Origins, History, and Future of TLUD Micro-gasification and Cookstove Advancement

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Abstract / Executive Summary

Two major cookstove entities, ESMAP and the GACC, wrote in their May 2015 technical report: "The most exciting technology trend in the biomass cookstove sector is the growing range of forced draft and natural draft gasifier stoves." (ESMAP, 2015, p. 90). These words refer to TLUD stoves and related micro-gasification technology that originated in 1985. Their origin, history, and future development are covered in seven time periods, each with progress that builds upon prior efforts:

Pre-1985	Before modern TLUD micro-gasification – Processes observed, but not developed.
1985 ~ 1993	Inception – Reed, Wendelbo, LaFontaine, Hottenroth, and Miles.
1994 ~ 2000	Early exposure to others – Larson, English, Early Internet, Conference in India.
2001 ~ 2006	Additional exposures and incremental progress – Anderson, BP-Oorja, ETHOS.
2007 ~ 2010	Slowly moving toward acceptance – Wendelbo, Belonio, Stove Camps, PCIA.
2010 ~ 2015	Enlightenment – BEIA Project, GACC, Roth, Winter, Harris, Char-making for biochar.
2015 ~ 2020	Onward for dissemination and acceptance by users – Toward 30 million TLUD stoves.

Following the time periods, the authors conclude with a comment about the change of focus onto user acceptance and carbon into soils.

† Readers are encouraged to send to the authors any comments, corrections, and additional content for possible inclusion in a future version of this document. All versions of this document will be announced and made available at **www.drtlud.com** and other websites. This document's primary URI: **http://www.drtlud.com/tlud-history**

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Note about Content

Because TLUD-related micro-gasification activities in some parts of the world are less published or known than in others, this document is a non-exhaustive history. In fact, the primary focus herein is on TLUD-related history *before* 2010. And while the authors regret not being able to cover every TLUD or semi-TLUD stove development since 2010, readers should note that many products and projects from this period are, in fact, mentioned in Christa Roth's excellent book, *Micro-gasification: Cooking with gas from dry biomass* (Roth, 2014). Other limiting factors affecting the completeness of this document are language barriers and limited communications with remote locations.

This document is primarily a statement from an active developer (Paul S. Anderson) and an observer/writer (James S. Schoner) in the world of micro-gasifier cookstoves, and it should not be used to imply favor or disfavor with stoves or efforts that are mentioned or unmentioned. The authors have tried to be accurate and have incorporated review comments from several individuals who are mentioned and have first-hand experience with the events of these historical periods. Most of the references cited in this document can be found in the bibliography and in the search results of common Internet search engines.

Any errors or omissions are the responsibility of the author, and corrections will be incorporated in future revisions (visit http://www.drtlud.com/tlud-history to find the latest revision). Corrections, suggestions for additional content, and all other inquiries should be emailed to the primary author, Paul S. Anderson, PhD (psanders@ilstu.edu).

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Introduction

The inception and initial scientific study of what is known as TLUD micro-gasification (defined below) began in 1985. By 2008 – 09 "… gasifier technologies were [still] highly experimental…" (ESMAP, 2015, p. 91). But in May 2015, ESMAP (Energy Sector Management Assistance Program, a World Bank organization) and the GACC (Global Alliance for Clean Cookstoves) jointly published this statement in their technical report, *The State of the Global Clean and Improved Cooking Sector*: "**The most exciting technology trend in the biomass cookstove sector is the growing range of forced draft and natural draft gasifier stoves**. These stoves have shown the greatest potential to improve health and environmental outcomes, at least under laboratory conditions." (ESMAP, 2015, p. 90). Also, at the January 2015 meeting of ETHOS (Engineers in Technical and Humanitarian Opportunities of Service), counting separate presentations and the update of TLUD efforts in Paul Anderson's presentation (Anderson, 2015), twenty progress reports about micro-gasification were presented. Some were about million-dollar projects that included significant TLUD research and development. [Visit http://www.ethoscon.com/proceedings-archive to find an archive of ETHOS conference proceedings from 2005 to present.]

To explain this degree of interest and enthusiasm, it's important to recognize how TLUD technology in various forms, sizes and applications is favorably impacting a wide variety of serious world issues: 1) clean air inside of kitchens that 2) use a wide variety of low-value solid dry biomass fuels like wood and agricultural residues (stalks, hulls, briquettes, and pellets) that 3) reduce deforestation and 4) reduce costs to competitive levels. 5) Batch operations can require less fire tending. 6) The distinctive char-making capability offers opportunities for carbon sequestration to combat climate change. And 7) all of this is accomplished with relatively simple technology and equipment that encourages local job creation. Challenges

FIGURE 1: VARIOUS MICRO-GASIFIERS AT A STOVE CAMP IN ITALY [PHOTO SOURCE: (ROTH, *MICRO-GASIFICATION: COOKING WITH GAS FROM DRY BIOMASS (SECOND EDITION)*, 2014)]

remain, especially regarding development of appropriate fuel supply chains, high-volume stove production, and the needed cultural adaptations to changes of some long-established habits of stove users.

How did it happen so fast, and why did it take so long? What happened between 1985 and 2015 is the topic of this document, including comments on what is yet to come.

Gasification and Gasifiers

Combustion is a physical-chemical process involving sub-processes of pyrolysis, char formation, char gasification, and the combustion of gases from carbonaceous materials (hydrocarbons and carbohydrates). Gasification occurs in nature in all combustion of organic material, and the sub-processes are usually intermingled and almost simultaneous. Gasification was not invented by anyone and has no owner. In contrast, a gasifier is a device or method created or invented by someone to influence in desired ways the various sub-processes of gasification, especially to separate in time and/or in space one or more of the sub-processes from the others. Therefore, gasification is a science (where practical ends are reconciled with scientific laws), and a gasifier is an object that is part of the history of how humankind has utilized gasification.

There are many types of gasifiers, large and small, updraft and downdraft and other-draft, etc. One specific type is called **Top-Lit UpDraft**, well known by the acronym **TLUD** (pronounced tee-lud). That name was first written in 2004 and spoken as an acronym in 2005. [However, the TLUD name is now also loosely accepted to include micro-gasification devices in which the **MPF** (see next paragraph) has reached the bottom of the fuel column and transitioned into char-burning at the bottom (becoming bottom-burning, although not bottom-lit).] From 1985 to 2005, the name was Inverted Down Draft, or IDD.

The most distinguishing characteristic of TLUD (and IDD) technology is the **Migratory Pyrolytic Front** (MPF) that produces a quite constant and controllable flow of combustible gases while creating char (charcoal). Essentially, TLUD micro-gasifiers are "gas-burning stoves that create their own gases" and also "charcoal producers that release usable combustible gases." The understanding and development of this micro-gasification MPF process (to create separable char and combustible gases) are central to this history of the evolution of micro-gasification and the many variations of TLUD gasifier devices. For more of the technical information, see *Micro-gasification Terminology: An Instructional Summary of MG* (Anderson, 2013b) and *Micro-gasification: Cooking with gas from dry biomass* (Roth, 2014); both are available as Quick Picks at the Dr TLUD website (www.drtlud.com/quick-picks).

The historical periods defined below do not have precise time boundaries, but rather conveniently have 4- to 7-year spans that overlap. Also, the people named had many preparatory years of study and employment prior to initiating their involvement in the development of TLUD (Top-Lit UpDraft) micro-gasification stove technology. And they did not necessarily innovate or develop their ideas in isolation, without collaboration, or in single giant steps.

Pre-1985: Before modern TLUD micro-gasification

History is created by those who are remembered either by their recordings (written, video, etc.) or in the recordings by others about their actions. What is particularly important is the transmission of knowledge to other people, and that usually means some noted usefulness that is replicated by others. As with genealogy of families, some lines of activity flourish at different times, and some can die out. For example, concerning TLUD cookstoves, the Paal Wendelbo story (below) was literally a heartbeat away from being untold when he was hospitalized with severe malaria in 1999 (Cappelen, 2012).

It is highly probable that various people prior to 1985 have ignited a pile of fuel on its top and observed that there are advantages over bottom-lighting, mainly that there is less smoke and the fire is more consistent or uniform during the time of the burning event.

Humankind's long history of making charcoal in earth-covered piles of biomass has probably included some top-ignition experiences, but their impact (if noted) did not spread to other areas. Dr. A.D. Karve knows of one such undocumented practice in one area in India.

As a youth in the 1950s on a windless day, Anderson (author) saw the separate burning of gases at the top of a typical "burn-barrel" for trash, but he did not sufficiently understand or appreciate the event enough to commence any further investigation.

