

Pellet-fed gasifier stoves approach gas-stove like performance during in-home use in Rwanda

Wyatt M. Champion*, **Andrew P. Grieshop**

Environmental Engineering, North Carolina State University, USA

go.ncsu.edu/grieshop_lab

Funding:

*now an ORISE postdoctoral researcher at US EPA



NC STATE
UNIVERSITY

Partner:



30 May 2019 – Pathways 2 Clean Cooking 2050 – Wexford, Ireland

Full paper: go.ncsu.edu/champion-and-grieshop

This is an open access article published under an ACS AuthorChoice [License](#), which permits copying and redistribution of the article or any adaptations for non-commercial purposes.



Article

Cite This: *Environ. Sci. Technol.* XXXX, XXX, XXX–XXX

pubs.acs.org/est

ENVIRONMENTAL
Science & Technology

Pellet-Fed Gasifier Stoves Approach Gas-Stove Like Performance during in-Home Use in Rwanda

Wyatt M. Champion[†] and Andrew P. Grieshop^{*ID}

Department of Civil, Construction, and Environmental Engineering, North Carolina State University, Raleigh, North Carolina 27695, United States

Inyenyeri: a focus on fuel, stove and household

Implementer: Inyenyeri, a Rwandan Social Enterprise

- Mimi Moto stoves and **locally-produced biomass fuel pellets**
- Innovative business model: **Pay/trade for pellets, get free stove**
- **Pellets compete with charcoal (purchased) and fuelwood (gathered)**
- Large **emphasis on customer service** and follow-up
- See Jagger and Das, 2018, *ESD* for more...

Stove: Mimi Moto

- Pellet-fed forced-draft cookstove
- Lab tests: ISO Tier-4 for emissions and efficiency measurements (CSU)

Location: Gisenyi, Rwanda (small city)

- Headquarters and pilot roll-out

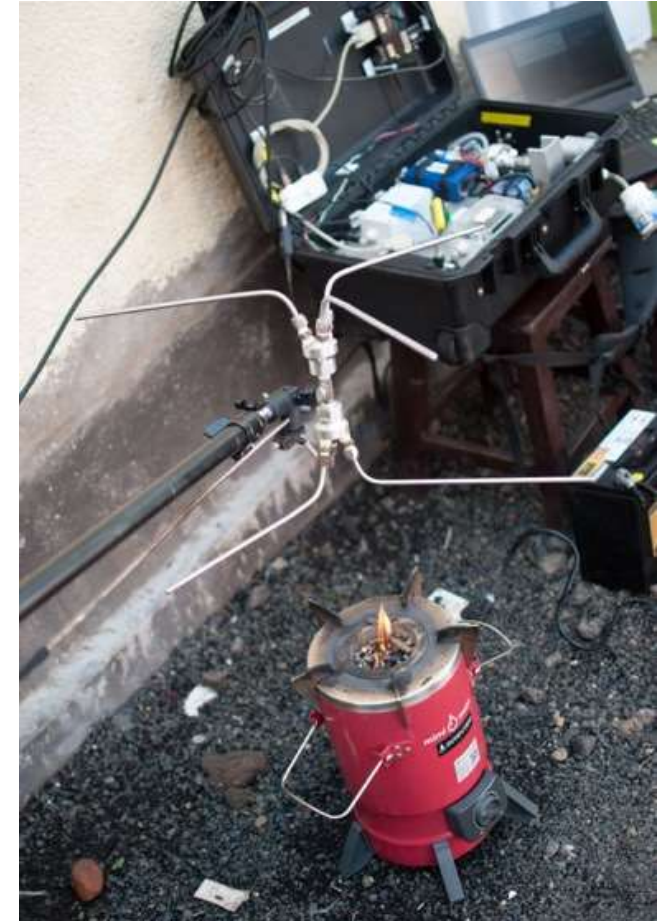


Photo: trendhunter.com



In-home measurements of Mimi Moto and baseline stoves

- 'Randomized' Household Selection
 - Pellet (~70% urban, ~30% rural)
 - Wood (100% rural)
 - Charcoal (100% urban)
 - 2 'seasons', testing same households (Dec '17, May '18)
- Sampling Equipment
 - Stove Emission Measurement System (STEMS)
 - Plume-sampling probe
 - Real-time:
 - CO and CO₂
 - PM_{2.5} Scattering and Absorption (Aethlabs μ Aeth)
 - Integrated PM_{2.5} filter samples:
 - Mass, and Organic and Elemental Carbon (OC/EC)
- Carbon-balance method for emission factors
- Uncontrolled Cooking Test (UCT)
 - Participant cooks a meal of their choice with (ideally) minimal disruption



