ADVANCES IN DOMESTIC SCALE CLEAN COAL COMBUSTION IN EAST AND CENTRAL ASIA

Domestic Use of Energy Conference – Cape Town
April 2018

Crispin Pemberton-Pigott
Research Associate
Faculty of Engineering
North-West University – Potchefstroom Campus

Heating and Cooking in Central Asia

- Several hundred million people in Asia depend on solid fuels for heating and cooking – **coal**, wood and dung.
- The majority burn **coal**, if they can afford it.
- In Ulaanbaatar, Mongolia there is one choice: **coal.**
- In most countries **coal** is the lowest cost option for the poor.

Heating and Cooking in Central Asia

Kyrgyzstan highlands

Bishkek -27°

Naryn -30°

Heating and Cooking in Central Asia

Something ***big*** is happening in Central Asia!

Heating and Cooking in Central Asia

- **Coal** is almost universally described as a '**dirty fuel**'
- The main reason is that almost all **coal** burning appliances make **smoke** – a lot of it
- The default comparison for stoves is continuously operated **power stations**
- Domestic stoves are **fundamentally different** because they are started, stopped and adjusted frequently
- Majority of emissions are from ignition and refueling

Heating and Cooking in Central Asia

Political drivers for this
Air quality
Health
Coal industry
Cold climate
Briquettes
Political interference
Policy changes without testing the effects
!

Dirty Coal?!! Or Clean Stove?

Cross draft coal gasifying heating and cooking stove

Design Features

10 kg capacity hopper - automati
gravity feed of sized coal
Crossdraft gasifier, angled grate
Single inlet control for primary and secondary air regulation
Dehydration, pyrolysis, coking and gas burning zones
Refractory ceramic lining
Fixed heat exchanger bypass

Dirty Coal?!! Or Clean Stove?

Mongolian raw coal-burning heating and cooking stove

Performance

Controllable power 3-14 kW

Cooking power 2.5 kW

Extremely low $PM_{2.5}$, CO

14 hr low power burn time

One-touch power adjust

80% space heating efficiency

Coal Combustion

- Coal burning produces **inherent emissions** consisting of two components: products of complete combustion (CO_2 and H_2O) and products of fuel impurities.
- Products of incomplete combustion (CO, VOC's, SVOC's, PAH's, tars, soot) are **incidental emissions** that can be altered by changing the combustion conditions.

Coal Combustion

- Impurity emissions can be minimized by pre-processing or changing the fuel, e.g. low-sulphur fuels
- Changing combustion conditions cannot, in principle, alter the inherent emissions due to fuel impurities (fly-ash, total S, Hg, As, F)

Coal Combustion

- **Bypass emissions** from ambient air (pollution from other sources)
  - Ambient particulate matter ($PM_{2.5}$ and PM_{10})
  - Ambient N_2, Ar, CO_2
  - Ambient NO, NO_2, CO, SO_2

Popular Understanding of PAHs

- **The EPA says**
  - "Polycyclic aromatic hydrocarbons (PAHs) are a class of chemicals that **occur naturally** in coal, crude oil, and gasoline."
  - "They also are **produced** when coal, oil, gas, wood, garbage, and tobacco are burned. "

Source

Popular Understanding of PAHs

- **The EURL says**
  - “Polycyclic aromatic hydrocarbons (PAHs) are chemical compounds that **can result from combustion processes** of organic substances or from heat processing of food ”
  - “Food contamination with PAHs largely arises from production practices, although environmental contamination is also an issue, since they are formed during **incomplete combustion** processes.”

Source

Popular Understanding of PAHs

- **Volatile or semi-volatile PAHs** may be formed from decomposition fragments arising during the combustion of hydrocarbon fuels and are not inherent.
- PAHs should therefore be categorized as **incidental emissions** that can be reduced or avoided by having good combustion conditions.

