Classification of Stove Technologies and Fuels Version 1.0 (2017-04-10)

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Paul S. Anderson, PhD Email: psanders@ilstu.edu

Introduction

Accurate classifications can bring order to knowledge. But imprecise labels such as "clean," "dirty" and "improved"" are subjective, and their use perpetuates biases unfair to new combinations of fuels and stoves. A joint publication by the authoritative Global Alliance for Clean Cookstoves (GACC) and the World Bank's Energy Sector Management Assistance Program (ESMAP 2015) makes a good start for 21st Century classification, but its key table can be improved in at least eight ways (see Appendix). Incorporating those eight changes, the expanded classification presented here (page 2) defines ten distinct types of stove and fuel combinations, and is offered as a reference point for classification discussions.

The Classification Table

Within each of the ten types of stove and fuel combinations, there will be some exceptions that are either uncharacteristically clean burning or dirty. But exceptions caused by poor maintenance or contaminated fuel or distorted laboratory controls or specially-processed fuels (such as carefully sawn kiln-dried wood) are acknowledged only in this sentence. All other statements refer to typical circumstances and realities.

The two major headings are "Not-Clean Cooking Solutions" (including what has commonly been called "Improved" or ICS) and "Modern Advanced Clean Cooking Solutions" (MACCS). The designations are based on repeated worldwide studies in the 21st Century (reviewed by Kshirsagar and Kalamkar 2014) to measure with great accuracy **stove emissions in relation to human health**. Efforts in the second half of the 20th Century introduced stoves with the designation of ICS, meaning "Improved Cook Stoves." It is now clear that the label "improved" during that time period is not indicative of stoves sufficiently improved to meet modern requirements to be called "clean." The "I" in ICS could now denote "inferior" or "insufficient."

[Note: This classification table does not refer to stove emissions in relation to climate impact. The GACC / ESMAP health-based classifications give no penalty for ambient emissions from remote refining to make LPG and NG, or the burning of fossil fuels to make electricity. Nor does this classification refer to important issues of costs of fuels and of stoves, the dual use of stoves for space heating in cold climates, or numerous societal and personal preferences around the world. Also, the simple addition of a chimney to an ICS stove to put the emissions "outside" of the kitchen is not sufficient to raise an ICS stove to the MACCS status.]

On the right-hand side of the table are three of the cleanest stove-fuel combinations: solar, electricity and the processed fossil fuels of LPG and NG (natural gas). Electricity, LPG and NG thoroughly dominate cooking in hundreds of millions of households in developed societies, and in affluent households in impoverished countries. To very low-income families that cook with wood, dung and other dry biomass, these three modern fuels and stoves are "aspirational" but unavailable because of significant recurrent costs for fuel production and distribution. But perhaps 300 million modest-income households might transition to these fuels by 2030.

On the left-hand side of the classification table are standard solid-fuel technologies: Baseline 3-stone fires, legacy & basic & intermediate types of "Improved Cooking Solutions" (ICS) stoves, and charcoal stoves. These have been frequently vilified as "dirty" fuels and/or stoves. "ICS" is almost universally understood to mean "**direct burning of solid biomass**" with legacy, basic and intermediate "improved" (but not advanced) stove technologies. Altogether, these less-than-desirable "Not-Clean Cooking Solutions" are still found in daily use in 500 million households in impoverished societies. By default, they will continue to be used until clean burning MACCS stoves with affordable fuels are sustainable in those 500 million households.

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Div	Not-Clean Cooking Solutions (ICS)					Modern Advanced Clean Cooking Solutions (MACCS)					
Fuel	Solid Biomass as Solid Fuel: Wood, dung, agro-refuse, charcoal, (Coal is localized and fossil solid fuel.)					Solid Biomass as Initial Fuel for Creation of Gases & Liquid Fuels			Non-Biomass Fuels		
Cooking Technologies	**Base-line: Three-stone fire**	**"Improved Cooking Solutions" (ICS)**				**Advanced Clean Cooking Solutions (ACCS)** Combustible gases and liquids for cooking are created ("refined" or "derived") from initial biomass that undergoes an intermediate process.			**Fossil-Fuel Stoves** Processed petroleum to become gases.	**Electric Stoves** Electricity remotely generated. Much from fossil fuels.	**Solar Stoves** Depen-dent on sunlight.
		Legacy & Basic **ICS** Stoves	Inter-mediate **ICS** Stoves	**Char-coal ICS** stove							
what is Combusted?	**Bio-mass as Solid Fuel**	**Bio-mass as Solid Fuel**	**Bio-mass as Solid Fuel**	**Char-coal** has only 30% of energy of wood.		**Woodgas from Biomass:** Gas-burning with gases from solid dry biomass; makes char.	**Biogas from Biomass:** Gas-burning with gases from solid wet biomass.	**Liquids from Biomass** Ethanol, Methanol from biomass.	**LPG, NG** (nat. gas), DME, (Exclude kerosene) (Coal is solid and seldom clean-burning.)	**Electricity** Derived from renewable hydroelectric, solar, & (min) biomass. Also from fossil fuels (oil, gas, coal) and nuclear.	**No com-bustion** present in solar cook-stove.
Key Features and Stove Types	**Three rocks to support a pot;** Open fires and shel-tered fires. Many supple-mental stoves.	**ICS Clay, mud, brick, and simple metal to contain fire** Artisan produced.	**ICS Rocket-style stoves** w/ high fuel efficien-cy and moder-ately clean burning.	**ICS Char-coal stoves** cause defor-estation and high C0 emis-sions.		**Pyrolysis** in fan-assisted or natural draft **TLUD gasifiers** produce gases & "C negative" charcoal with re-sale value. **TChar stoves** can replace charcoal ones.	**Anaerobic digestion** of biomass decaying in containers yields combustible gases. Always local production; biogas is never transported.	Industrial **distillation** of biomass yields **liquid alcohol t**o burn in appropriate stoves. Many as supplemen-tary.	**Processed fossil fuels, with high fuel and combustion efficiencies;** LPG in metal cylinders or NG via pipelines. Subsidized. "C positive".	**No combus-tion** present in the stove; dependent on grid power; batteries are not sufficient. Electric or induction heating elements in a stove structure.	Reflective "dish" or solar-collector box, with need to **orient toward the sun.** Solar box ovens.

