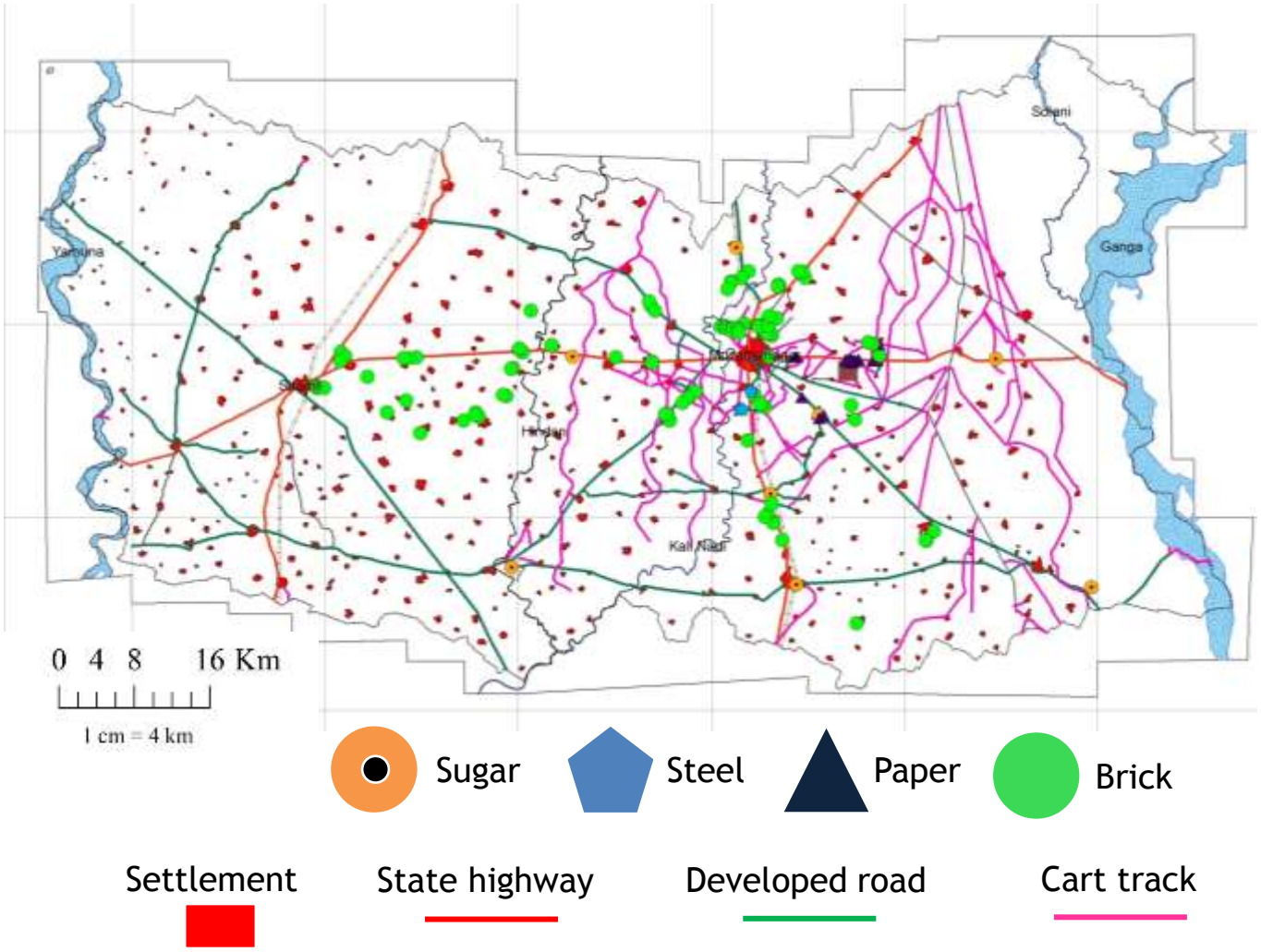



55% reuse
24% symbiotic exchanges
(5% if sugar industry is excluded)