In Turkey, a stove primarily for coal burning with TLUD attributes has the brand name "Silver" and is reported to have roots dating to the 1950s or maybe earlier. [Documentation is sought for its history between its origin and when it came to the general attention of stove developers after 2010.] Dr. Julien Winter recently searched available literature on combustion science in English and found 69 articles under the subjects "fixed bed" (36), "packed bed" (27), "pot furnace" (4), and "underfed combustion" (2) that discussed what were ostensibly forced draft TLUDs. A few of the articles were written pre-1985, with one in 1934 by P. Nicholls giving the earliest clear example of laboratory research that included a descending pyrolytic front downward through bituminous coal (related to making coking coal); use of the created gases was not of interest (Nicholls, *Underfeed Combustion, Effect of Preheat, and Distribution of Ash in Fuel Beds*, 1934, p. 14). US Patents were also searched. In 1966, Frederick W. Hottenroth and Harry D. Jacoby patented "a forced draft solid carbon fuel burning cooker" (for charcoal) containing elements found in modern fan-driven stoves, such as the preheating of primary and secondary air (Hottenroth, *Forced Draft Solid Carbon Fuel Burning Cooker*, 1966).


FIGURE 2: PAAL B. WENDELBO

In Norway during World War II, resistance fighters made very small open fires (without containment) for careful, controlled cooking. Top-lighting prevented smoke from revealing a fighter's location. It is extremely likely that this "smokeless campfire" technique was known and used even thousands of years ago by diverse peoples worldwide who needed protection from their enemies. This would be almost irrelevant to the history of TLUD cookstoves except that the Norwegian use was observed by a teenager, Paal Wendelbo, who remembered it forty years later when he went to Africa. More about the Wendelbo observation is found in the next section.

Other events or devices possibly existed, especially in Asia from where we have very little information. Pre-1985, there was indeed considerable work throughout the world involving gasification of many types, but not TLUD (MPF) technology. Although vague claims are not sufficient evidence to become history, new and/or additional information is always welcomed and appreciated.

Pyroneers of TLUD Technology (1985 ~ 2006)

1985 ~ 1993: Inception

The two men credited with independently creating the first TLUD devices in our modern period are Dr. Thomas B. Reed and Paal B. Wendelbo. They were unaware of each other's work until 2007, and met only once when they were honored at the 2011 Partnership for Clean Indoor Air (PCIA) Forum in Lima, Peru for their "significant contributions to the development of top-lit updraft gasifier stove technology." [Visit http://www.pciaonline.org/2011ForumAwards for additional details.] Both honorees are pictured below with Paul S. Anderson (Figure 3).

FIGURE 3: (SEATED, LEFT TO RIGHT) PAAL B. WENDELBO, THOMAS B. REED, AND PAUL S. ANDERSON

FIGURE 4: THOMAS B. REED, PHD

In 1985 Reed, a world-recognized expert on biomass gasification, was traveling in South Africa where he saw the smoky conditions of inefficient cookstoves and heaters. He awoke one morning with thoughts of inverting a downdraft (DD) gasifier, resulting in an updraft (UD) device with ignition at the top. Thus began years of experimentation to develop this creation back home in Colorado, USA, where he worked at SERI (Solar Energy Research Institute, which later became NREL, National Renewable Energy Laboratory). He called it "Inverted DownDraft" or IDD, and the downward movement of the pyrolytic front was observed and explained. Reed certainly recognized the unique characteristic that all of the biomass is turned into charcoal before very much charcoal is burned, but his major focus was on the energy and clean-combustion issues. Working scientifically, he discussed with colleagues and experimented with both natural draft (ND) and forced air (FA, which also denotes fan-assisted) devices.

Two of Reed's very knowledgeable colleagues were Harry LaFontaine in Florida and Fred Hottenroth in California. Harry LaFontaine, a former Danish resistance fighter in WWII, brought to America his experience with gasification for vehicles. LaFontaine founded the Biomass Energy Foundation (BEF) in 1982 and led it until his death in 1994, at which time BEF's then-vice president, Tom Reed, assumed the leadership role. Reed and LaFontaine were well aware of and connected with the continuing innovative work of Fred Hottenroth. Hottenroth must have worked fast, because he obtained a U.S. Patent in 1988 for a "Biomass Stove" (Hottenroth, 1988). See Figure 5.

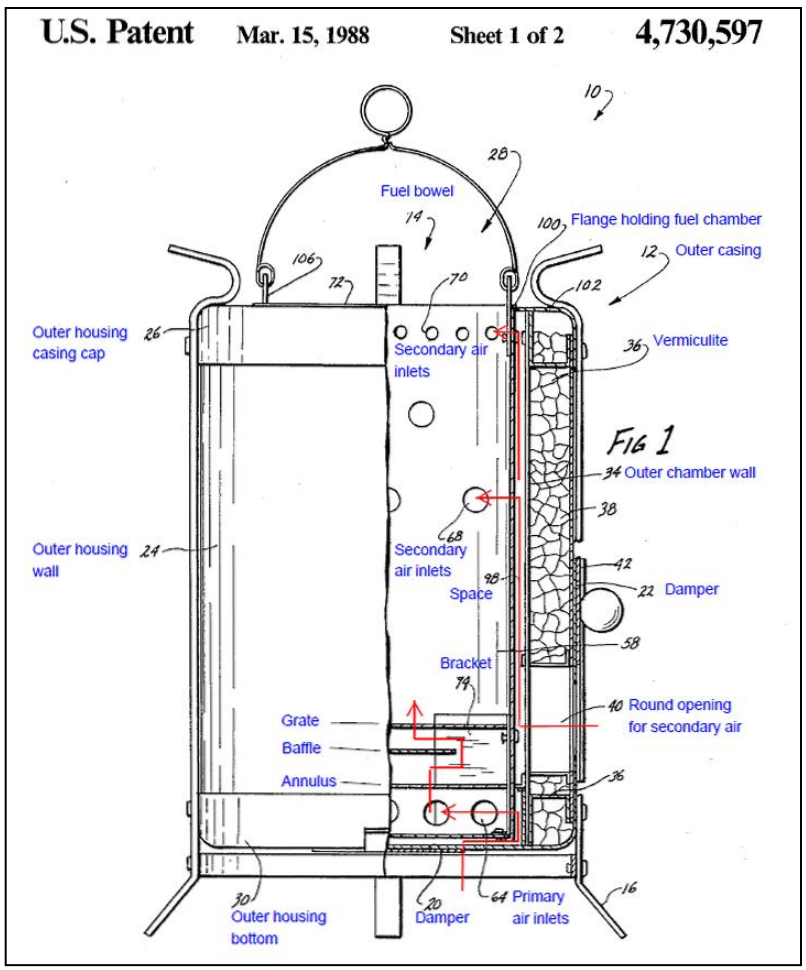


FIGURE 5: FRED HOTTENROTH'S PATENTED BIOMASS STOVE (1988)

In 1991 LaFontaine and Reed released the earliest known paper about what would be later known as TLUD technology and devices: *An Inverted Downdraft Wood-Gas Stove and Charcoal Producer* (LaFontaine & Reed,

FIGURE 6: ZMART ZIP ZTOVE

1991). This paper states: "During a lecture trip to the far east in 1988, … our [BEF] members became aware of the Third World's wood crisis, and after 2 years of extensive research, our Foundation developed the World's first naturally aspirated wood-gas-stove in 1990." A diagram and photos for the Zmart Ztove (stove) are included in this 1991 paper. Additionally, Tom Miles recently shared a separate dimensioned sectional drawing of the 4kW Zmart stove (Miles, 1992). See Figure 7.

Miles' records reveal that LaFontaine and Reed of "the BEF had been making Zmart Ztoves by hand in California [with Hottenroth who established ZZ Corp to manufacture the stoves] in 'batches of 100' and 'distributing them free of charge to Government and Agencies in the 3rd World.' They were 'running 4-6 months behind' on requests. … Several people tested their experimental unit, including the university in Tamil Nadu in India." Knowledge of this dissemination effort is only being remembered recently in 2015, and this helps explain the significant developments by others that were shown at the 2000 conference in Pune, India (discussed later).

Tom Miles also remembers that "… we [Tom Miles Sr. and Jr.] tested the LaFontaine stove in 1992. We were asked to evaluate the stove for the Office of Technology and Assessment [part of US NIST] that was approached by LaFontaine and Reed for a grant. We were impressed and recommended the stove for further development." That grant request was denied, and probably set back micro-gasifier development by twenty years. These early efforts by Reed, LaFontaine, and Hottenroth were important groundwork about natural draft TLUDs, but did not yield acceptable solutions or lasting products, as will be discussed later.