How to Burn **Coal** Completely

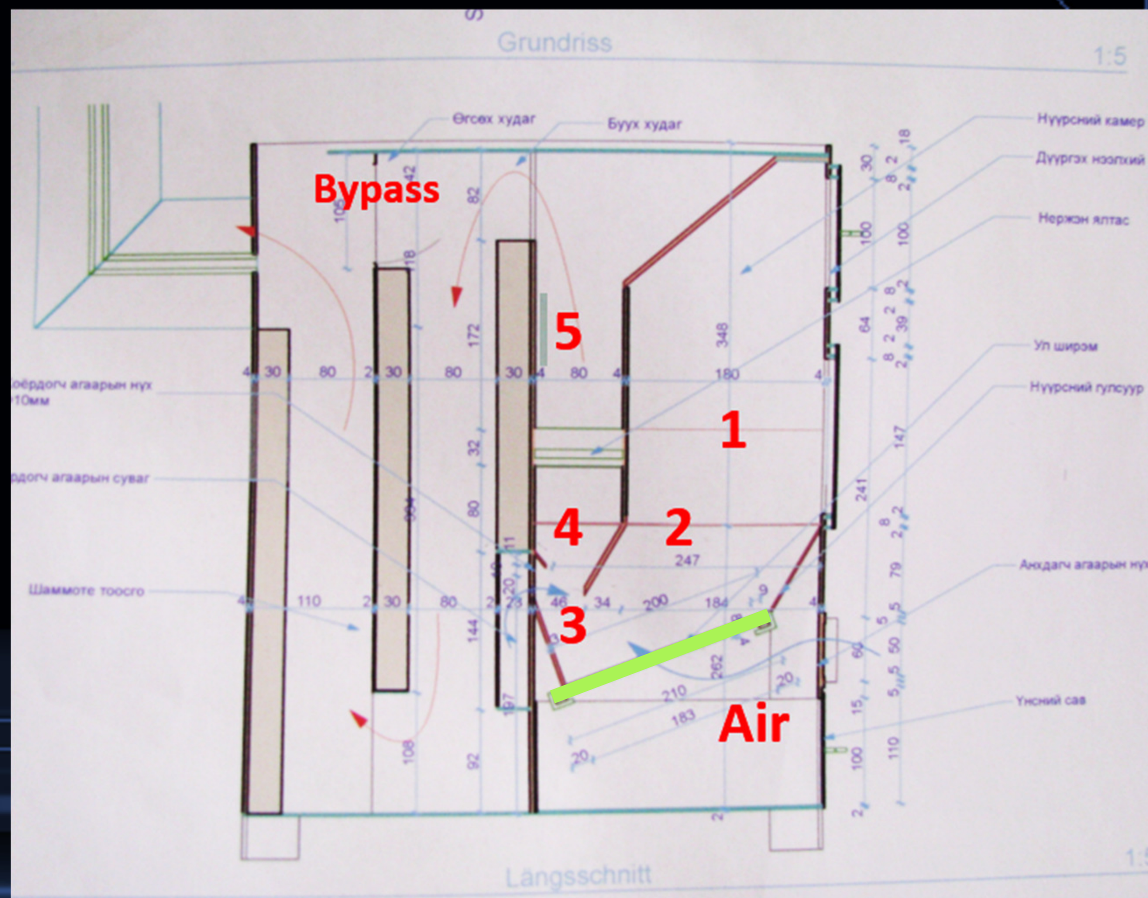
- Heat the coal to dry it
- Pyrolyse the raw coal gently in a low oxygen environment
- "Crack" all the gaseous pyrolysis products to CO, CH_4 and H_2 by thermal decomposition
- Heat the pyrolysed coal to make semi-coked coal (yellow flame)
- Continue heating semi-coked coal to make coke (blue flame)
- Burn the coke with low oxygen to produce CO, CO_2 and H_2
- Burn gases to completion in an O_2-controlled environment (transparent slightly blue and pink flame)

German Furnace – Mongolia 2010

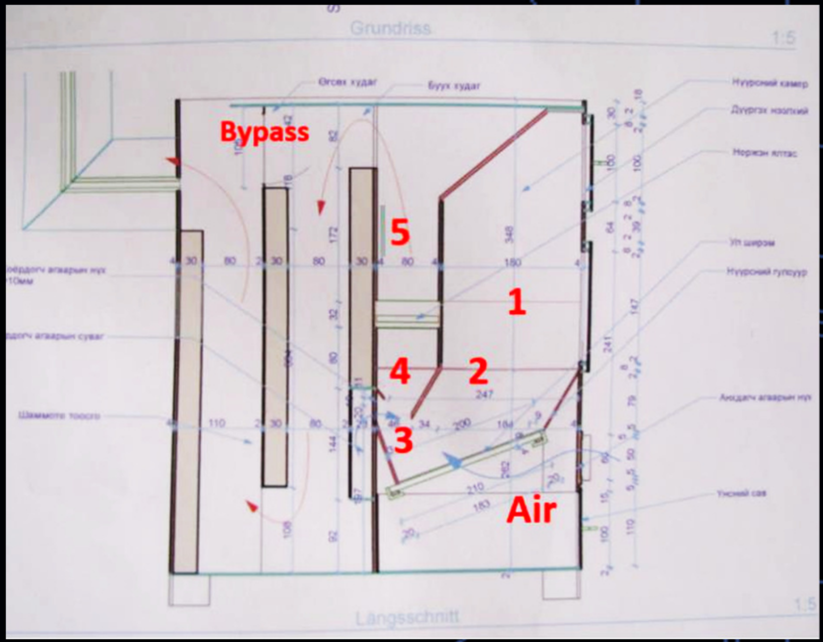
GTZ 6 The Precursor

Miniaturized copy of a steam boiler

1 Hopper
2 Pyrolysis
3 Coke
4 Secondary air
5 Gas burning
Grate is **green**



German Furnace – Mongolia 2010



GTZ 6 The Precursor's Problems

- Difficult to light
- Overheats the local lignite fuels
- High excess air (low gas temperature)
- Low thermal efficiency
- Excessive CO and PM 'sneakage'
- Complex to make – has multiple air channels
- Bypass closes completely ➔ CO and smoke leak through cooking surface
- The original design was not suitable for cooking and broad power control