21% of solid waste currently used → proposed exchanges raise that to 46%

67% of liquid waste currently used → proposed exchanges raise that to 100%

# Focused study on boiler ash in the region



# Valorization of boiler ash to construction materials


**Co-authors:**

**Michael Laracy,**
**Dr. Thomas Poinot,**
**Prof. John Ochsendorf,**
**Prof. Hamlin Jennings**

**CEE, MIT**

# Potential use of ash in low-temp cured bricks


Boiler

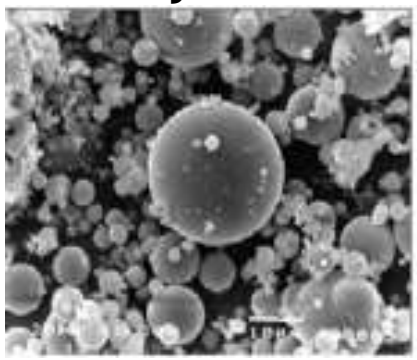
Energy

luct: Ash

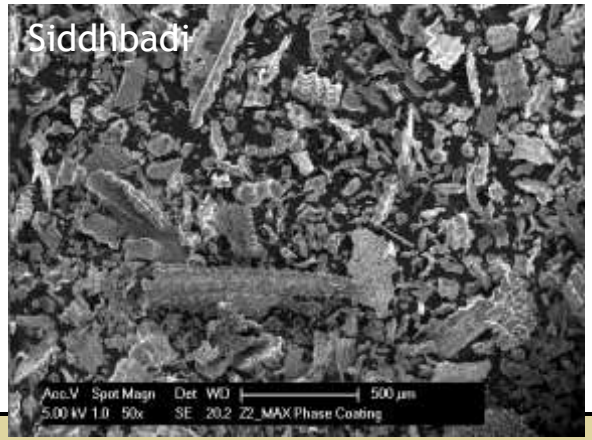
# Coal fly ash versus boiler ash from varied combustion sources

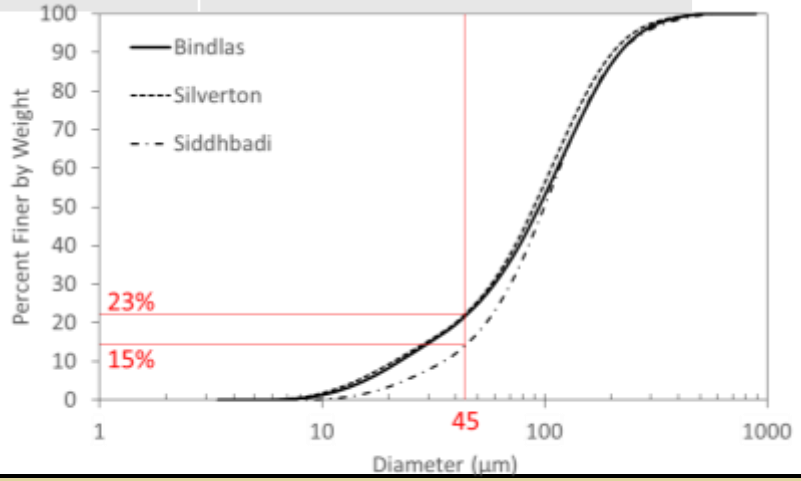
| Characteristics | Coal fly ash (used in cement) | Boiler Ash |
|---|---|---|
| Shape | Spherical | Varies |
| Particle Size < 45 μm | > 75% | < 25% |
| Loss on Ignition | < 6% | 8-35% |
| Reactive Silica Content | > 40% | > 80% (bulk) |
| Reactive Alumina Content | > 15% | < 4 % (bulk) |
| Iron Content | < 10% | < 2 % |