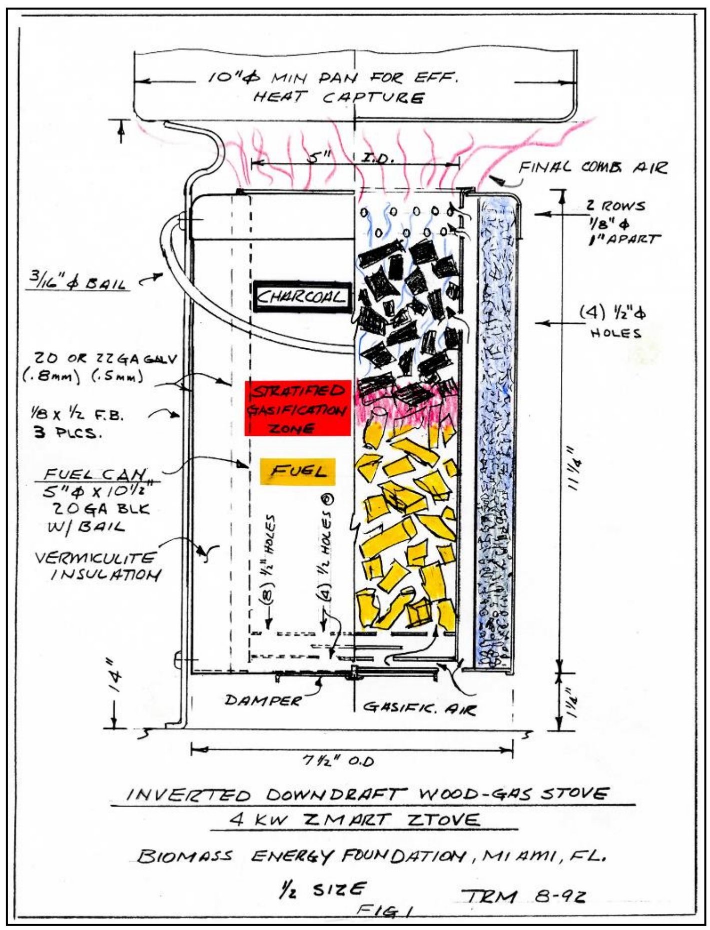


FIGURE 7: DIAGRAM OF 4KW ZMART ZTOVE

Meanwhile, in virtual isolation, a solution was found. In the late 1980s, Paal Wendelbo shifted from his profession as an architect in Norway to being a development worker in projects in eastern Africa. He remembered the top-lit open fires of the resistance fighters and began attempts during his off-duty hours to create such a fire inside small metal containers, trying to make a functional cooking stove. He was a persistent experimenter for several years, even being teased by his friends about his near-obsession to make a better stove. By 1993 or thereabouts, he was successful in creating the Peko Pe micro-gasifier in Uganda. Details of the Wendelbo story are found in a paper co-authored by Paal Wendelbo and Dr. Paul Anderson: *Paal Wendelbo and His "Peko Pe" Top-Lit UpDraft (TLUD) Gasifier Cookstoves* (Anderson & Wendelbo, 2009).

Reed and Wendelbo, at their separate starting points, did their independent creative efforts in 1985 and a bit later. At that time, major micro-computers included the Apple IIe, IBM PC, and TRS-80. The Internet, email, listservs, websites, and digital photography were in their infancy. Skype, YouTube, smart phones, and texting were not even imagined except, perhaps, as science fiction. And biochar and climate change were years away from being widely-discussed topics. Interestingly, all of the above have greatly assisted the advancement of TLUD stoves, although these stoves developed at a slower pace in the same thirty-year period.

1994 ~ 2000: Early Exposure to Others

Activities by the Originators (1994 ~ 2000)

Paal Wendelbo launched production of his Peko Pe cookstove in northern Uganda and made approximately 5000 units by 1999. But that year, at age 70, he was severely stricken by malaria and evacuated to Norway for a long recovery. Without his leadership, his project and innovation gradually died out, and Wendelbo and his functional Peko Pe TLUD-ND stove were virtually unknown to other stove developers until 2007 when his solution to natural draft TLUD gasification finally came to light (thus, his innovation is discussed in that later section).

FIGURE 8: PEKO PE TLUD STOVES IN UGANDA (ABOUT 1994)

Dr. Ronal Larson, who worked at SERI and knew Tom Reed, had specific interests related to the ability of the IDD (TLUD) devices to make charcoal (char), including an early version made of two vertically-stacked tin tomato cans from a local pizzeria in Colorado, possibly the first "tincanium" TLUD. His initial motivation was to develop a more efficient (stove-oriented) method of making charcoal than he had observed when leading a USAID group in Sudan ten years earlier. In 1994 Larson lived a semester in Sweden where he conducted some experiments for char-making with IDD/TLUD devices. Later that year he visited Ethiopia and attempted to have TLUD heat for cooking injera. He also made and demonstrated early versions of his char-making stove on trips to Nicaragua and Zimbabwe. As is the case with many introductions of new technologies, seeds were planted, but we cannot trace subsequent TLUD activity which may have stemmed from that trip.

Whereas Dr. Larson was emphasizing making char, others were more interested in gasifying the char (turning char into gas), as was the case for Dr. Reed's work in 1985 on an IDD gasifier (not a stove). In 1994 Larson and Reed, individually and together, began testing various char-making stoves. In December of 1995, Larson began talking about char-making stoves (later called TLUDs) on the Tom Miles discussion list called "BioEnergy" (more on this below). Visitors to http://www.bioenergylists.org/newsgroup-archive/stoves/1996-February.htm will find the early dialog, which was almost exclusively on char-making stoves. By reviewing succeeding monthly summaries [replace "February" with "March", etc. in the URL], one can readily gain a good sense of the growth in understanding of char-making stoves.

In 1995-96 Reed and Larson collaborated on what became the best-known early TLUD/IDD publication: *A Wood-gas Stove for Developing Countries*, first presented in 1996 at an IEA Thermochemical conference in Banff, Canada (Reed & Larson, 1996). Their now-classic paper was circulated worldwide via the electronic communications of that time. That natural draft IDD/TLUD device (Figure 9) was an improvement over earlier designs because the upper can added height to create some natural draft. But it still had some inherent limitations and was never designed to go into production. Larson (and his review from the Stoves Listserv archives) points out: "By the end of February 1996, we had not yet found agreement that TLUDs would work [as a useful device]." Reed soon shifted his full focus to fan-assisted (FA) capabilities, and Larson continued with his focus on char-making, including TLUD cookstoves and larger devices.

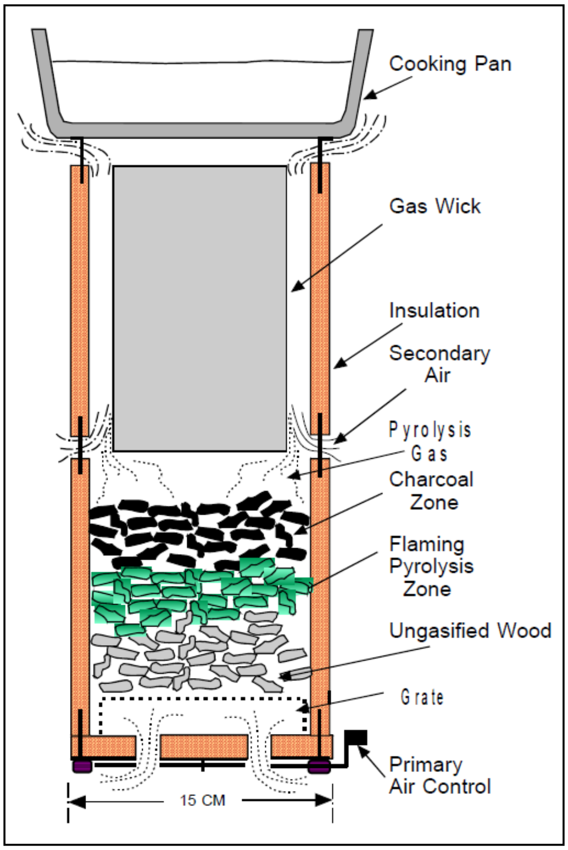


FIGURE 9: REED-LARSON "INVERTED DOWNDRAFT GASIFIER" STOVE (1996)

Also in the early to mid-1990s Tom Miles started bioenergy discussions as electronic bulletin board lists available through dial-up Internet access. In 1994 he created the BioEnergy Discussion Lists (Listserv mailing lists). Two separate discussion themes caught on immediately with various subscribers around the world: gasification (which is more focused on larger gasifiers making clean gases for internal combustion engines) and biomass cooking stoves (all types of stoves, including the TLUD/IDD efforts). Moderators of the Stoves Listserv have included Alex English, Elsen Karstad, Ronal Larson, Etienne Moerman, Tom Miles, and Andrew Heggie.

As a young Canadian engineer in the 1990s, Alex English specialized in combustion, such as for heating greenhouses. With encouragement from Tom Reed and others, he did various experiments with the nascent IDD technology, eventually including barrel-size units, and later made the largest known TLUD, a 400 gallon (1600 liter) unit with blower-induced draft. English was the public face of the Stoves Listserv in this early time period and a proponent and experimenter of IDD, both natural draft and forced air versions.