Crossdraft Stove – Mongolia 2010

The innovation:
GTZ 7.1

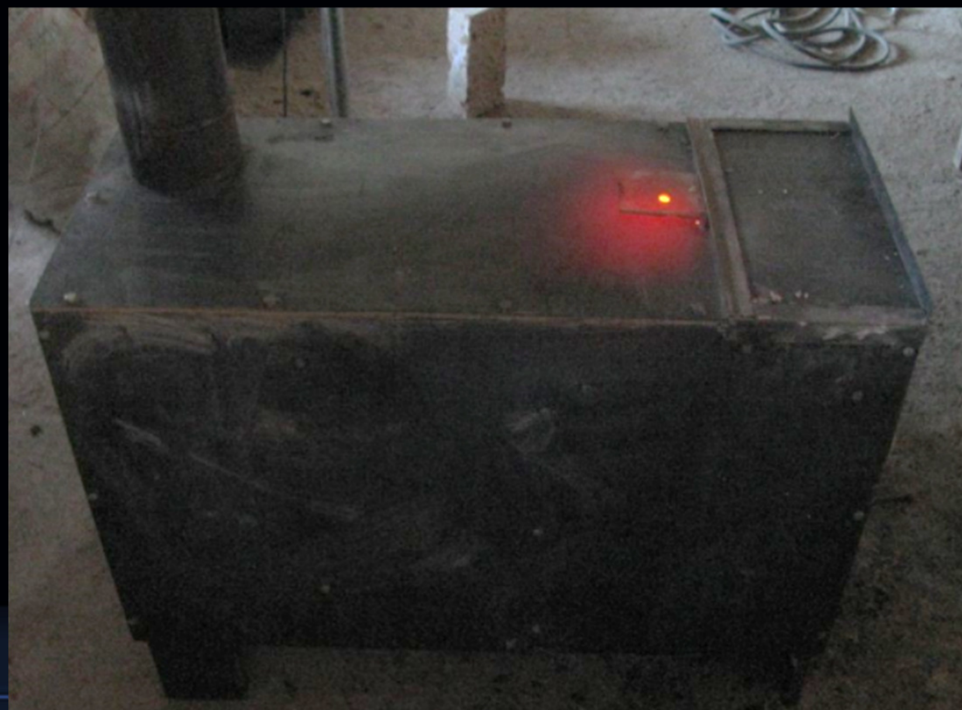
- Vertical hopper
- Ceramic fire box
- Secondary air
- Larger heat exchanger

Crossdraft Heating Stove – Mongolia 2010

GTZ 7.1

Excess Air is under control

➔ high flame temperature



Crossdraft Heating Stove – Mongolia 2010

GTZ 7.2

“The Tractor”

Modular:

Heat only (for heating walls)

Bolt-on rear heat exchanger

Optional bolt-on cooking module

Crossdraft Heating Stove – Mongolia 2011

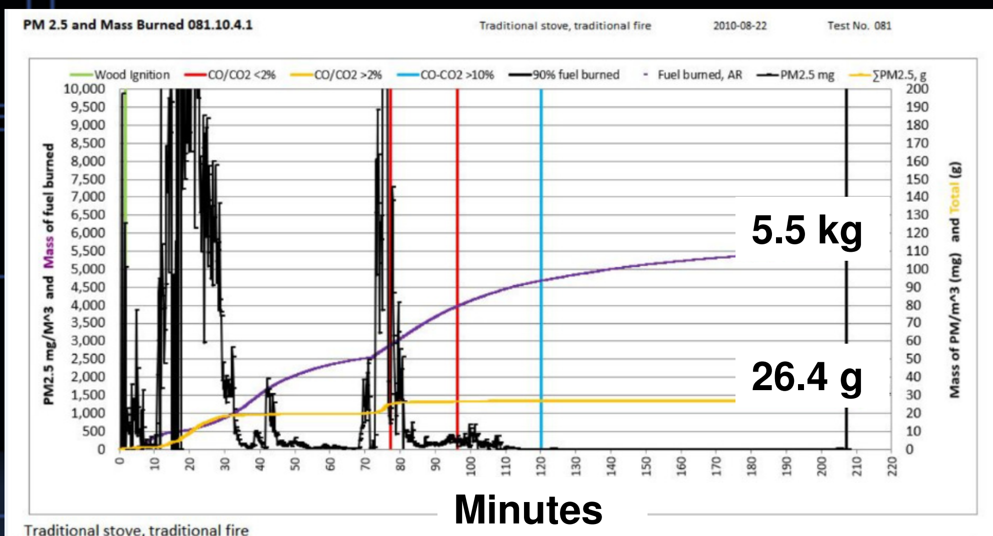
GTZ 7.4 $130

Efficient
Clean-burning
Bolted, very little welding
Integrated body
Easy lighting