*Fly Ash*



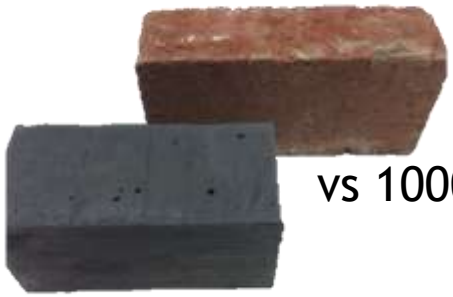
*Boiler Ash*



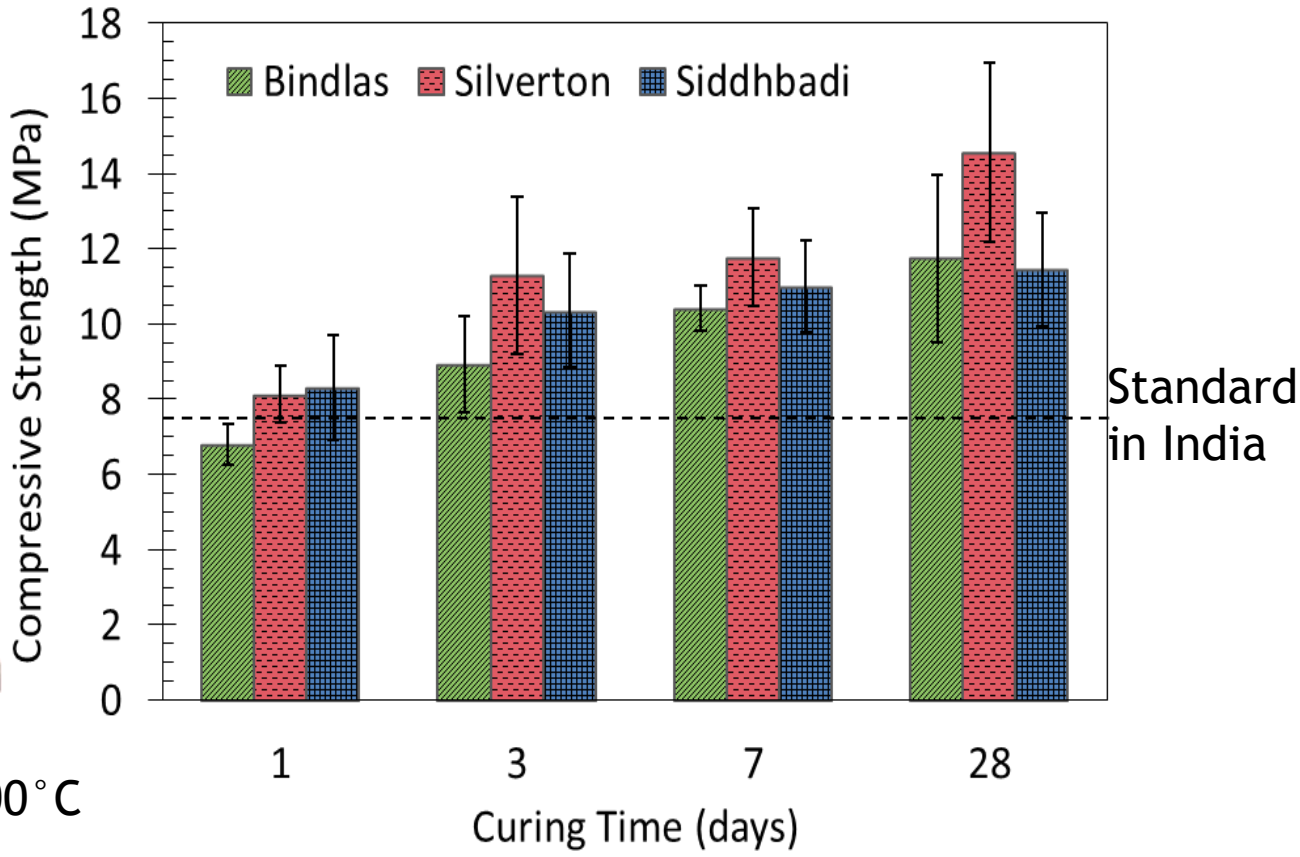
# Proposed solution: use of alkali activation technology