Mimi Moto and Sampling Equipment



Pellet
n=59

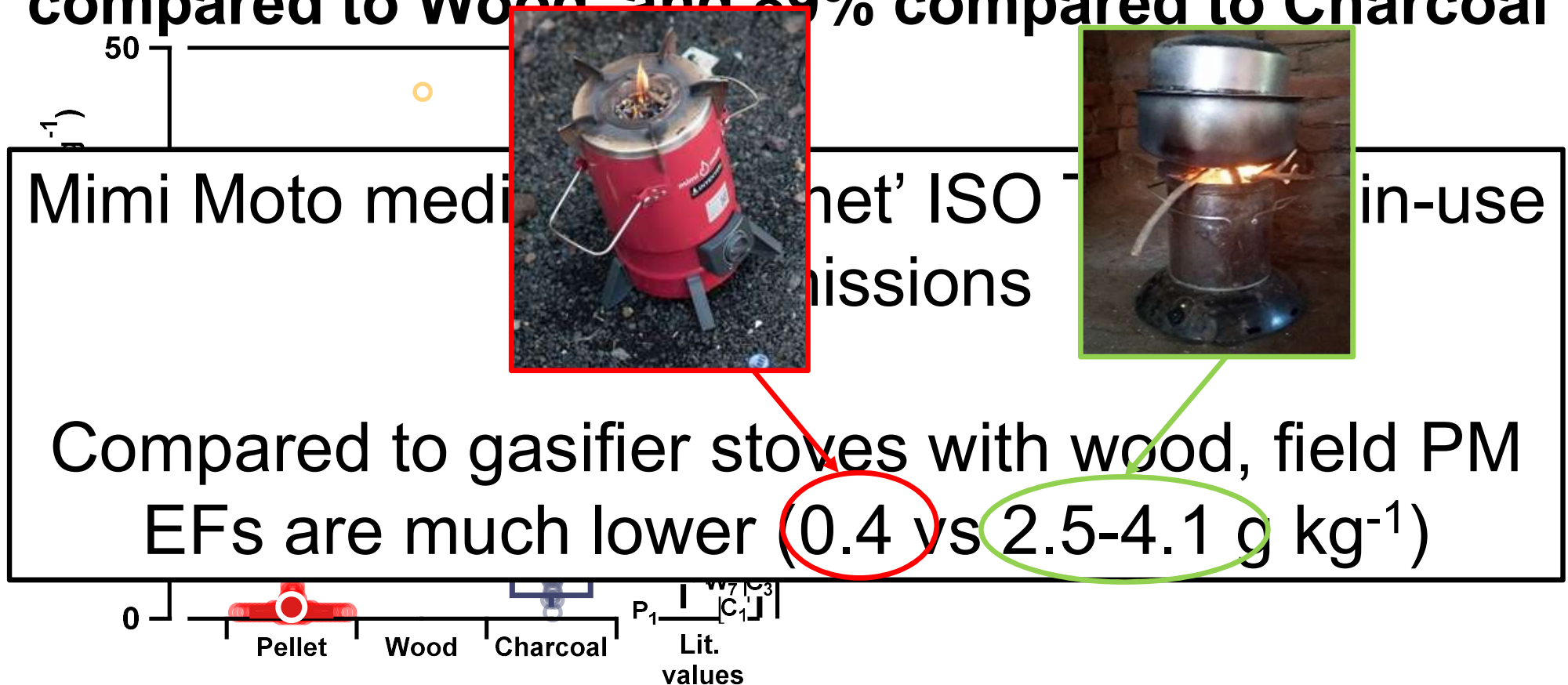


Wood
n=16



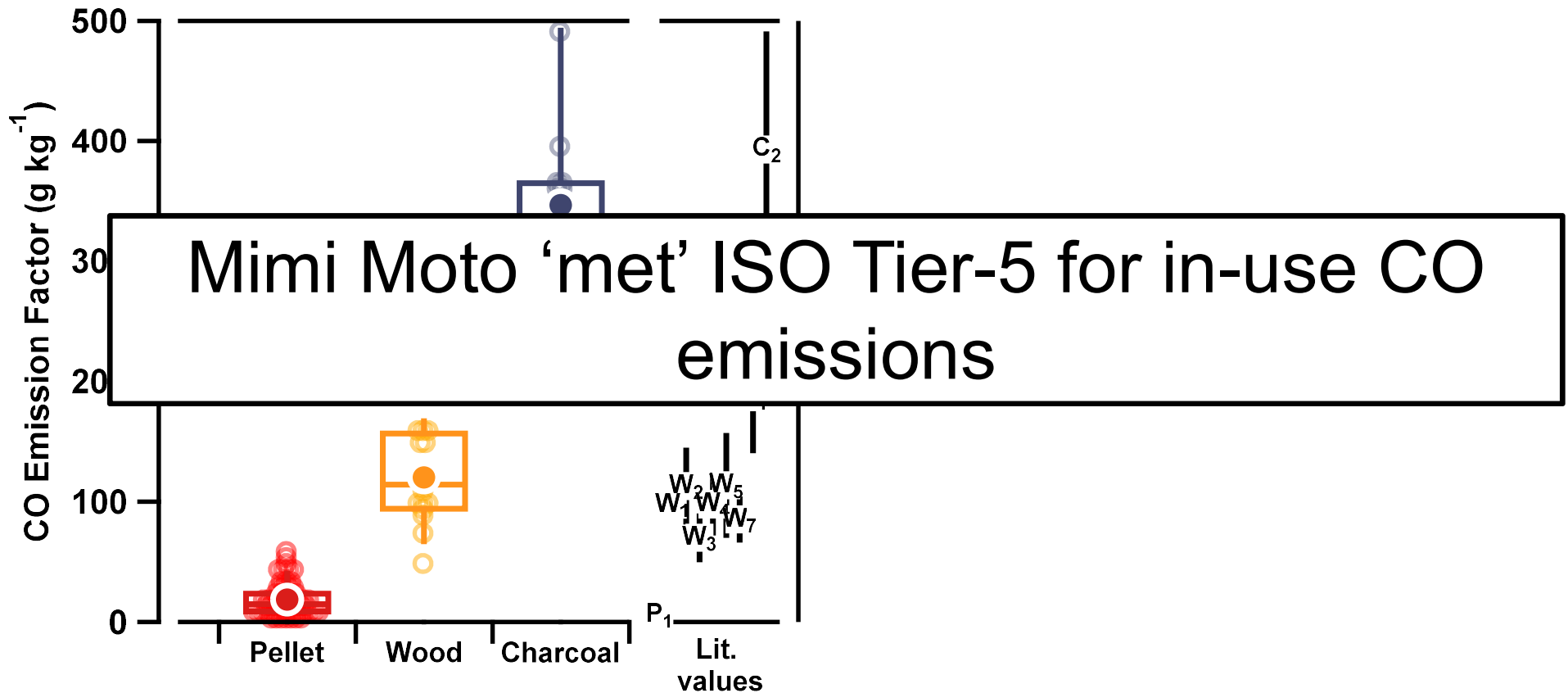
Charcoal
n=16

Pellet stoves reduce PM_{2.5} emissions by 97% compared to Wood, and 89% compared to Charcoal



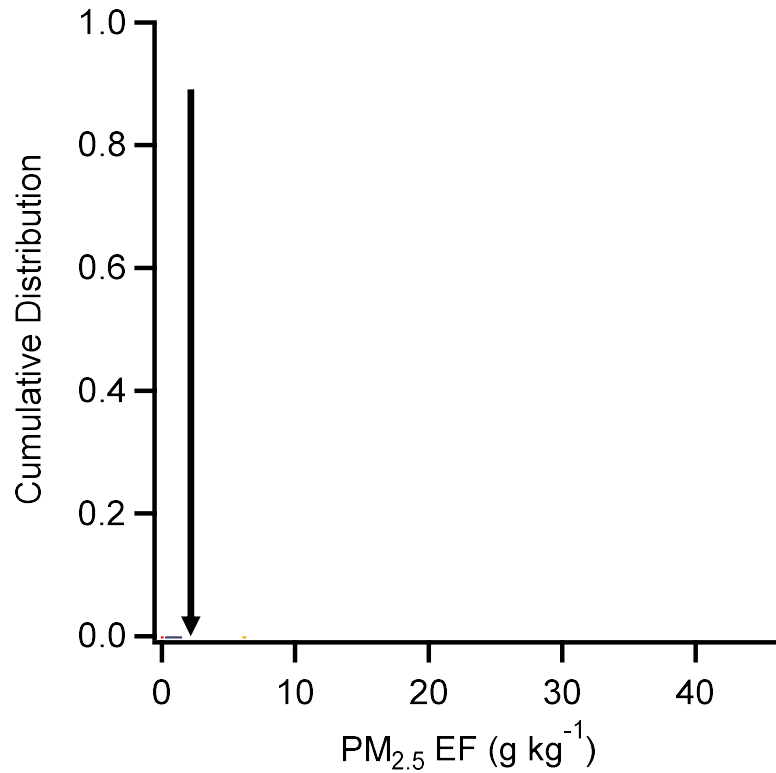
5. Global Alliance for Clean Cookstoves, 2018; 6. Garland et al., 2017; 7. Roden et al., 2009; 8. Coffey et al., 2017; 9. Wathore et al., 2017; 10. Rose Eilenberg et al., 2018; 11. Lefebvre 2016; 12. Grieshop et al., 2017