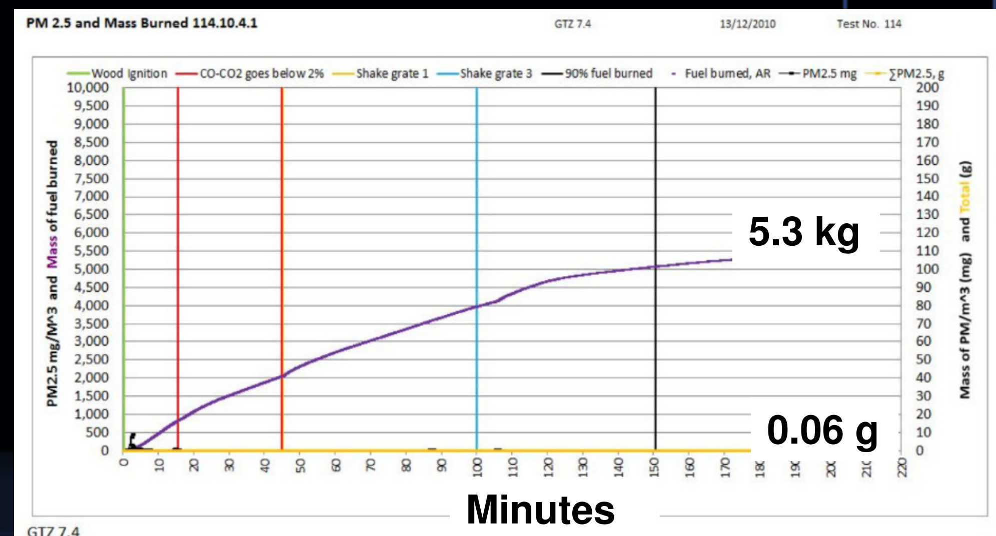
Complicated to make
Over-heats the hopper
Thermal runaway
Limited operating time

Early results: Emissions – Mongolia 2011

Traditional Stove – Nalaikh Coal



GTZ 7.4 Stove – Nalaikh Coal



4,810 mg $PM_{2.5}$ / kg burned

11 mg $PM_{2.5}$ / kg burned

Reduction 99.8%

Crude simplification – Tajikistan 2016

Revived the original GTZ 7.2

CARITAS Switzerland, World Bank, Tajikistan

Refractory bricks: recycled from old homes

Long chimney forms part of the heat exchanger

Refining the construction – Kyrgyzstan 2016

World Bank, Kyrgyzstan

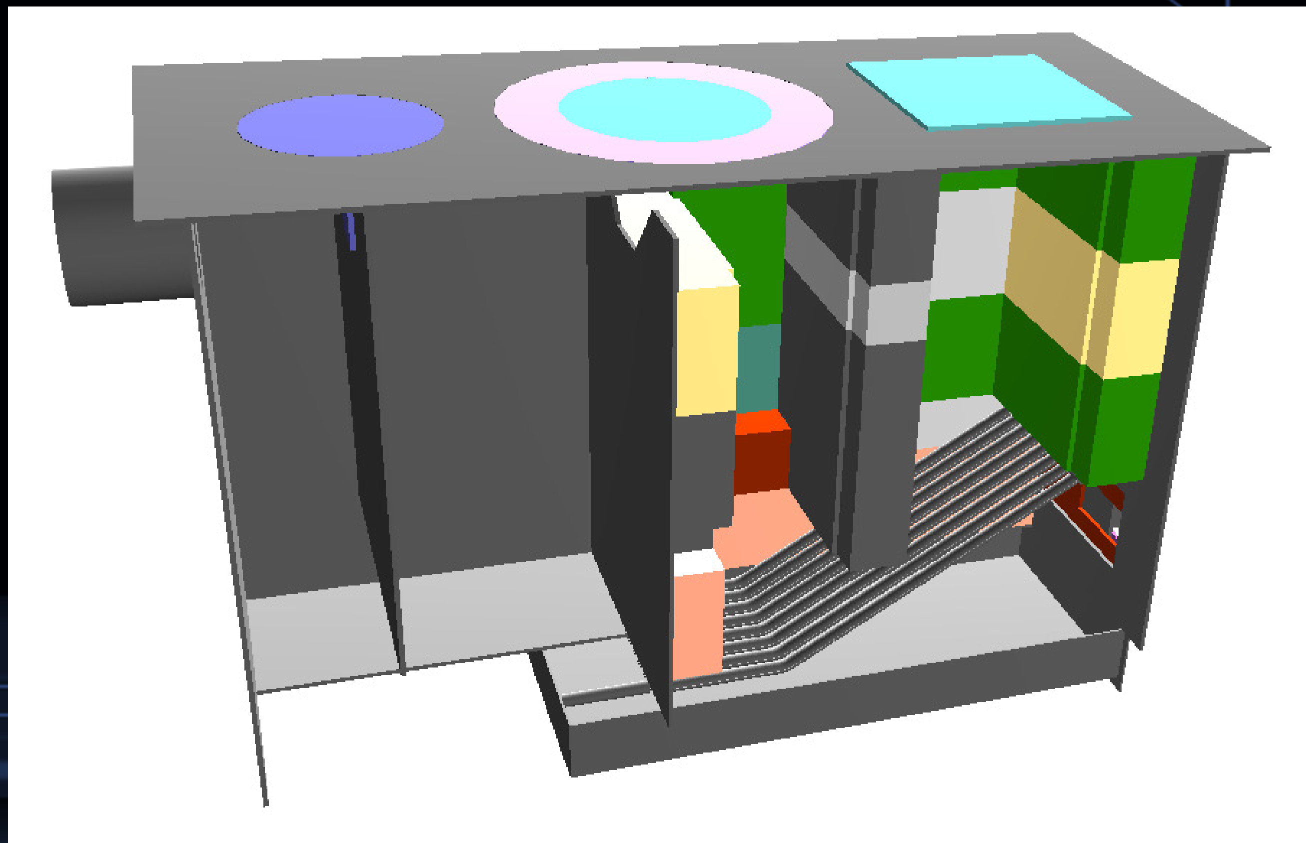
Incorporates 'air bleeder' to drive the chimney draft