In June 1997, Alex English started a website to document the activities of the Stoves Listserv. There, English posted accounts of Elsen Karstad's and his own experiments with IDD methods. This grew to be the immensely important "Stoves website," which is known more formally as the Improved Biomass Cooking Stoves website (www.stoves.bioenergylists.org). This website also introduced many persons to the Rocket-elbow stoves created by Dr. Larry Winiarski in Oregon, USA in the mid-1980s and nurtured by Dean Still at Aprovecho (http://www.aprovecho.org/lab). Rocket stoves rose to prominence very quickly, but they belong to a different history for others to write. In 2001 English turned over the Stoves website to Tom Miles, the Stoves Listserv sponsor then and still in 2015, with the dedicated assistance of Mrs. Erin (Miles) Rasmussen. Unquestionably, the Internet and the Listservs played (and still play) crucial roles in the past 25 years of cookstove development, allowing historical and contemporaneous information to be rapidly shared around the world.

Larson states: "It was not uncommon that qualified people learned of the IDD technology and dismissed it. The archives of the Stoves Listserv messages from the first few months reveal that folks from Eindhoeven [research group for cookstoves] in the Netherlands were mostly saying that a top-lit design would never work."

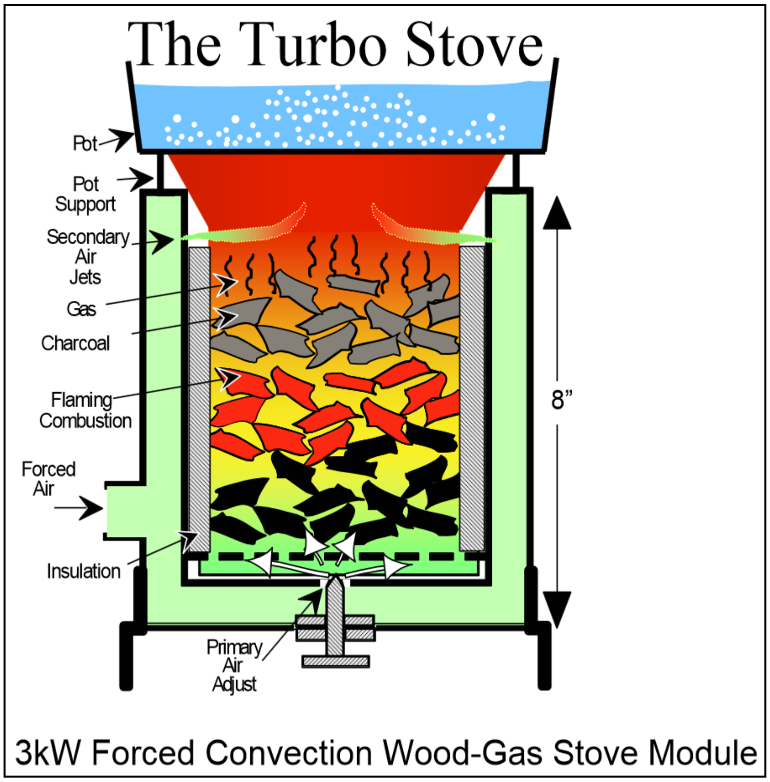
Ron Larson recalls: "I think all the interesting discussion on the top-lit design was over by early 1996, probably. I don't recall much new coming up that wasn't already said on Tom Miles' earlier list in 1995." But there were some spots of activity that were not reporting to the Stoves Listserv.

www.bioenergylists.org/newsgroup-archive/stoves/Past_Archives_Index.htm

www.lists.bioenergylists.org/pipermail/stoves_lists.bioenergylists.org

FIGURE 10: WEB ADDRESSES FOR OLDER AND RECENT ARCHIVES OF THE STOVES LISTSERV

In 1999, Tom Reed and Rob Walt released a report on *The 'Turbo' Wood-Gas Stove* (Reed & Walt, 1999). Another presentation (September 2000) by Reed and two co-authors discusses *Testing & Modeling the Wood-Gas Turbo Stove* (Reed, Anselmo, & Kircher, 2000). The abstract of that document contains virtually the same statements about the advantages (low emissions, control, fuel feeding, efficiency, etc.) of fan-assisted micro-gasifiers as are made by researchers and the ESMAP report now, fifteen years later. Then and now, the news of impressive success with the use of forced air in TLUD stoves continues to be distributed worldwide via the Internet.



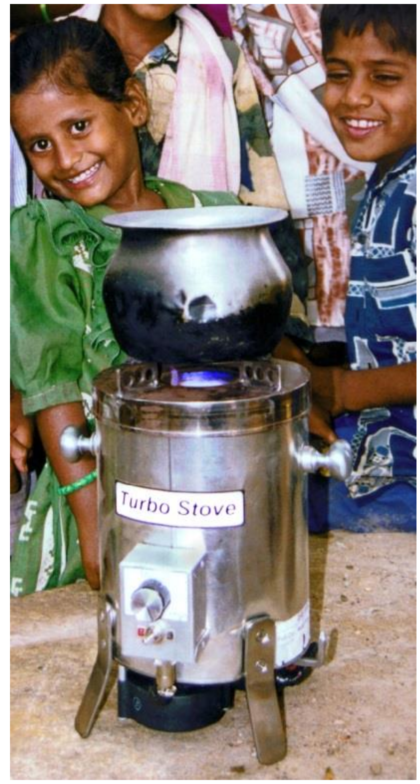


FIGURE 11: FORCED AIR TURBO STOVE (DIAGRAM AND PHOTO OF FUNCTIONING TURBO STOVE)

Early Activities around the World (1994 ~ 2000)

As the initial IDD (TLUD) work by Reed, LaFontaine, Hottenroth, Walt, and Larson became known to many cookstove activists via the Internet, others became active or were observers on the periphery, and they were not necessarily staying in contact with Reed or the Stoves Listserv. Some insights from this time period include:

A recollection from Andrew Heggie of the UK: “The first time I came across this type of combustion, it was described as the Reed-Larson stove. Between finding the list around 1995 and about 2005, I was trying to develop various types of burners, principally to enable better means of producing lumpwood charcoal on the small scale without pollution and ultimately making use of the offgas rather than simply flaring it. Until the early part of the century, finding a justification for the char from a char-making stove was seen as a problem, then we heard about terra preta. IDD did seem to have problems scaling up, and in UK it is quite difficult to get wood dry enough without indoor storage. A chap from the [Stoves] list and I developed a high speed dryer in order to have consistently dry wood for charcoal making. IDD was one of the methods we tried to make charcoal smokelessly, but concluded it was not appropriate. My biggest unit was about 4 of 25-litre steel barrels welded on top of each other, but it was largely unsuccessful.” Ron Larson adds that Andrew was “very important in being the only one besides Alex English with an interest in larger (greenhouse, etc.) char-making systems. But he also experimented with smaller hardware (and still is).”

Tom Miles remembers: “In 1999 CREST [computer server] died, so we moved the stoves discussion onto another server until about 2006. When that organization was unstable, I started hosting the lists and website on our bioenergy lists site. By that time, we had bioenergy gasification, stoves, anaerobic digestion, and straw building (houses). Straw building has since moved to Yahoo. We now host stoves, gasification, and anaerobic digestion on our server and biochar on Yahoo.”

In the mid and late 1990s Larson (retired from NREL) traveled widely with the message of making char in TLUD and other devices. “I visited Elsen Karstad in Nairobi, who made char in a very clever large-scale, bottom-burning downdraft device, and designed his own small TLUD. His business sold charcoal briquettes from char he made from sugar cane refuse.” Larson “also visited Rogerio Miranda, a Brazilian then living in Managua, Nicaragua. I was trying there (unsuccessfully) to use the wonderful lava blocks that were plentiful. I eventually showed Rogerio the TLUD principle using several hollow concrete blocks [stacked to create the fuel chamber and riser similar to the previously mentioned stacking of two tin cans].”

We have no information about when, where or how the TLUD information arrived in China. But if it did by 2000, it had little impact, because as late as 2006 there was only one true TLUD stove design (by Daxu) in a major Chinese stove competition (Anderson, 2007).

We know more about TLUD activities in India and Sri Lanka because of the important meeting held in India in November 2000.

The 2000 Conference in Pune, India Concerning Biomass Energy

During the year 2000, the participants on the Listservs laid plans for a gathering that became the International Conference on Biomass-based Fuels and Cooking Systems, in Pune, India, on 20 – 24 November 2000. Dr. Priya Karve authored a report following the conference: *International Conference on Biomass-based Fuels and Cooking Systems (BFCS-2000): A Report* (Karve, 2000).

“In all, 80 delegates participated in BFCS-2000. Of these, 55 delegates were from different parts of India, and 25 delegates were from outside the country. Of the non-Indian delegates, 12 delegates were from other Asian countries, 1 was from the African continent, 5 were from the European countries and 7 from the American continent.” The IDD/TLUD technology and devices were only part of the total event, but major contacts and information exchanges took place.