...and CO emissions by 87% compared to Wood, and 96% compared to Charcoal

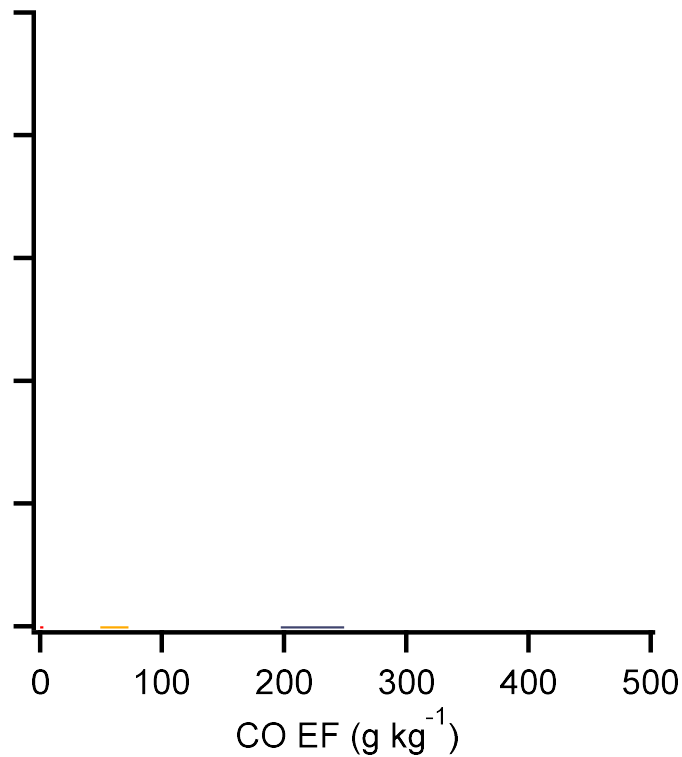


In general, pellet stoves work great, but not always!

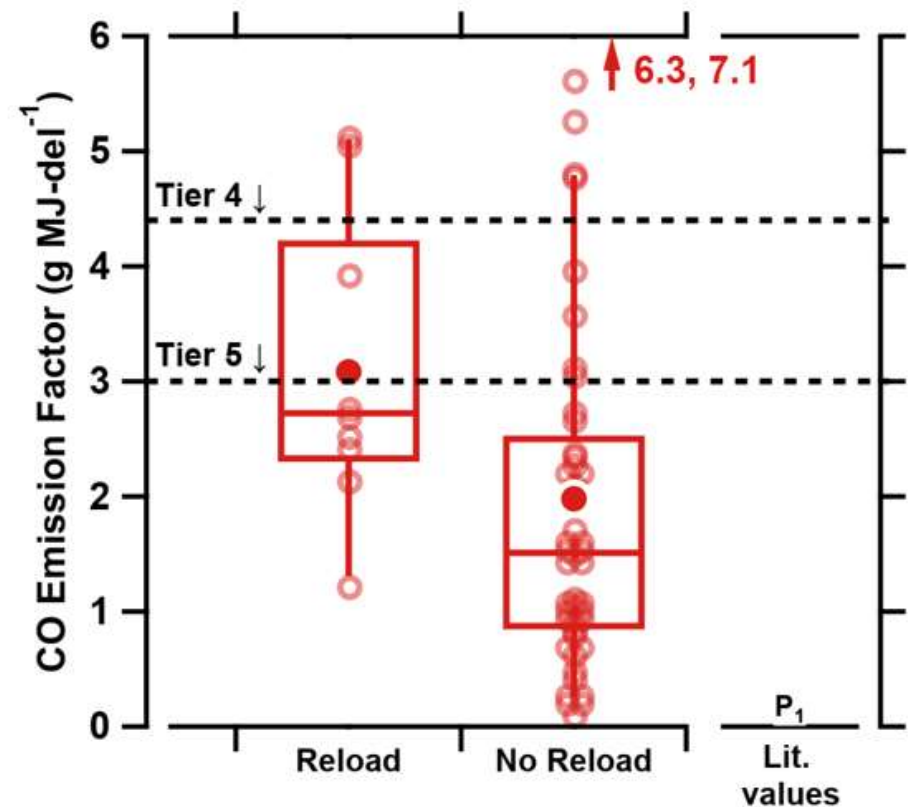
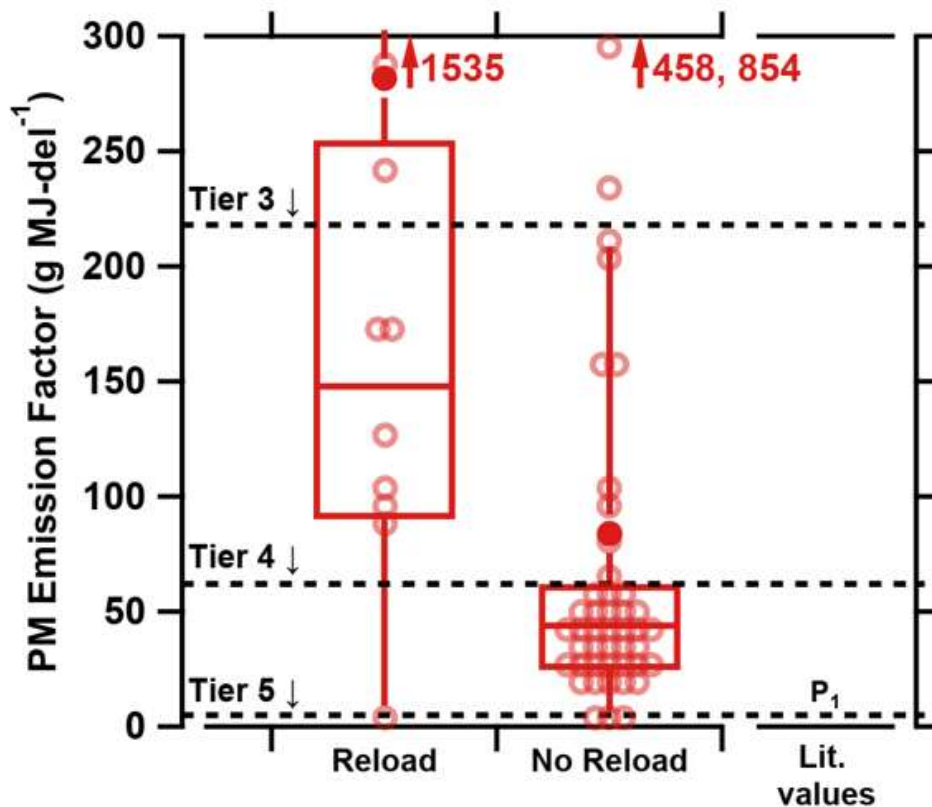
PM_{2.5} EF Distribution