Recycled bricks

Two cooking stations

Eight hour burn time

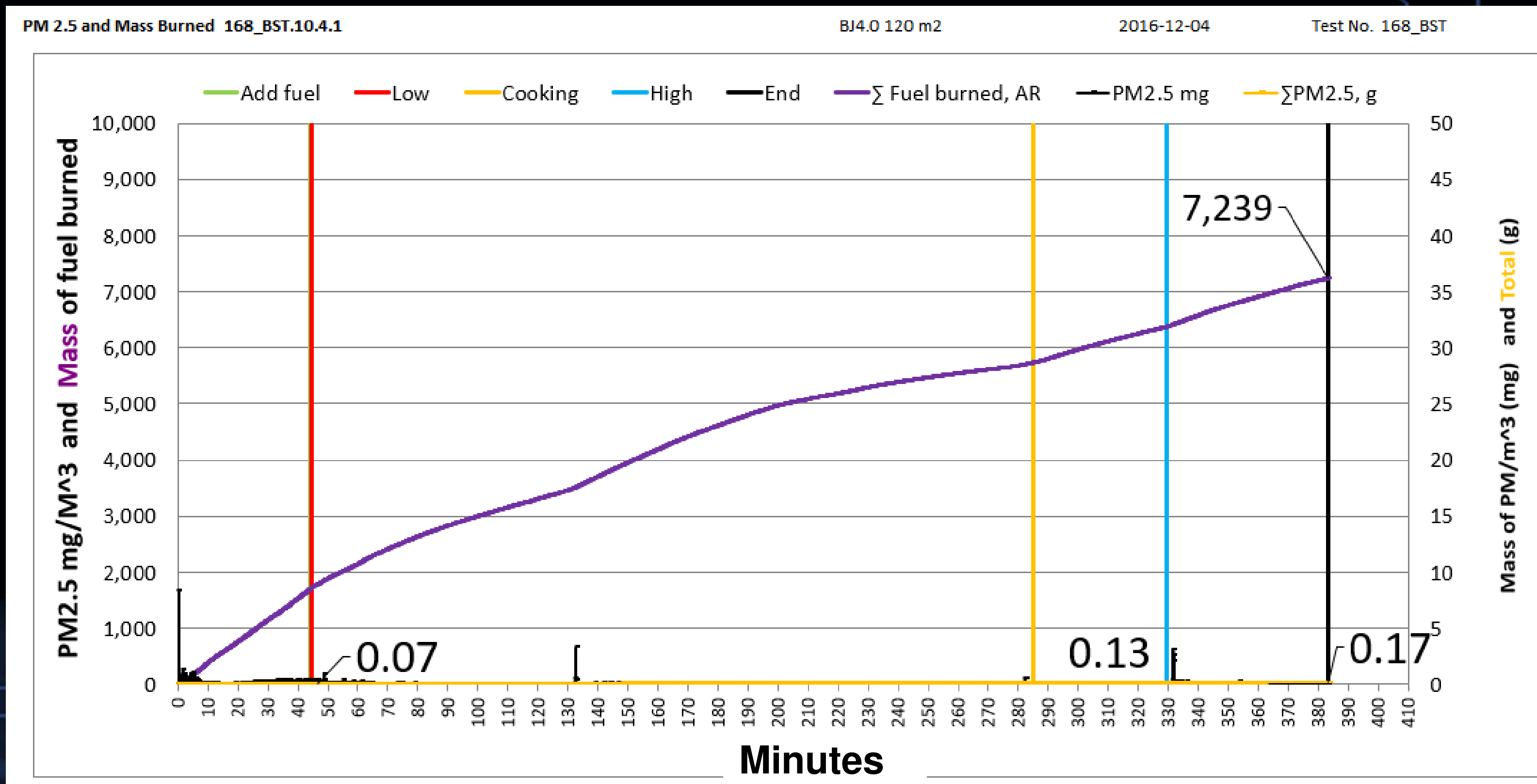
But: Grate assembly difficult to assemble