FIGURE 12: RONAL W. LARSON, PHD

Participants included:

> Dr. Ronal W. Larson, who was the first of dozens to present to the conference (Figure 12). He reviewed the Internet origins of this conference.
>
> Dr. Thomas B. Reed, who provided practical demonstrations of his forced-air “Turbo” IDD stove.

Alex English, who comments that "Ron Larson had encouraged me to go to Pune so that the IDD stove would have a greater presence. I borrowed some combustion testing equipment from Federal Combustion Lab, CANMET in Ottawa. I logged some tests and wrote up a paper [including combustion emissions and temperature data] which was presented in Pune and published in a publication edited by [Dr. Krishna] Prasad (English, 2002)." [Note: The preceding citation refers to a paywall-restricted document. An earlier, free version of this document is available on the Improved Biomass Cooking Stoves website (English, 2000).] English remembers: "After the conference I went with A.D. Karve to Phaltan to try and build a top lit charcoal maker out of an oil drum [with a very tall chimney] (Figure 13). I worked with their field station engineer. Time was limited, but the result was a moderate success, and they adapted the concept which I understand is still the basis for their distributed charcoal production from ag residues."

FIGURE 13: ALEX ENGLISH'S TLUD BARREL CHARCOAL MAKER (2000)

Mr. (and later Dr.) Punchibanda of Sri Lanka is remembered by Alex English as "a young government employee who had a few years of experience in selling a really well-done, fan-powered TLUD. I don't recall there being a substantive difference between the Reed stove and Punchibanda's." Ron Larson recalls that the "Sri Lankan Punchibanda had been selling a fan-powered unit for some time that made char quite cleanly. No one at that meeting had ever heard of his excellent work prior to the meeting. He probably should get credit for the first commercial, fan-driven TLUD." There are no known photos (or actual units) of the Punchibanda FA-TLUD, or of its sales accomplishments. Recent communications attempts to reach him have not been successful. [Note: The Reed WoodGas Camp Stove (TLUD-FA) entered the market in 2003.]

Mr. (later Dr.) Sri Srinivas of TERI (which later developed TLUD stoves); he is most recently with UNDP in India.

Faculty (but not Dr. Mukunda) and students of the CGPL of the India Institute of Science (IISc-Bangalore) that later had a major role with the BP Oorja stove.

Representatives of the Asian Institute of Technology stove research institute in Thailand, a facility that was active in gasifier research and favorably impacted TLUD history (see next section).

Dr. Mark Bryden of Iowa State University, who one year later was a founder of the ETHOS (Engineers in Technical and Humanitarian Opportunities of Service), a non-profit organization that holds cookstove conferences each year in late January in the Seattle area, USA.

Dr. A. D. Karve and his daughter (now Dr.) Priyadarshini Karve of ARTI. As Pune residents, they were the conference hosts.

The Pune cookstove conference of 2000 is probably the source of additional stories that impact early efforts with gasifier stoves.

2001 ~ 2006: Additional Exposures and Incremental Progress

TLUD technology continued to spread via two forms of contact: personal travel and the Internet. Physical demonstrations are impressive with live fire in TLUD devices. Low cost dialogue via email also allowed early enthusiasts to be in frequent contact.


FIGURE 14: PAUL S. ANDERSON, PHD (PHOTO FROM 2005)

In the Spring of 2001, Tom Reed visited his cousin, Bob Weldon, in Normal, Illinois, USA. Weldon invited his Rotarian friend, Dr. Paul Anderson, to his home to meet Reed, saying "He is as weird as you are." That afternoon Anderson was captivated by Reed's demonstration of a prototype TLUD-FA (essentially the Reed – Walt Turbo wood-gas stove), and wanted it for developing societies, but with natural draft instead of a fan. Reed did not tell Anderson until years later that he had determined that natural draft IDD was not possible with sufficient control to be viable in small cookstoves. The day after Reed's demonstration, Anderson began his initial, four-year effort, with Reed as his mentor. That effort resulted in the Champion Stove and the name, Top-Lit UpDraft or TLUD, to describe the technology.

In 2001-03, Anderson had visiting professor duties that took him numerous times between Illinois and Mozambique. During this timeframe, he produced scores of TLUD prototypes with tinsmiths and with tin cans to test key differences in designs. In 2003, a multi-day, stove-focused gathering was organized by Marlis Kees of GTZ (now GIZ) in Vereeniging, South Africa. Others in attendance included Christa Roth, Crispin Pemberton-Pigott (based in Swaziland), and South African John Davies (who built a successful TLUD gasifier for coal that he then used to heat his home). Roth remembers this as being her first "stove" meeting and that it "was a quite decisive one when a lot of people were there that are still heavy-weights in the stove business."

Anderson's retirement from university teaching at the end of 2003 allowed him to work full time on TLUD technologies and issues. By 2005, he had designed over 150 meaningfully-different experimental TLUD units, often traveling across America and to Mexico, Bolivia, Brazil, India, and other countries with stoves in his luggage.


FIGURE 15: JUNTOS B TLUD GASIFIER

In November 2004, a presentation and paper in Chile by Anderson and Reed about Biomass Gasification (Anderson & Reed, 2004) included the first usage of the descriptive words "top-lit updraft" (but not the TLUD acronym) and included Anderson's "Juntos B" stove (Figure 15) with forced air and separate air-base, gasifier canister, and pot supports. On that same trip, Anderson spent two weeks in Brazil at Rogerio

FIGURE 16: COMBINATION TLUD AND ROCKET PLANCHA STOVE, BRAZIL (2004)

Miranda's EcoFogão workshop. Using basic EcoFogão materials, he incorporated TLUD gasification into a dual-system TLUD & Rocket plancha/griddle stove with sufficient chimney to accomplish strong natural draft. Noeli Anderson used this stove (Figure 16) for cooking a meal for the staff at the end of this trip. This prototype plancha stove was made eight months prior to having the concentrator disk innovation. Anderson's first implementation of the concentrator disk occurred during his trip to Bolivia in mid-2005. Two weeks later he brought that TLUD-ND stove (with concentrator disk) to the August 2005 Stove Camp at Aprovecho (Figure 17) where it won the award for cleanest combustion (as tested on the new emissions equipment there at Aprovecho). In contrast to the known earlier natural draft TLUD attempts, this stove attained a reasonably consistent, controlled flame by incorporating a concentrator disk (or lid) with a short riser above it to improve the draft. It earned the name "Champion" that is still used to describe that natural draft TLUD configuration incorporated into subsequent designs (e.g., Mwoto and Troika). The first use of the acronym "TLUD" was by Anderson at this stove camp, and the pronunciation is credited to Dr. David Pennise, who pronounced it "T-LUD, as in T. Rex."

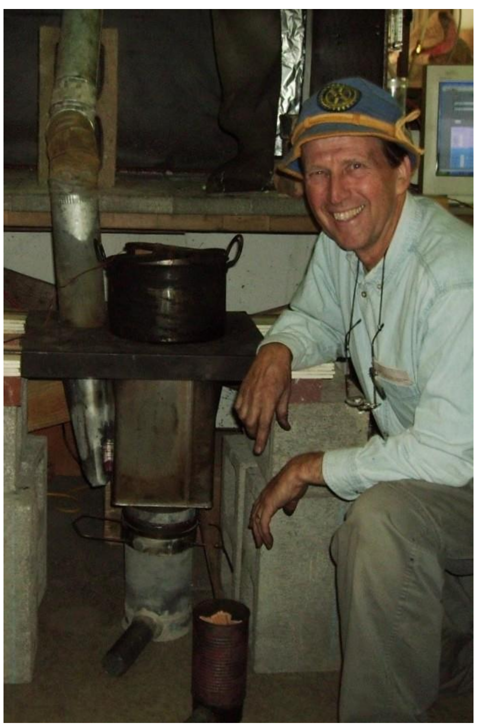


FIGURE 17: ORIGINAL "CHAMPION" TLUD (2005) WITH SECOND FUEL CONTAINER

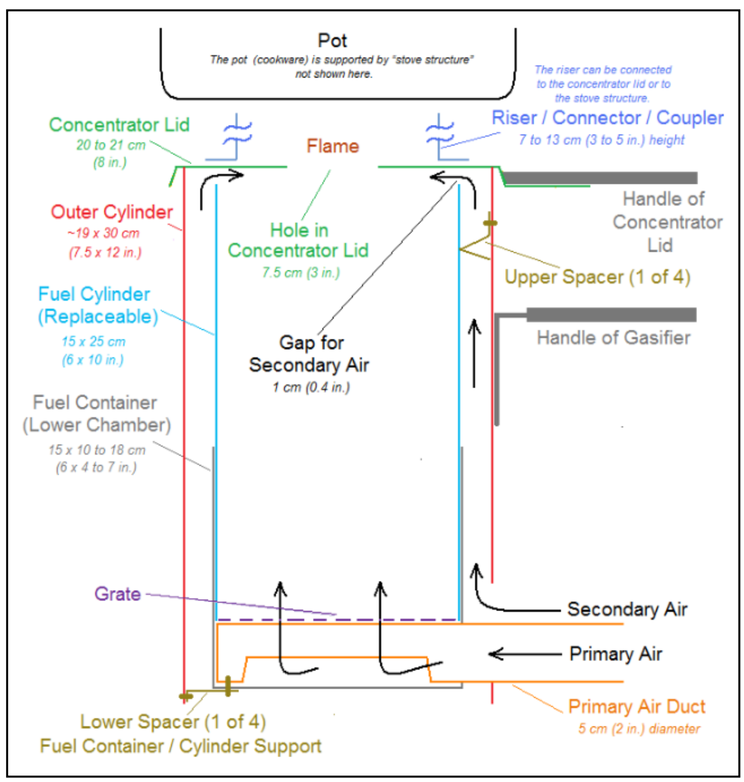


FIGURE 18: CHAMPION TLUD STOVE (2008)