CO EF Distribution



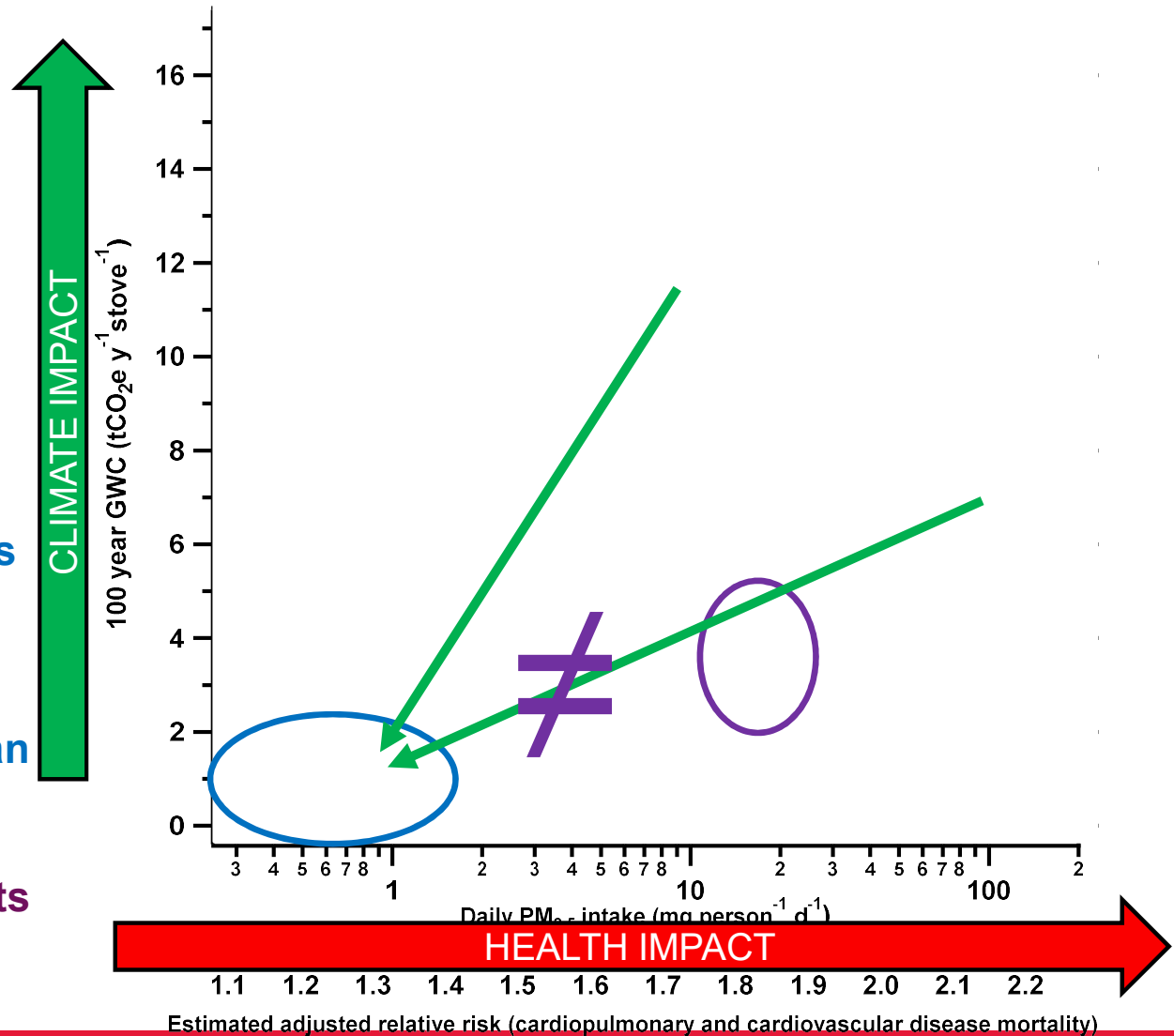
Refueling associated with higher PM and CO emissions (also start-up and misoperation)



Estimated pellet stove health and climate benefits *approach* LPG

Takeaways:

- 1) Huge potential co-benefits implied by field emission performance of pellet stove relative to traditional stoves/fuels.
- 2) Climate benefits match/surpass LPG, depending on feedstock renewability and energy for pellet production. Health impacts are slightly greater than LPG.
- 3) Use of pellets (homogenous fuel) leads to enormous benefits relative to gasifier with 'gathered' biomass.



Thank you! Questions?

Acknowledgements:

Thanks to all study participants!

Funding: Climate and Clean Air Coalition and
Clean Cooking Alliance

Logistics: Inyenyeri management and staff (esp.
Eric Reynolds, Ephrem Rukundo, Bertille
Kampire, Doreen Murerwa), Didier Gashema
(field assistant), Lambert Habimama (field
assistant)

NCSU Lab support: Maksim Islam, Stephanie
Eberly, Ky Tanner, Amanda Vejins, and Andrew
Whitesell



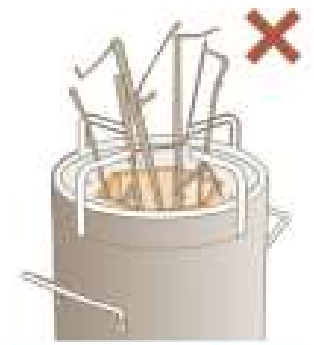
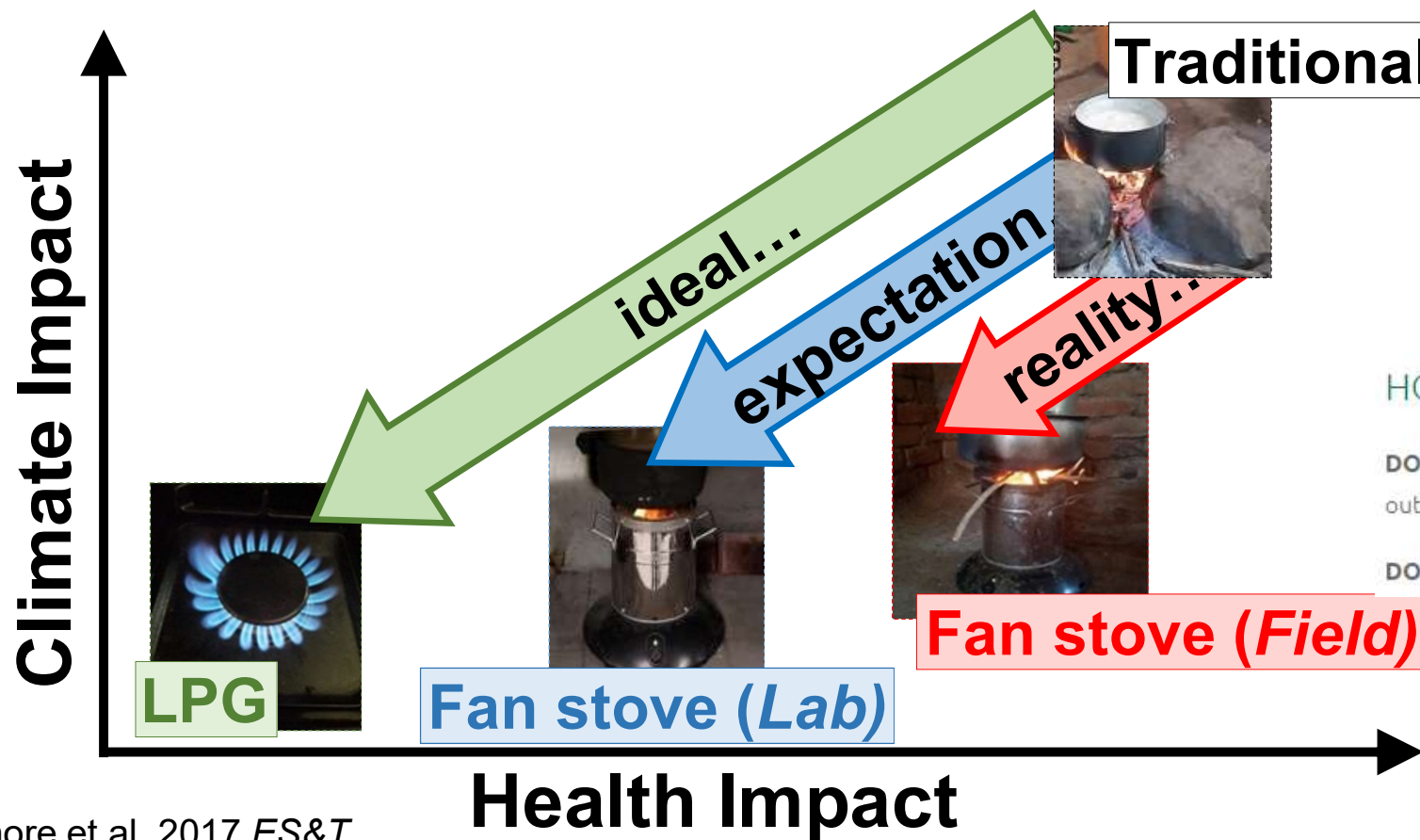
Web: go.ncsu.edu/grieshop_lab