Refining the construction – TJ4.0 2016

Altanzul's Thesis 2017
CAU, Beijing

Low power:
≈10 mg/hr

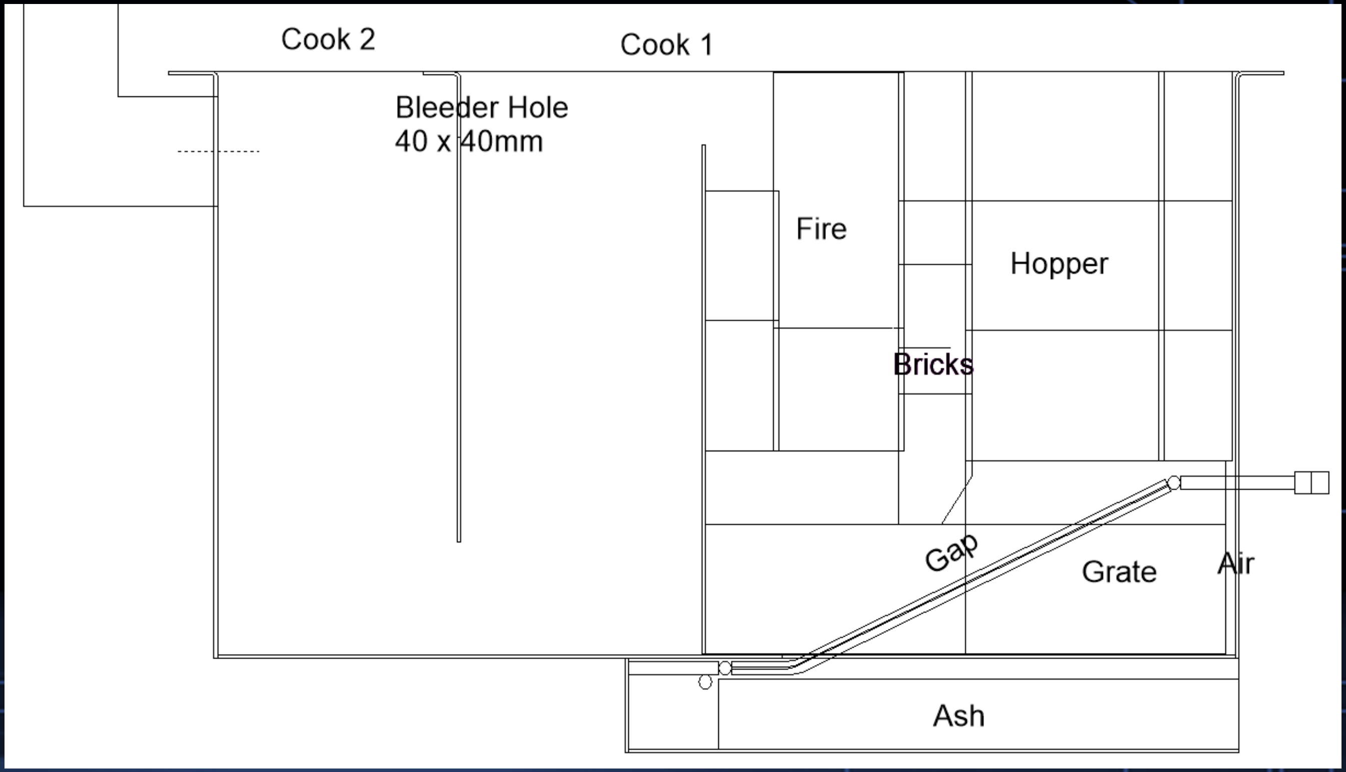


Average 6.8 mg $PM_{2.5}$/kg including ignition

Production Prototype – Kyrgyzstan 2017

World Bank, Kyrgyzstan

- Refractory bricks
- Straight grate
- Increased the grate-bridge gap lowers the excess air
- Bleeder hole
- 1 cooking station
- Multiple cooking/water heating stations
- Strong positive user response



New Features – Kyrgyzstan 2017

World Bank, Kyrgyzstan

Simplified body with metal bending
Downdrafting heat exchanger saves material
Operable bypass for cooking
Bleeder hole retained

1 cooking station 300mm dia.

Crossdraft Stoves – South Africa 2017

North-West University, Potchefstroom

1 Cooking station

1 braai station

Commercial refractory bricks

Phosphate Ceramics – Mongolia 2017

MN4.1 Heated Hopper

Plastic refractory ceramics

Large cooking station

High alumina material bonded with aluminium dihydrogen phosphate:

- **No kiln needed**
- **1300°C resist**

Further refinements – Kyrgyzstan 2017

Jalalabad, Kyrgyzstan

Cast Iron top deck

Machined hopper cover to seal the top

Further refinements – Kyrgyzstan 2017

Jalalabad, Kyrgyzstan
Cast Iron Top, rings hopper cover

Rotate hopper cover to clear smoke before refueling

Further refinements – Kyrgyzstan 2017

Bishkek, Kyrgyzstan

More sophisticated refractory brick processing

Custom made local refractory bricks

Field Evaluations – Kyrgyzstan 2018

Naryn Town, Kyrgyzstan

- 3000m altitude

Low Pressure Boiler for hot water heating systems

- Heats 50-70 sq metres in -30˚C weather
- 12 hr burn time often reported

- Excessively high efficiency is a problem with metal chimneys – only brick chimneys can cope with condensation.

Further refinements – Mongolia 2018

Ulaanbaatar Clear Air Project UB-CAP

Six cast iron Bridges of different heights

Final Product MN4.2 – Mongolia 2018

MN4.2 Mongolian raw coal burning heating and cooking stove

- Crossdraft coal gasifier
- Plastic refractory ceramics
- Cast iron critical parts
- Highly controllable power
- 12-14 hr burn at low power
- One-touch cooking control
- Convective cooling of the hopper
- 80% space heating efficiency
- Advanced combustor geometry
- Produced by local artisans

The Death Of A Paradigm

Incidental emissions decoupled from mass of coal burned

The generalizations are being overturned include:

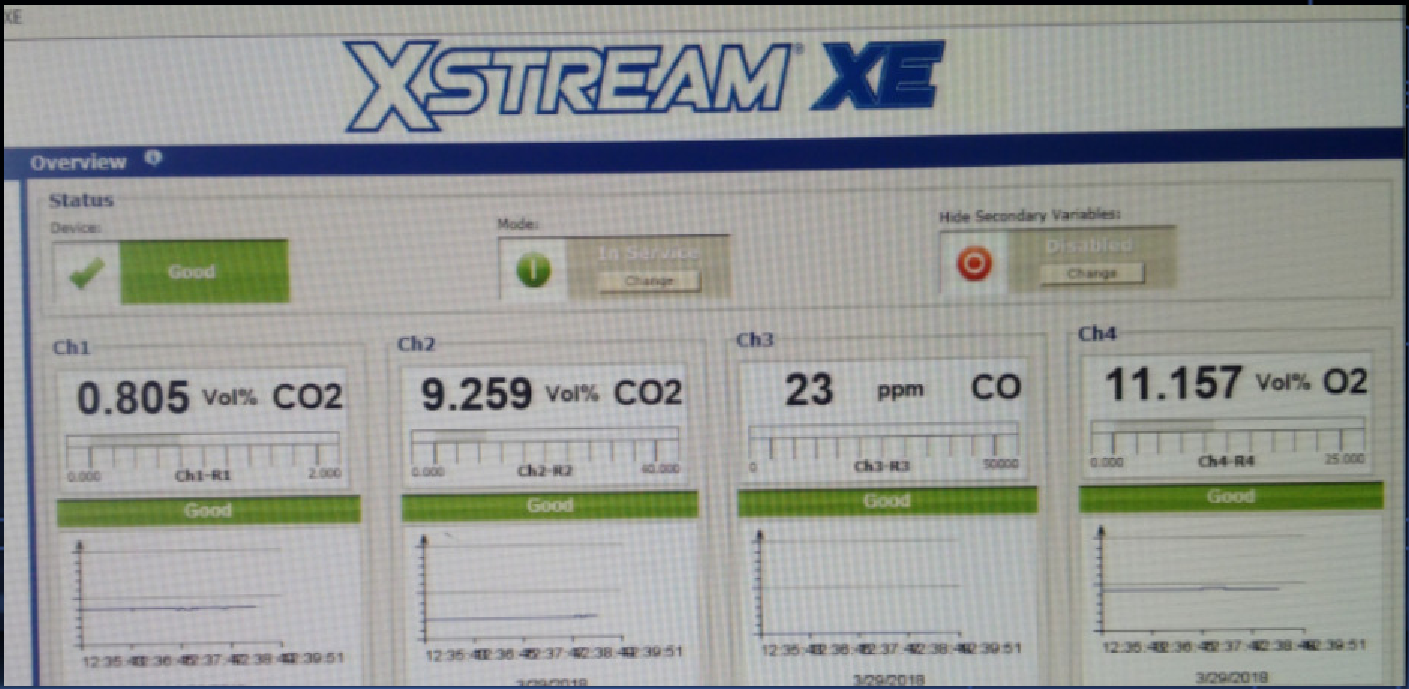
- $PM_{2.5}$ emissions from small scale coal combustion was said to be directly related to tons burned (EPA, EU, WHO, GBD, HAPIT, ICCI)
- Coal smoke, CO, PAH, VOC's etc said to be **inherent** in the fuel
- Black Carbon pollution assumed to be the inevitable consequence of coal combustion
- Coal cannot, by its nature, be burned cleanly or completely