In November – December 2005, Anderson and his wife Noeli went to India for five weeks, mainly in Phaltan at the operational center of the Karve-led ARTI (Appropriate Rural Technology Institute). There he produced several TLUD-ND stove configurations, including a natural draft gasifier water heater, as described by Barbar and Karve in their publication, *Natural draft gasifier water heater for rural households* (Babar & Karve, 2009).

FIGURE 19: WATER HEATER WITH TLUD HEAT SOURCE

By the end of 2006, Anderson had taken TLUD stoves to about a dozen countries for numerous meetings, conferences and short demonstrations. At present (January 2016), that number exceeds two dozen countries, including many where he hired and guided local tinsmiths to make TLUD stoves that he used in demonstrations showing local capabilities, materials and associated costs, including locally-gathered biomass fuels. He has attended twenty week-long, open-access stove camps (some with emphasis on the biochar-making capabilities of TLUD stoves). These camps were held in Uganda, Kenya, Honduras, China, Australia, Germany, and four USA states (IL, MA, CA, and nine times in OR at Aprovecho). At fourteen of them, he has been an official instructor or organizer, usually with Christa Roth, Hugh McLaughlin or Dean Still. Anderson and others point out the great utility of such "camps/workshops" to deliver practical, hands-on experiences as well as technical instruction. The camps have been extremely important to the dissemination of TLUD knowledge and for the testing of TLUD capabilities for low emissions and strong efficiencies.

In July 2006 in Kunming, China, ARECOP (Asia Regional Cookstove Program, based in Indonesia) organized a four-day event for "Regional Training on Biomass Gasification for Thermal Applications in Small/Cottage Industries," which was conducted masterfully by Drs. H.S. Mukunda and Bhaskar Dixit of CGPL, IISc, India. Participants came from eight Asian countries (including Alexis Belonio from the Philippines) and the USA (Anderson and Dean Still). This was largely classroom training of quantitative calculations and project planning, plus some demonstrations. The TLUD technology was well-represented in most of the participants' after-workshop projects. The business representative from BP did not disclose BP efforts to the participants, but did confidentially discuss with Anderson the development of the Oorja stove project.

The continuing growth and important networking of the Stoves Listserv should be noted in this timeframe. Also, an additional forum for discussions was started in May 2004 as a public group named WoodGas at Yahoo! Groups (https://groups.yahoo.com/neo/groups/WoodGas/info). The discussions in this group are specific to woodgas, including topics beyond stoves. Significant early discussions led by William Carr revolved around the "Midge" variation of TLUD stoves, mainly using tincans as "no-cost" stove-making materials. This site should not be confused with the WoodGas website (www.woodgas.com) started by LaFontaine, developed by Reed for the Biomass Energy Foundation (BEF), and now owned by Anderson for future development.

In 2003 Reed and his engineer godson Shivayam Ellis (son of Agua Das, another pioneer expert of micro-gasification) produced the Reed WoodGas Camp Stove (Figure 20) for commercial sales that have exceeded 5000 units. Essentially the same forced-air, stainless steel TLUD-FA

FIGURE 20: WOODGAS CAMP STOVE

(including at least two larger sizes) is still in production today by a company in India named Alpha Renewable Energy Pvt. Ltd. (http://www.ecochula.co.in/). [Note: Recent requests for information from Alpha Renewable Energy have gone unanswered.] With few exceptions, the WoodGas Camp Stove has been the developmental starting point of most forced-air micro-gasifiers.

Engineer Alexis T. Belonio of the Philippines was a university instructor and is an expert on all aspects of rice husks, including their gasification in large installations. On March 19-21, 2003, Belonio attended a seminar entitled "Training Workshop on Improved Wood Gasifier Stove" in Bangkok, Thailand, organized by the Asian Institute of Technology. The presenter was from Sri Lanka and is believed to have been Dr. Punchibanda. He demonstrated a TLUD gasifier with a fan. When informed that TLUD gasification would not work with rice husk fuel, Belonio took that as a friendly challenge. In 2006 he claimed on the Stoves Listserv that he had successfully achieved rice husk gasification in a TLUD-FA device. Upon verification of his success, he was encouraged by Anderson to continue that development work. He was eventually awarded a Rolex Prize for Excellence (Rolex, 2008). All known efforts today (about six) regarding rice husk micro-gasification in TLUD devices have been traced to Alexis Belonio's pioneer work.

FIGURE 21: ALEXIS T. BELONIO

Pyroneers

of TLUD Micro-Gasification Stove Technology

pioneer [From Merriam-Webster Dictionary (online)]

noun pi·o·neer \ˌpī-ə-ˈnir\

- : a person who helps create or develop new ideas, methods, etc.
- : someone who is one of the first people to move to and live in a new area

pyroneer [First known usage was by Alex English.]

noun pi·ro·neer \ˌpī-rə-ˈnir\

- : a person who helps create or develop new ideas, methods, etc. **about fire.**
- : someone who is one of the first people to move to and live in a new **topical space concerned with fire.**
- TLUD micro-gasification stove technology is one **pyroneer specialty** of many.

The individuals and entities named below are identified as **TLUD pyroneers**. Listed in approximate chronological order of initial involvement, each pyroneer had a substantial role in the early (pre-2007) years of the development of TLUD (Top-Lit UpDraft) micro-gasification stove technology.

1985 ~ 1993	**1994 ~ 2000**	**2001 ~ 2006**
Thomas B. Reed	Ronal W. Larson	Paul S. Anderson
Paal Wendelbo	Elsen Karstad	Alexis Belonio
Harry LaFontaine	Alex English	Sai Baskar Reddy
Fred Hottenroth	Andrew Heggie	Christa Roth
Tom R. Miles	Rob Walt	Daxu (company)
	Agua Das (Charles Ellis)	Paul van der Sluis
	Shivayam Ellis	John Davies
	Punchibanda	
	H. S. Mukunda	
	Sri Srinivas	
	A. D. Karve	
	Priyadarshini Karve	

Note: Individuals or entities initiating their involvement in later years might be called settlers or inventors, as the topical space they enter was already shaped and defined by the efforts of pyroneers in earlier years when "survival" was quite uncertain. Additional pyroneers can be added to this list if adequate documentation of their roles exists. Bystanders, observers, and critics are not included.

FIGURE 22: PYRONEERS OF TLUD MICRO-GASIFICATION STOVE TECHNOLOGY

Coming of Age (2007 ~ 2015)

2007 ~ 2010: Slowly Moving Toward Acceptance

In 2007 Paal Wendelbo wrote to the Stoves Listserv, mentioning his African experiences and his Peko Pe stove design. It was confirmed that he independently created a true TLUD-ND stove and that its most distinctive feature for successful ND operation, the concentrator ring, was conceived and utilized about twelve years before Anderson's usage of a concentrator lid on the Champion TLUD-ND. To Wendelbo goes the credit for making the first appropriately-successful natural draft TLUD stove. The Peko Pe has been reborn, with numerous people making copies. [Wendelbo provided good diagrams of the flat-metal parts and assembly (Figure 23).] Various efforts, mainly in Zambia, have included Wendelbo's son, Vetle, and fellow Norwegians Otto Formo and Jan Sorensen. Paal Wendelbo passed away in 2014, having seen fruits and worldwide recognition from his *pyroneer* labors with TLUD micro-gasifier cookstoves.