In summary...

- **Significant** reductions of PM_{2.5}, OC, EC, and CO emission factors and rates observed during in-home testing in Gisenyi, Rwanda
- Mimi Moto 'met' **Tier-4 for PM_{2.5}** and **Tier-5 for CO**
- However, ~10% of tests were “super-emitters”, with emissions **on-par with traditional stoves types**
 - Dead stove battery, refueling, or kindling ignition
- During poor performance, pellet stoves emitted high PM and BC primarily following **ignition**, and near the end of test (**refueling/burnout**)
- Estimated health and climate **cobenefits of pellet stoves approach those from a modern fuel/stove (LPG)**

Extra slides

Ultra-low cooking emissions required for health and climate benefits, but not seen in 'real-world' use of biomass stoves



HOW TO AVOID SMOKE

DO NOT use long pieces of wood that stick out above the burning chamber.

DO NOT fill the stove to the rim or above.

<http://www.africancleanenergy.com/>

Wathore et al, 2017 *ES&T*

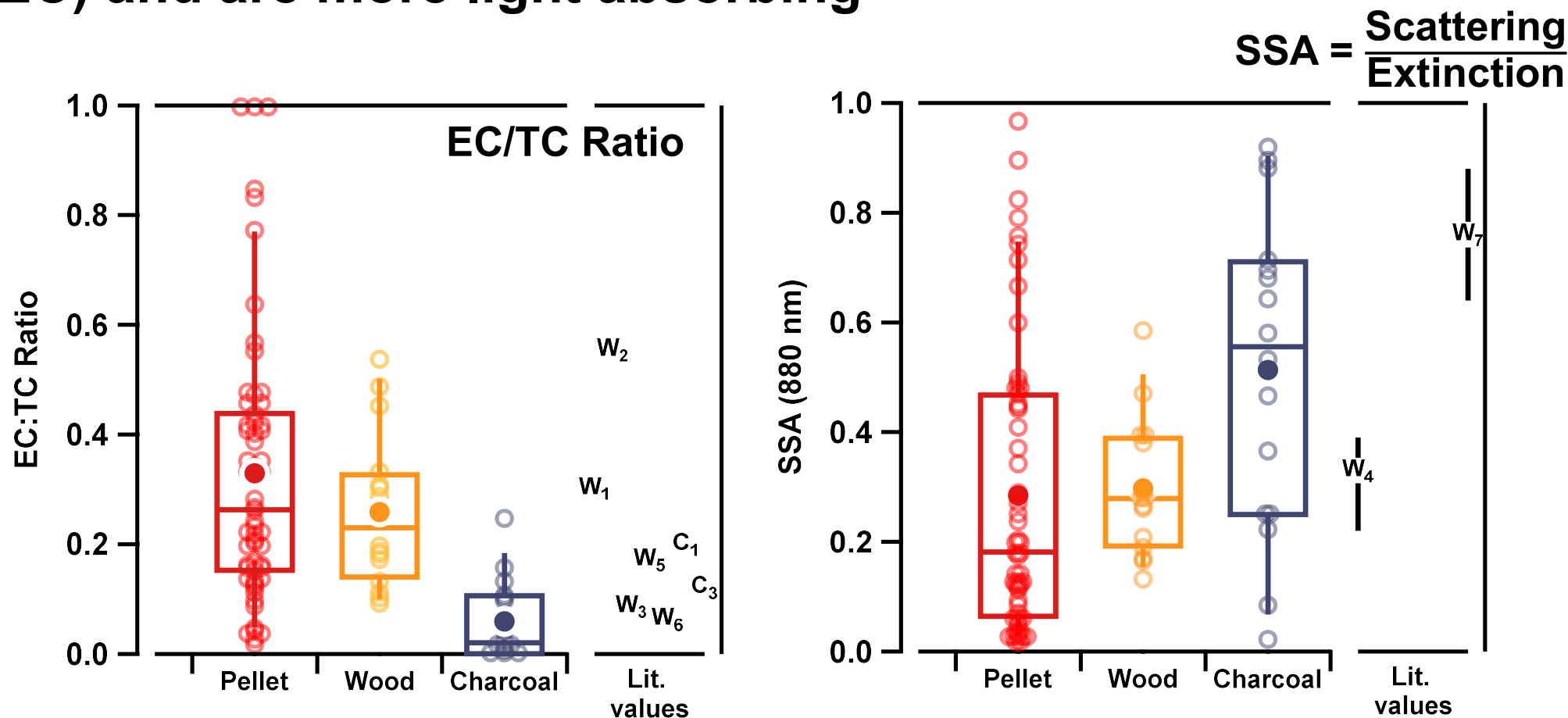
Rwanda, the land of a thousand hills and a million smiles

- Located in East Africa
- Most densely populated nation on the continent
- 95% of population relies on solid biomass for cooking.³
 - Wood is dominant in rural
 - Wood and charcoal split in urban
- Lower respiratory infection is the leading cause of disability-adjusted life years lost (DALYs) in Rwanda⁴.