The Death Of A Paradigm

MN4.2 Carbon combustion efficiency: 99.97%

12 kW$_{(T)}$
14 hr burn
80% Efficient

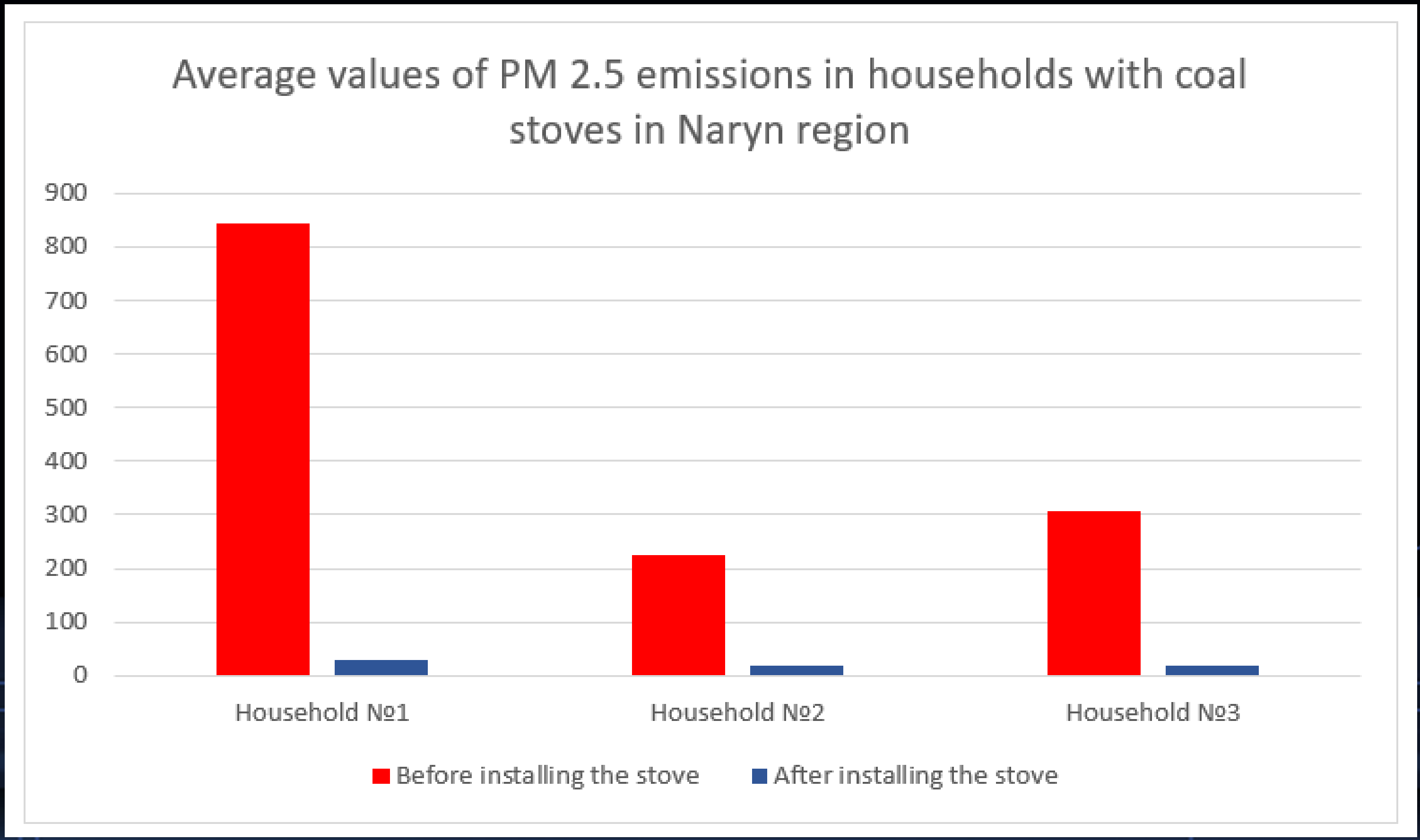
Channels:
CO_2 in the diluter [%]
CO_2 in stack [%]
CO in the stack [ppm]
O_2 in the stack [%]



The Death Of A Paradigm

- New combustor designs practically eliminate smoke
- Lab and field tests show dramatic improvements in performance
- Independent monitoring of IAQ shows large improvements in health:
  - eliminates chronic underheating
  - healthy living conditions
  - significant fuel savings

The Death Of A Paradigm



The Death Of A Paradigm

№	Symptoms	Before installing the stove	After installation of stoves, 2nd month
1	Headache	65%	0%
2	Irritated eyes	70%	0%
3	Ear infections	0%	0%
4	Irritated throat	72%	3%
5	Chest tightness	16%	0%
6	Nausea	8%	0%
7	Fatigue	66%	0%
8	Dizziness	11%	0%
9	Irritability	58%	0%

The Death Of A Paradigm

Stranded technologies

- Electrostatic precipitators
- In-chimney particle filters
- Catalytic converters
- Computer-controlled combustion
- Forced air
- Lambda control
- Semi-coked coal (raw coal is usually cleaner-burning)

Supporting The New Paradigm

Required technologies

- Refractory materials – great success with phosphate bonded high alumina which is cold-setting
- Cast iron grate, bridge, top, covers
- Fuel sizing and sorting 15-25mm mixed range probably best (12 kW)

Supporting The New Paradigm

Overturning the claim of "equitoxicity" of $PM_{2.5}$

- Equitoxicity has no physical or medical basis – claim was never true
- Particulate emissions have not yet been characterised (lab problem)
- MN4.2 PM probably consists mostly of fly-ash (engineering problem)
- The incredulity factor - difficulty accepting how cleanly "smoky coals" can be consistently burned (Witbank, Shanxi, Shenmu, Nalaikh)
- User acceptance easier than changing producer habits (training problem)
- Multiple localized models needed that consider fuel and users (designers)

Online videos

- https://www.youtube.com/watch?v=ZX7ExIRXsRc (TV show)
- http://www.bbc.com/kyrgyz/media-39377945 (BBC Docu)
- http://www.worldbank.org/en/news/video/2017/05/04/magic-stoves-for-cleaner-air-better-health-and-more-effective-heating-in-the-kyrgyz-republic (World Bank Cartoon)

Relevance to South Africa

- Poor households on the highveld rely on coal for winter space heating and year-round for cooking.
- High prices for electricity, LPG mitigate against total replacement of coal as a perceived “dirty” fuel.
- A model of the crossdraft stove suited to South African highveld users and fuels is in development at North-West University as part of the Highveld Atmospheric Emissions Offset programme.
- Preliminary tests on Witbank coal conducted in 2017 show good potential to meet social norms and reduced smoke emissions.

Acknowledgements

- North-West University, Potchefstroom
- ESKOM
- Ulaanbaatar Clean Air Project (UB-CAP)
- Stove Development Centre, Ulaanbaatar City
- World Bank Clean Stove Initiative (CSI) – Mongolia, Kyrgyzstan, Tajikistan, China
- China Agricultural University, Beijing