**70% boiler ash**
+
**20% clay**
+
**10% lime**
+
**1M or 2M NaOH**

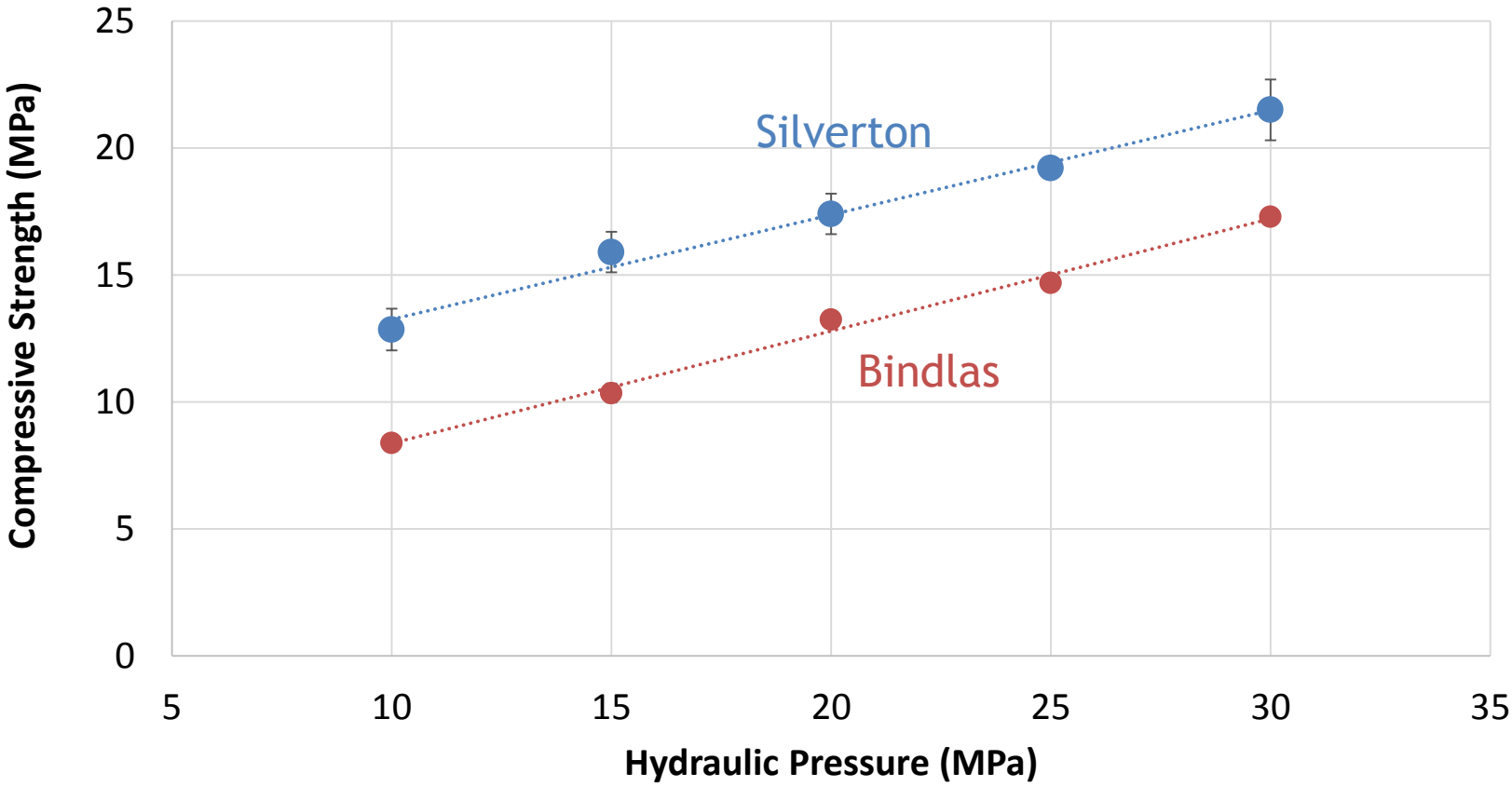


vs 1000˚C

at 30˚C



# Strength improves with increased forming pressure



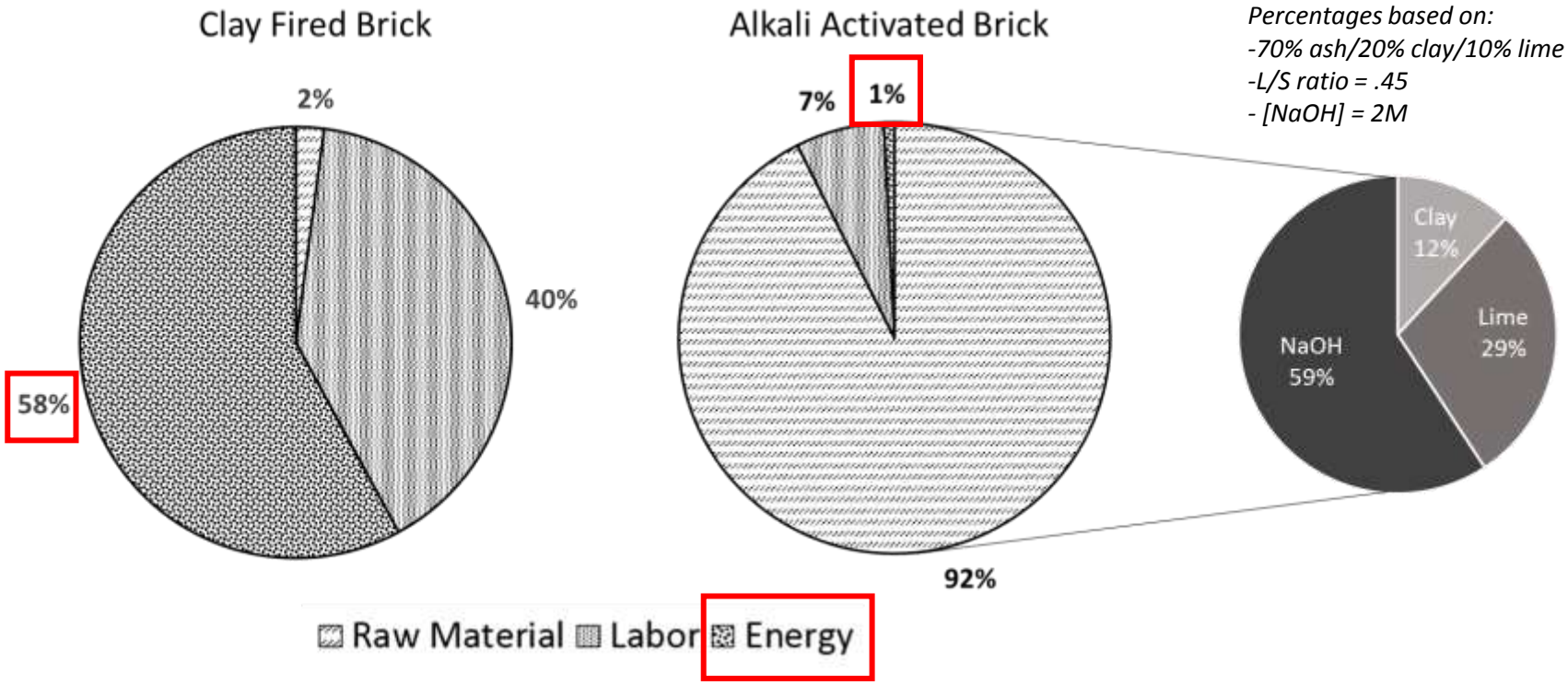
# Economic comparison between clay-fired and alkali-activated brick

CLAY FIRED BRICK

Production cost is approximately **3 INR** in Northern India where brick making is prevalent