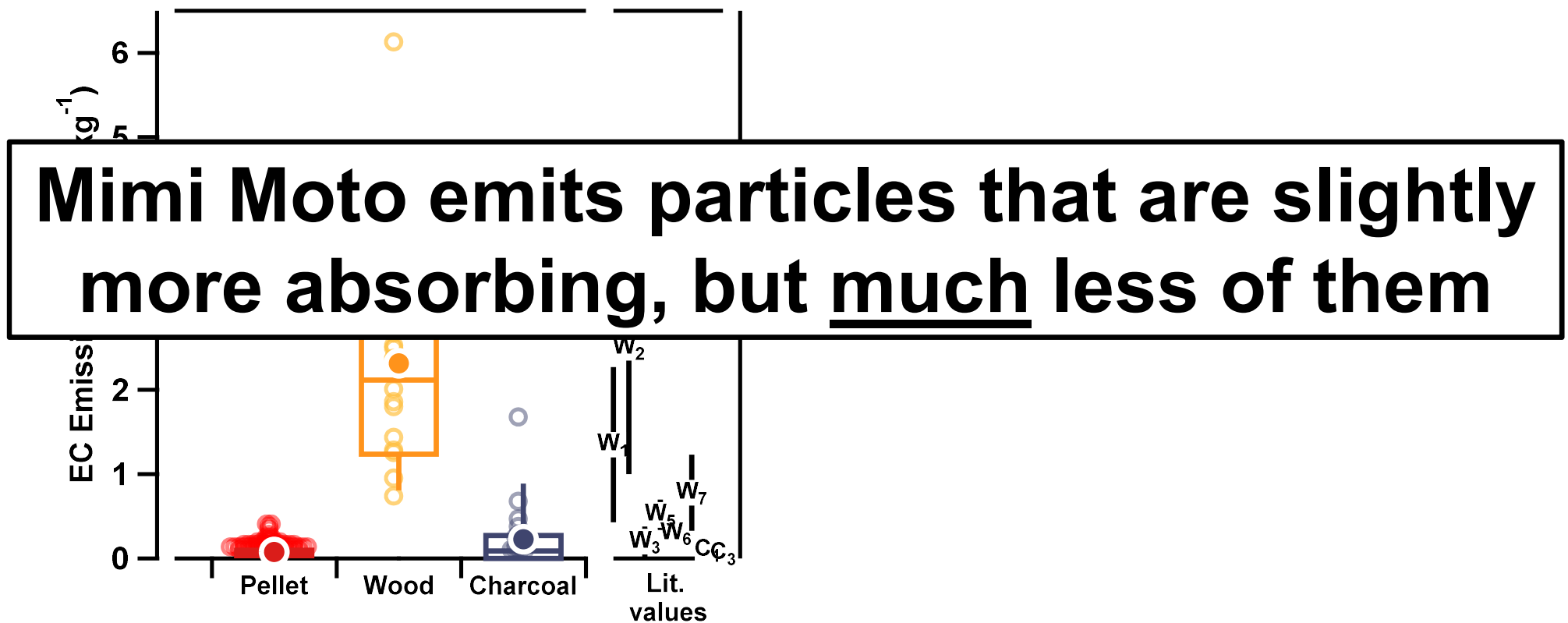


3. Global Alliance for Clean Cookstoves, 2012; 4. Institute for Health Metrics and Evaluation, 2018

Pellet PM contains greater proportion of elemental carbon (EC) and are more light absorbing



EC emission factors and rates from pellet stoves are extremely low



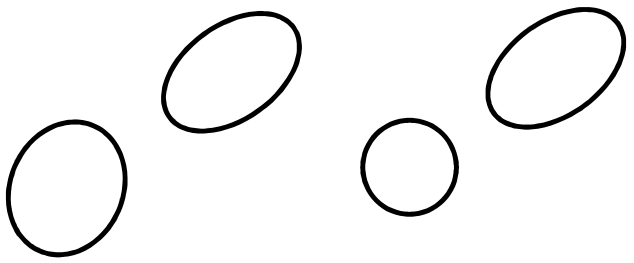
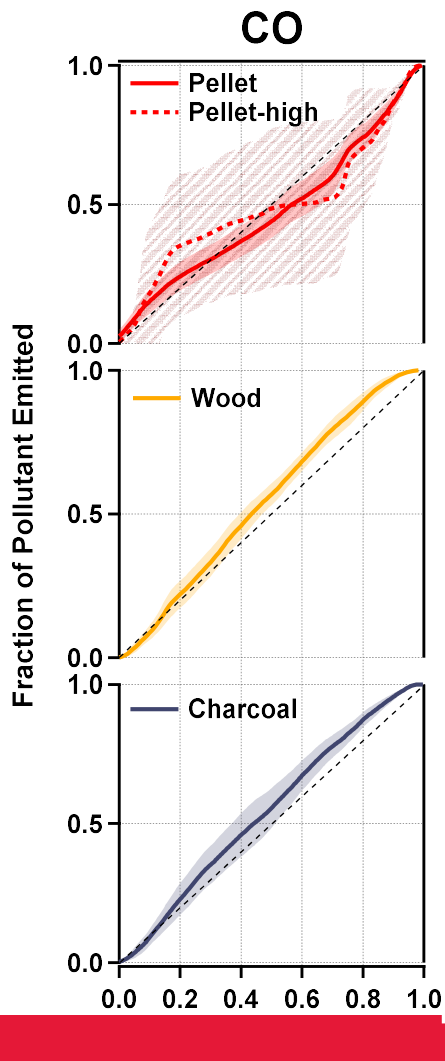
STove Emissions Measurement System (STEMS)