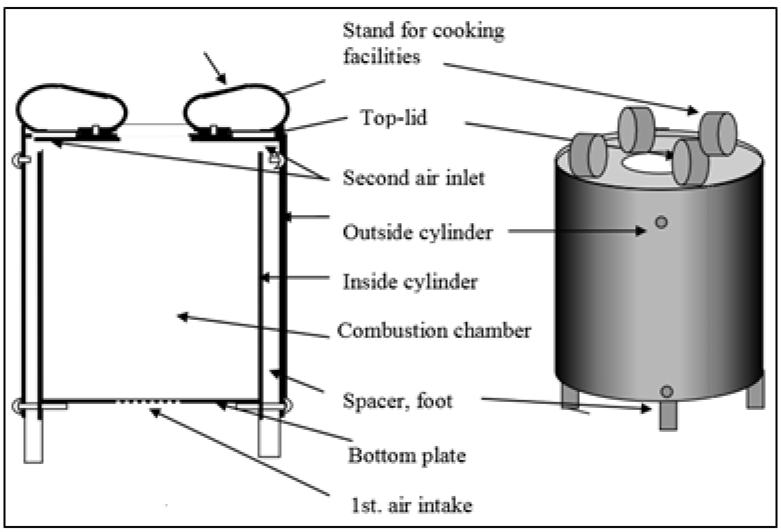


FIGURE 23: WENDELBO'S PEKO PE (2008)

FIGURE 24: PEKO PE STOVE (2013)

Engineer Paul van der Sluis, an avid outdoor cook in the Netherlands, started around 2007 to modify the WoodGas Camp Stove for personal use and later presented his design to his employer, Philips. This grew into the Philips HD4012 gasifier cookstove with FA. With about 15,000 units produced, Philips turned over its gasifier stove production to ACE (Africa Clean Energy) in Lesotho, southern Africa, until 2015. Note: An innovative feature in van de Sluis' personal stove (shown at Stove Camp 2010) is the use of five (5) concentric layers of metal, resulting in sufficient insulation to allow him to carry the ignited stove around, hugged in his arms.

The PCIA bi-annual Forum in 2007 was held in Bangalore, India, and brought Anderson and his TLUD materials into contact with stove enthusiasts from around the world, especially in India where TERI (The Energy and Resources Institute) was already conducting gasifier stove work, and where there was work (still confidential at that time) by BP on the Oorja stove.

In the mid- and late-2000s, BP (British Petroleum renewable energy office) conducted a massive project in India in cooperation with Prof. H.S. Mukunda's world-recognized gasification center at the Indian Institute of Science (IISc) in Bangalore. Eventually about 400,000 of the Oorja TLUD-FA gasifier stoves were produced (Figure 25). However, BP funding of the Oorja project stopped around 2010, and the off-shoot company First Energy has refocused its efforts on larger stoves for institutional cooking.

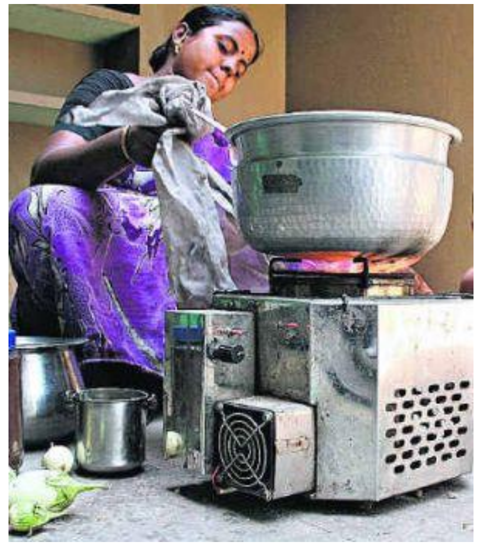


FIGURE 25: FIRST ENERGY OORJA STOVE

There are subtle but fundamental differences between the FA-TLUD stoves (with forced air) and the stoves known as "fan-jet" or "high turbulence" stoves. Fan-jet stoves include the Philips stove, the Biolite campstove, the forced-air Lucia stove by Worldstove, the Turbo stove by Rene Nunez of El Salvador, and the SalvaBosque design, also in El Salvador. These bottom-burning stoves have continual operation (with frequent fuel feeding required) and do not create char that can be easily extracted. See *Micro-gasification Terminology: An Instructional Summary of MG* (Anderson, 2013b).

Worldstove (company) also produced natural draft micro-gasifiers, but owner Nathaniel Mulcahy does not consider them to be TLUD devices and has not stated whether earlier TLUD/IDD stoves played any part in their development. They are discussed in detail at the Improved Biomass Cooking Stoves website (www.stoves.bioenergylists.org).

Interestingly, corporate ventures with big budgets to produce stoves are desirable, very serious efforts, but unfortunately their information about user acceptance (or lack of acceptance) and their stove testing emissions and efficiencies data are proprietary business information seldom shared with others. Most of what is known and readily available about TLUD stoves is from the free-sharing of experiences and data from individuals and, in the past five years, some non-corporate-funded reports.

FIGURE 26: CHAMPION TLUD-ND STOVE BY SERVALS

While in the Hyderabad area of India for three months in 2007 for stove development work at Sanghi Nagar, Anderson met Dr. Sai Baskar Reddy, who had a special interest in char production for biochar and was developing his own line of TLUD micro-gasifiers, mostly with forced air (FA). Anderson also shared information with Mr. P. Mukundan and Eng. Rajan Philip of the Servals company.

In 2009 sales began on the stainless steel Champion TLUD-ND by Servals in Chennai, India (Figure 26), yielding about 9000 units as of 2015, including the first TLUD stove project with carbon credit subsidy, in the Sundarbans region in the Ganges River delta. This stove was the first (and, until recently, the only) commercial TLUD designed with separate support of the cooking pot (by a tripod). It is one of the most available TLUD-ND stoves, with sales points spanning India, Australia, Europe and North America.

Cookstove innovator Crispin Pemberton-Pigott (a Canadian working for decades in Africa and more recently in Mongolia) has superior production skills that are seen in his Vesto stove (Figure 27). Vesto is somewhat of a hybrid because it can be operated in different modes of combustion, including a variation of TLUD micro-gasification.

FIGURE 27: VESTO STOVE

The road to acceptance has not been easy and includes some outright resistance to the TLUD technology in many sectors and by various participants. Being new and studied by so few people, micro-gasifier stove technology was not fully understood and certainly not fully developed as a technology in the early years. TLUD technology was only a curiosity item, even as recently as six years ago when an excellent cookstove article in The New Yorker Magazine (Bilger, 2009, p. 88) pointed out: "Like science and religion, stove design is riven into sects and disciplines. ….[For example], gasifiers can be remarkably clean-burning, but they're also finicky. …its flames are easily stifled when new fuel is added, turning the stove into a smoke bomb." The journalist did not get that information from the gasifier experts who certainly knew enough by then not to be adding new fuel while the stove is operating, as TLUD stoves operate in batch mode. In 2009 there was very little open interest in TLUD gasifiers, and such comments in the media (or behind closed doors) did not bring recognition or assistance. Indeed, the ESMAP report (ESMAP, 2015, p. 91) notes that "… six or seven years ago [2008 - 09] gasifier technologies were highly experimental…"

In general, progress was very slow and without financial assistance. Leaders of some established stove implementation projects (for rocket stoves, charcoal stoves, etc.) clearly declined to introduce TLUD gasifiers into their projects. One leader said "it could cause a mixed message and confuse the customers." But TLUDs kept on demonstrating very favorable low levels of emissions, and the stove designs improved.

The ability to conduct tests of stove emissions has dramatically improved in the 21st century. With moderate funding and vast volunteer efforts, engineers Dr. Tami Bond and Dr. Dale Andreata and staff at Aprovecho (then a community, now a research center) in 2004 – 05 developed relatively low-cost emissions testing equipment now in worldwide use. At Aprovecho each summer since 2005, the participants in Stove Camp can compete for the "Cat Pee Award" (so named because centuries ago the elimination of odor of feline urine on fuel was a test of emissions reduction). Each year the contest parameters are defined for a specific theme, and when the theme is related to clean combustion, the TLUD or other micro-gasifiers consistently dominate the competition. As mentioned earlier, Anderson's TLUD won the first Cat Pee Award and received the product name "Champion" in 2005. In 2009, Anderson used Aprovecho data to construct a graph comparing CO and PM emissions of several major types of cookstove technologies, including TLUD stoves (Figure 28). See *Interpretation of CO and PM Emissions Data from TLUD Gasifier Cookstoves* (Anderson, 2009). Due to ambiguities in definitions, some other comparative charts do not carefully distinguish between the different stoves lumped together as "gasifiers," delaying the recognition of what the best-designed TLUD stoves can accomplish.