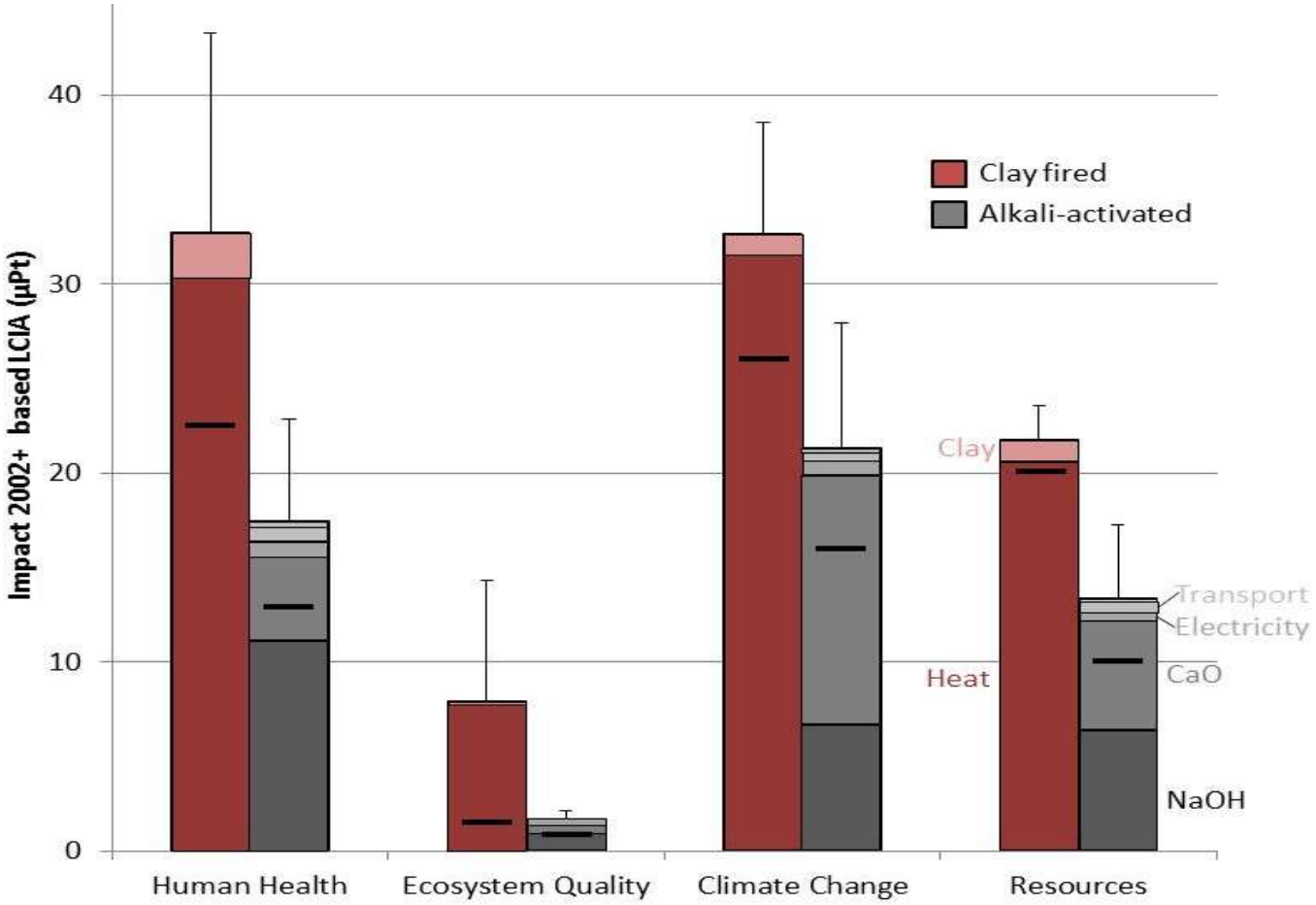
ALKALI ACTIVATED BRICK

Production cost for this mix design is **3.1 INR**



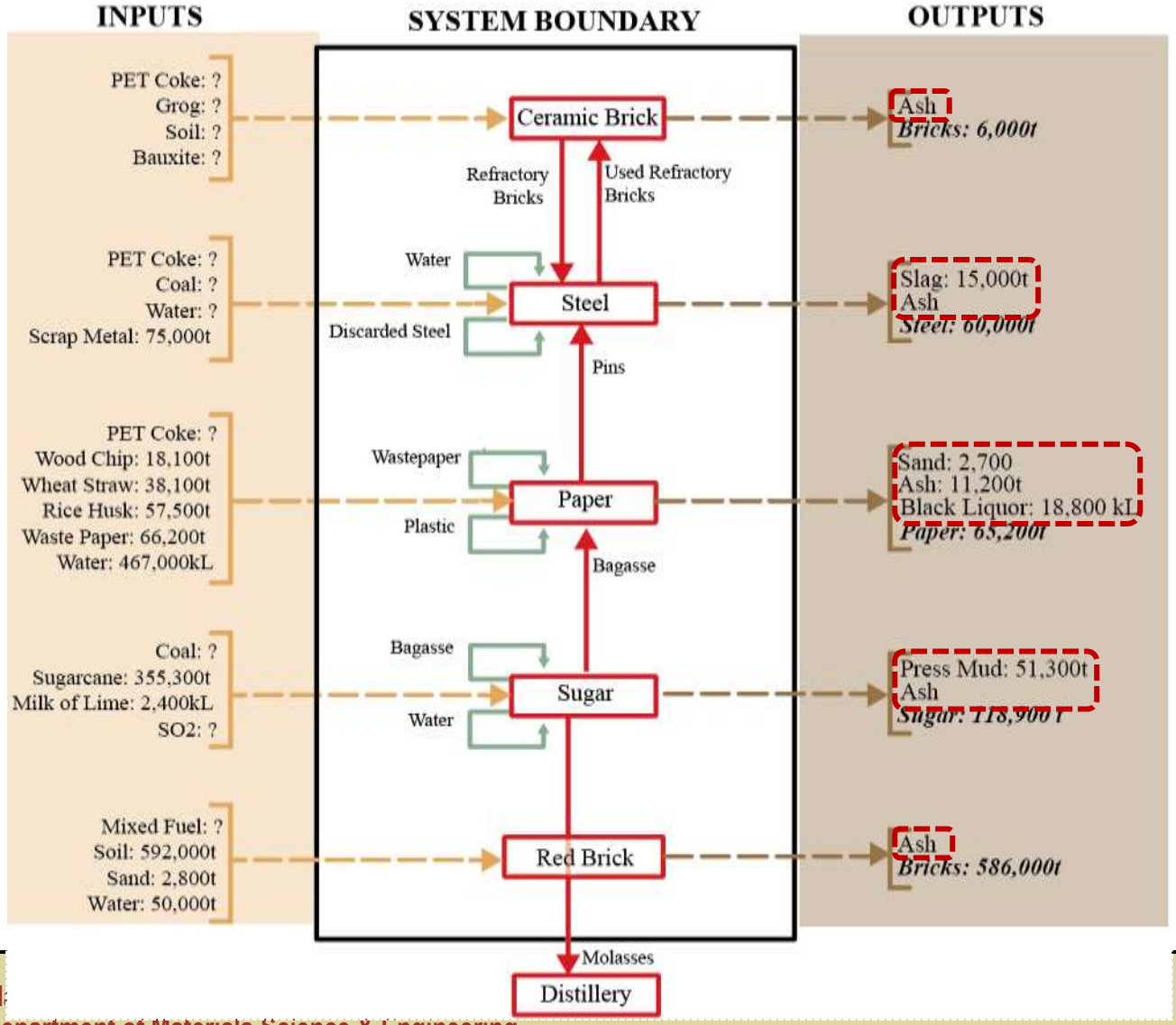

*Percentages based on:*
*-70% ash/20% clay/10% lime*
*-L/S ratio = .45*
*- [NaOH] = 2M*

# Environmental comparison of clay-fired versus alkali-activated




IMPACT 2002+

# More opportunities for beneficial use



# Conclusions

- As previous work has shown, many byproduct exchanges grow organically
- Potential increased for SME where economic pressure may be higher and strong bonds exist between owners
- Potential for use of boiler ash in bricks, show high strength with incorporation of supplemental materials

Recent testing of adhesion between mortar and bricks

# Leaching Test

**Method: 6010C - Metals (ICP) - TCLP**

| Analyte | Result | Qualifier | RL | MDL | Unit |
|---|---|---|---|---|---|
| Arsenic | 0.058 | | 0.015 | 0.0056 | mg/L |
| Barium | 0.28 | B | 0.0020 | 0.00070 | mg/L |
| Cadmium | 0.0029 | | 0.0020 | 0.00050 | mg/L |
| Chromium | 0.011 | B | 0.0040 | 0.0010 | mg/L |