References

- Chen, Yanju, Christoph A. Roden, and Tami C. Bond. 2012. "Characterizing Biofuel Combustion with Patterns of Real-Time Emission Data (PaRTED)." *Environmental Science and Technology* 46 (11): 6110–17. <https://doi.org/10.1021/es3003348>.
- Coffey, Evan R., Didier Muvandimwe, Yolanda Hagar, Christine Wiedinmyer, Ernest Kanyomse, Ricardo Piedrahita, Katherine L. Dickinson, Abraham Oduro, and Michael P. Hannigan. 2017. "Implications of New Emission Factors and Efficiencies from In-Field Measurements of Traditional and Improved Cookstoves." *In Review* 51 (21): 12508–17. <https://doi.org/10.1021/acs.est.7b02436>.
- Forouzanfar, Mohammad H., Lily Alexander, H. Ross Anderson, Victoria F. Bachman, Stan Biryukov, Michael Brauer, Richard Burnett, et al. 2015. "Global, Regional, and National Comparative Risk Assessment of 79 Behavioural, Environmental and Occupational, and Metabolic Risks or Clusters of Risks in 188 Countries, 1990-2013: A Systematic Analysis for the Global Burden of Disease Study 2013." *The Lancet* 386 (10010): 2287–2323. [https://doi.org/10.1016/S0140-6736\(15\)00128-2](https://doi.org/10.1016/S0140-6736(15)00128-2).
- Garland, Charity, Samantha Delapena, Rajendra Prasad, Christian L'Orange, Donee Alexander, and Michael Johnson. 2017. "Black Carbon Cookstove Emissions: A Field Assessment of 19 Stove/Fuel Combinations." *Atmospheric Environment* 169: 140–49. <https://doi.org/10.1016/j.atmosenv.2017.08.040>.
- Global Alliance for Clean Cookstoves. 2012. "Global Alliance for Clean Cookstoves: Rwanda Market Assessment."
- . 2018. "Clean Cooking Catalog: Mimi Moto." 2018. <http://catalog.cleancookstoves.org/stoves/434>.
- Grieshop, Andrew P., Grishma Jain, Karthik Sethuraman, and Julian D. Marshall. 2017. "Emission Factors of Health- and Climate-Relevant Pollutants Measured in Home during a Carbon-Finance-Approved Cookstove Intervention in Rural India." *GeoHealth* 1 (5): 222–36. <https://doi.org/10.1002/2017GH000066>.
- Grieshop, Andrew P., Julian D. Marshall, and Milind Kandlikar. 2011. "Health and Climate Benefits of Cookstove Replacement Options." *Energy Policy* 39 (12): 7530–42. <https://doi.org/10.1016/j.enpol.2011.03.024>.
- Institute for Health Metrics and Evaluation. 2018. "Country Profile: Rwanda." 2018. <http://www.healthdata.org/rwanda>.
- Lai, Alexandra M., Ellison Carter, Ming Shan, Kun Ni, Sierra Clark, Majid Ezzati, Christine Wiedinmyer, Xudong Yang, Jill Baumgartner, and James J. Schauer. 2019. "Chemical Composition and Source Apportionment of Ambient, Household, and Personal Exposures to PM_{2.5} in Communities Using Biomass Stoves in Rural China." *Science of the Total Environment* 646: 309–19. <https://doi.org/10.1016/j.scitotenv.2018.07.322>.
- Lefebvre, Olivier. 2016. "Household Air Pollution Study Part 1 Black Carbon Emission Factor Measurement for Ethanol Charcoal and Kerosene Stoves in Kibera Kenya." https://climate-solutions.net/images/Black-Carbon-EF-Report-30_10_2016.pdf.
- Roden, Christoph A., Tami C. Bond, Stuart Conway, Anibal Benjamin Osorio Pinel, Nordica MacCarty, and Dean Still. 2009. "Laboratory and Field Investigations of Particulate and Carbon Monoxide Emissions from Traditional and Improved Cookstoves." *Atmospheric Environment* 43 (6): 1170–81. <https://doi.org/10.1016/j.atmosenv.2008.05.041>.
- Rose Eilenberg, S., Kelsey R. Bilsback, Michael Johnson, John K. Kodros, Eric M. Lipsky, Agnes Naluwagga, Kristen M. Fedak, et al. 2018. "Field Measurements of Solid-Fuel Cookstove Emissions from Uncontrolled Cooking in China, Honduras, Uganda, and India." *Atmospheric Environment* 190 (March): 116–25. <https://doi.org/10.1016/j.atmosenv.2018.06.041>.
- Wathore, Roshan, Kevin Mortimer, and Andrew P. Grieshop. 2017. "In-Use Emissions and Estimated Impacts of Traditional, Natural- and Forced-Draft Cookstoves in Rural Malawi." *Environmental Science and Technology* 51 (3): 1929–38. <https://doi.org/10.1021/acs.est.6b05557>.

During poor performance, pellet stoves emit in distinct events

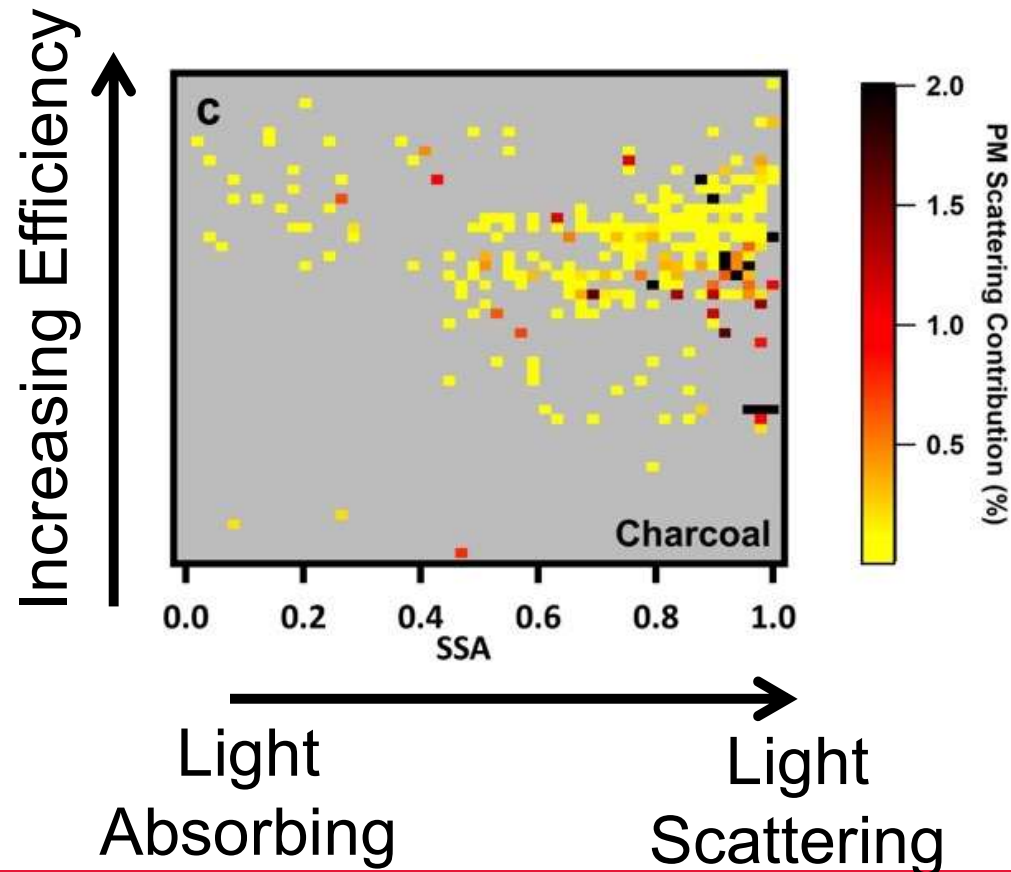


Patterns of Real-time Emissions Data (PaRTED)