Adapted and expanded from *The State of the Global Clean and Improved Cooking Sector,* ESMAP 2015, Tech Rpt 007/15, Figure 1.1 (p. 13).

In the center of the classification table are three combinations of stoves and fuels that **use solid biomass as the initial fuel, but do not burn it directly.** Modern society uses such energy transformations to attain Modern Advanced Clean Cooking Solutions (MACCS). Examples include 1) crude oil used for making LPG, 2) wood for making charcoal (which remains solid), 3) nuclear power and flowing water and solar cells to produce electricity, and 4), 5), 6) the biomass used in three different methods (pyrolysis, digestion and fermentation) to create woodgas, biogas and alcohols (in the three center columns). In those latter three cases, the initial biomass fuels are converted into gases or liquids that can be cleanly burned, clearly showing that solid biomass is not a "dirty fuel" when appropriate processes and stoves are utilized. Renewable, sustainable, affordable, and locally available dry biomass can be a clean fuel, even for the most impoverished households in remote places.

Burning of Combustibles Derived from Solid Biomass Initial Fuels

Initial biomass can be converted into combustible gases and liquids by 1) anaerobic digestion for biogas, 2) fermentation-distillation for liquid alcohol, and 3) pyrolysis for woodgas. Unfortunately, two of the three have serious limitations that prevent scaling up of clean stove installations to serve tens of millions of households while keeping costs low enough for very impoverished people to afford:

1. In biogas stoves, the fuel (mainly methane) is very clean burning. But gas production is governed by the needs of living bacteria and microbes that depend on relatively close attention to temperature control, daily supply of biomass feed-stock (especially manure), water content, and regular processing maintenance. Construction costs are not trivial, but are highly variable by capacities and suppliers.

2. Creating liquid alcohol fuels requires industrial processing (fermentation and distillation) of relatively limited and somewhat costly starch or sugar biomass (such as corn/maize, sugar cane, and root crops). The "food vs. fuel" debate does not favor alcohol production, and alcohol cannot compete economically against currently abundant fossil fuels and their already-established, post-refinery distribution mechanisms (pipelines and cylinders). The cost of alcohol stoves is comparable to the cost of other respectable clean cookstoves.

In contrast, cooking with woodgas utilizes a highly functional, existing, tested combination of woodgas stove technology (especially Top-Lit UpDraft (TLUD) micro-gasification) and the same available wood and other dry biomass fuels currently being burned in the Not-Clean Cooking Solutions. And one step better, woodgas stoves for hundreds of millions of families can be sustainably financed with the carbon credits generated by the use of those same stoves. Substantial writings about woodgas stoves are available.

[Please continue with the next document about "Woodgas: A Modern Clean Stove-type and Fuel."]

Paul S. Anderson, PhD, Executive Director of Juntos Energy Solutions, NFP
Email: psanders@ilstu.edu
Websites: www.drtlud.com and www.woodgas.com and www.juntosnfp.org

References

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Kshirsagar, Milind P., and Vilas R. Kalamkar (2014). *A comprehensive review on biomass cookstoves and a systematic approach for modern cookstove design.* Available at: https://www.researchgate.net/publication/259158774_A_comprehensive_review_on_biomass_cookstoves_and_a_systematic_approach_for_modern_cookstove_design

Many articles about TLUD / woodgas stoves are available at: www.drtlud.com

Appendix: The GACC and ESMAP Classification 2015

In 2015, the Global Alliance for Clean Cookstoves (GACC) and the World Bank's Energy Sector Management Assistance Program (ESMAP) jointly published *The State of the Global Clean and Improved Cooking Sector.* Figure 1.1 on page 13 of the joint publication contains a graphic labeled "Overview of Improved and Clean Cooking Technologies" with images of the stove types], and is reprinted below and found at: https://openknowledge.worldbank.org/bitstream/handle/10986/21878/96499.pdf (Yellow highlight added.)

Differences to be noted, and were changed in the "Classification…." table:

1. LPG and NG should not be together with electricity.
2. Biogas and liquid alcohols and solar should all be separate, not in one category.
3. Charcoal should be a separate category.
4. Baseline Three-Stone Fires should be shown as a category.
5. Woodgas, biogas and biomass-derived liquids, which are all from solid biomass, should be three categories that are grouped together.

6. Retained heat cooking (RHC) should be removed because it does not add any heat from a fuel.
7. The term “modern” (if used at all) should apply to more than just fossil fuels and electricity.
8. The term “ICS” (if used at all) should not be used to refer to solid fuels, nor applied to woodgas stoves.

FIGURE 1.1:
Overview of Improved and Clean Cooking Technologies

Sources: World Bank; Global Alliance for Clean Cookstoves; Task Team analysis.

a Although legacy stoves are categorized as "improved" within the typology, the actual performance of many legacy stoves likely falls below provisional ISO/IWA standards.

b Controlled tests of good quality kerosene pressure stoves show low emissions, but field data suggest that many kerosene stoves are actually highly polluting.

c "Potential impact" defined as potential positive impact on health and environment outcomes vis-a-vis traditional cooking solutions.