| Lead | ND | | 0.010 | 0.0030 | mg/L |
| Selenium | 0.012 | J | 0.025 | 0.0087 | mg/L |
| Silver | ND | | 0.0060 | 0.0017 | mg/L |

**Method: 7470A - TCLP Mercury - TCLP**

| Analyte | Result | Qualifier | RL | MDL | Unit |
|---|---|---|---|---|---|
| Mercury | ND | | 0.00020 | 0.00012 | mg/L |

**Client Sample ID:** 70/20/10_2M_30C_1D
**Lab Sample ID:** MC42186-1
**Matrix:** SO - Solid

**Project:** ECOBLAC

**Metals Analysis, TCLP Leachate SW846 1311**

| Analyte | Result | HW# | MCL | RL | Units |
|---|---|---|---|---|---|
| Arsenic | 0.054 | D004 | 5.0 | 0.010 | mg/l |
| Barium | < 0.50 | D005 | 100 | 0.50 | mg/l |
| Cadmium | < 0.0040 | D006 | 1.0 | 0.0040 | mg/l |
| Chromium | < 0.010 | D007 | 5.0 | 0.010 | mg/l |
| Lead | < 0.010 | D008 | 5.0 | 0.010 | mg/l |
| Mercury | < 0.00020 | D009 | 0.20 | 0.00020 | mg/l |
| Selenium | < 0.025 | D010 | 1.0 | 0.025 | mg/l |
| Silver | < 0.0050 | D011 | 5.0 | 0.0050 | mg/l |

(1) Instrument QC Batch: MA18573
(2) Instrument QC Batch: MA18575
(3) Prep QC Batch: MP25312
(4) Prep QC Batch: MP25323