- 2-D frequency plot
- Type of particle
 - During what type of combustion event

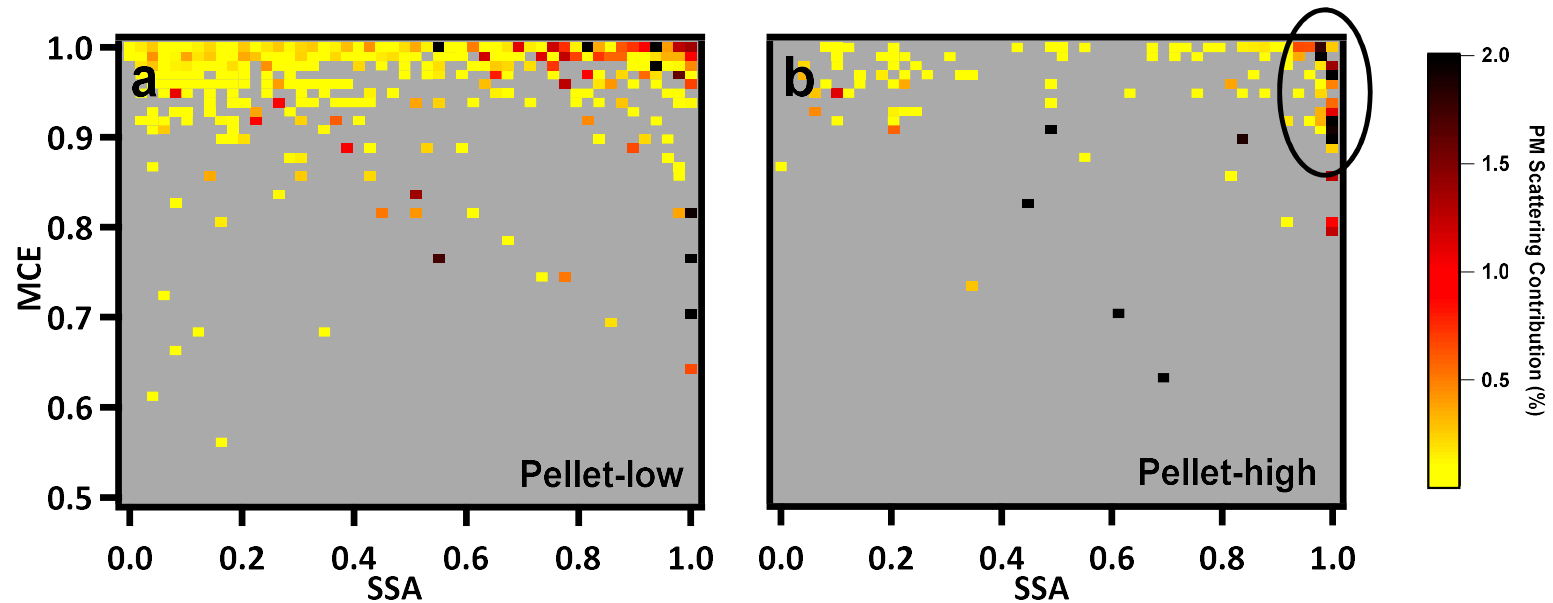
$$\text{MCE} = \frac{\text{CO}_2}{(\text{CO} + \text{CO}_2)}$$

$$\text{SSA} = \frac{\text{Scattering}}{\text{Extinction}}$$

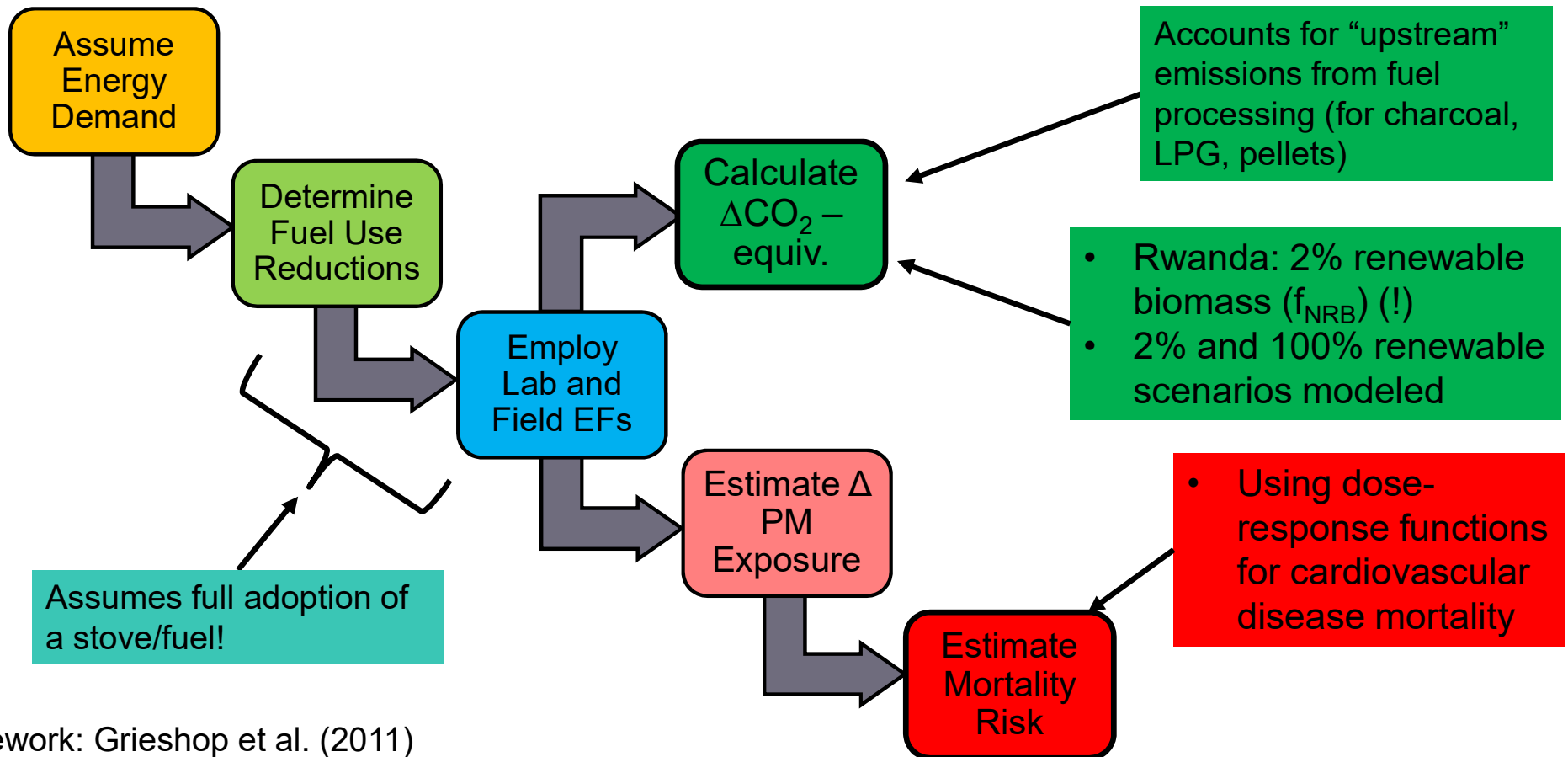


13. Chen et al., 2012

Remember, Pellet stoves have generally lower SSA...
Pellet-high stoves emit primarily high SSA PM



Apply a framework to estimate *potential* climate and health impacts and (co)benefits from stove options



Framework: Grieshop et al. (2011)