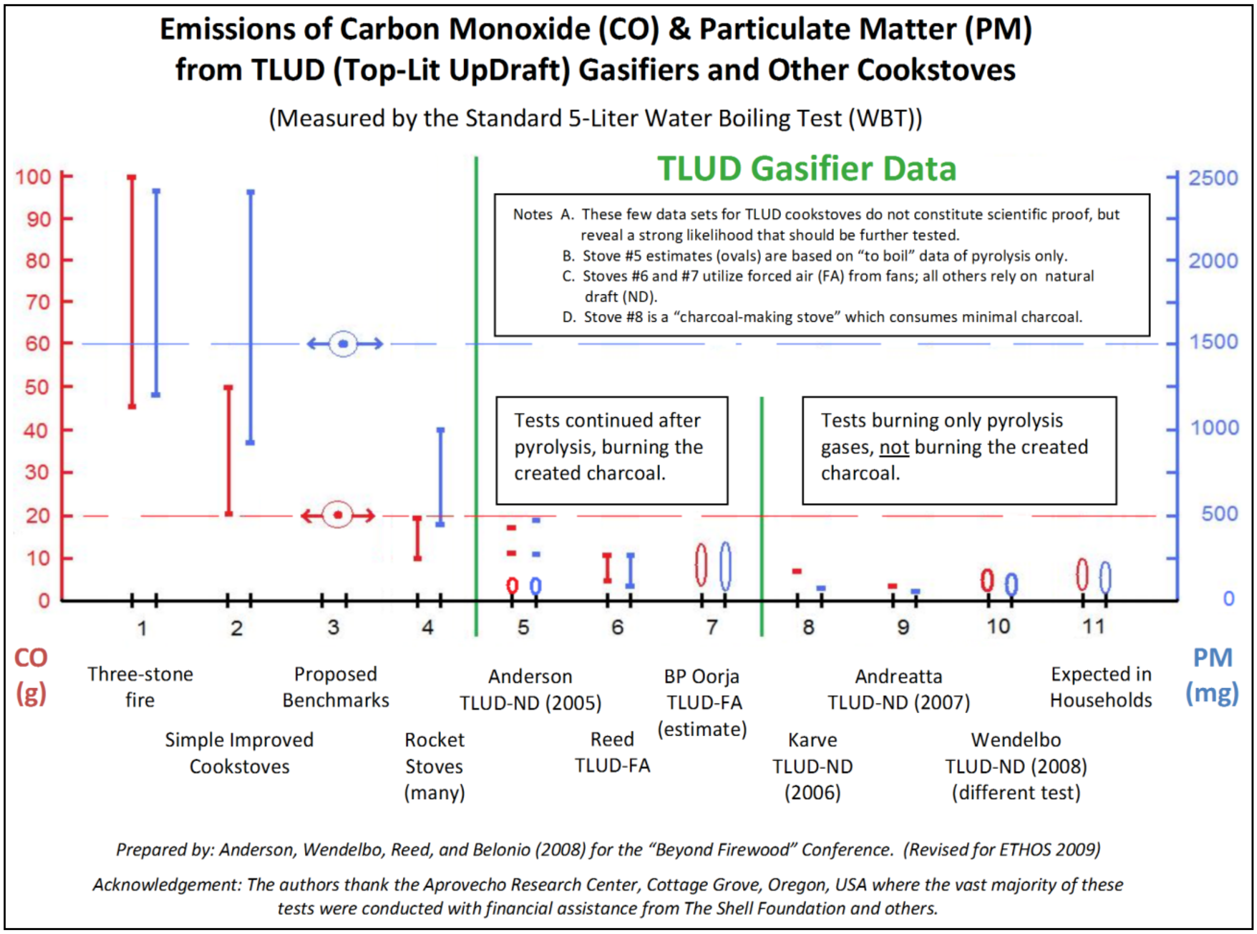


FIGURE 28: CO AND PM EMISSIONS GRAPH

Relating to more rigorous emissions testing at Aprovecho, the US EPA, and other locations, micro-gasifiers have consistently performed well whenever they have been included. Unfortunately, inclusions of the best TLUD designs were infrequent until recent years, partly because either most gasifier stoves were experimental prototypes without financing for production and implementation projects or they lacked an influential advocate to have them included.

2010 ~ 2015: Enlightenment

FIGURE 29: DAXU TLUD STOVE

In 2007, only a single TLUD entry [by Daxu (Anderson, *TLUD Gasifier in Ashden Award for Enterprise (Daxu cookstove from China)*, 2007)] was a finalist in (and won) a rigorous contest for clean cooking stoves made in China (Figure 29). By 2014 there were several TLUD gasifier stoves available in China, including ND and FA designs by Xunda that are sold in the USA by Silverfire. Stoves in

China, including micro-gasifiers, are also required for heating in the country's cooler climates, and they are notably heavier with longer life expectancy, greater fire-power (over 10 kW), and higher prices. These stoves illustrate the increasing range of designs and prices and features, including some designs with chimneys.

Several concurrent but unrelated TLUD projects have arisen since 2010 (or thereabouts). During 2010-2012, the first significant competitive funding was provided to a TLUD cookstove project by the World Bank's Biomass Energy Initiative for Africa (BEIA) project. In Uganda the Centre for Research in Energy and Energy Conservation (CREEC), with Paul Anderson as the lead stove designer, created the Mwoto TLUD-ND (Anderson, 2013a). [See Figure 30 and visit http://www.mwotostove.com for additional information]. It has gasifier and combustion characteristics very similar to the Champion TLUD, but with design changes that include support for a pot directly on the stove top. Approximately 3000 stoves were produced by independent tinsmiths in numerous districts. When the project finished in late 2012, two small companies (Mwoto Factories and Awamu Biomass Energy) were privately created for TLUD stove business in Uganda. Awamu (http://www.awamu.ug) has shifted its production to make the Troika Bingwa TLUD-ND (Figure 31). [Bibliography: (Anderson, 2013c) and (Anderson, 2014)] Similar TLUDs are produced in small quantities by tinsmiths in Kenya and Rwanda, and sample units have been recently provided for evaluation studies in Tanzania, Ethiopia, Haiti, and elsewhere from documentation found on the Internet.

FIGURE 30: MWOTO TLUD STOVES OF THE BEIA PROJECT IN UGANDA

Significant recognition and information dissemination about TLUD stoves resulted from a publication by Deutsche Geselischaft für Internationale Zusammenarbeit (GIZ) GmbH: *Micro-gasification: Cooking with gas from biomass*. Authored by Christa Roth (with co-author credit for the explanation of micro-gasification to Drs. Hugh McLaughlin and Paul Anderson), there currently exist two versions: a 96-page first edition (Roth, 2011) and a 158-page second edition (Roth, 2014). This publication is considered to be the single most important document available to newcomers to the field, including project administrators. It should be considered as both "required reading" and a major reference item for students, educators, stove designers, and experts in all fields related to improving cookstoves of all types.

FIGURE 31: TROIKA BINGWA TLUD-ND STOVE

Christa Roth's earlier appreciation and advocacy of TLUDs as being equal to other leading stove technologies was an important boost for acceptance.

National and international programs for clean cookstoves have a long history, but did not include any TLUD or other micro-gasifier stoves until the 2010-2015 period. The transition from the USA-led PCIA (Partnership for Clean Indoor Air) to the better-financed GACC (Global Alliance for Clean Cookstoves) happened to coincide with the rise of interest in micro-gasifier stoves. Testings of some TLUD stoves were included in the US EPA program. And the US DOE (Department of Energy) participated by providing some million-dollar grants that brought attention to TLUD capabilities. As mentioned in the introduction, some of those results were highlights at the ETHOS presentations in January 2015 and 2016. Additional programs by Winrock International, ACCESS and ESMAP (World Bank) also support and advance all cookstove progress, with some assistance reaching TLUD micro-gasifier efforts.

FIGURE 32: RICE HUSK TLUD GASIFIER

Professor M. Nurhuda in Indonesia initiated TLUD-ND production and, following the 2013 GACC Cookstove Forum in Cambodia, received financial backing by Differ for producing the Prime TLUD stoves. Except for the earlier big-budget gasifier stoves by BP and Philips (both with forced air), the Prime stove is among the first TLUDs to effectively utilize sheet-metal pressing to make stove parts in industrial quantities for TLUD stoves.

A few other TLUD projects emerged by 2014. Forced air TLUD stoves for rice husk (RH) fuel (Roth, 2014, pp. 138-144) include two units in India (TERI and Agni), five units in Vietnam (Thai Binh, Olivier, 2-walled SS from Rua, the Infrared modified DD, and CCS-SPIN stove), and one in the USA (JJQuad design by Joseph James). The originator of TLUD-FA-RH stoves, Alexis Belonio, has several designs (see Figure 18 and bibliography entry (Belonio, 2012)) and is continuing his work in the Philippines with sponsorship of Carbon Neutral Commons of Canada (www.carbonneutralcommons.org). Considering the massive abundance of rice husks (or hulls), these TLUD-FA stoves are poised to make great contributions for solving cookstove issues in many rice-producing countries.

In 2011 Christa Roth, Paul Anderson and Robert Fairchild were the innovators of the TChar style of TLUD stoves (Anderson, Roth, & Fairchild, 2011) in which the charcoal created in the TLUD

FIGURE 33: TCHAR TLUD STOVE IN USE IN AFRICA

top (the removable upper part) comes to rest in the lower half of the stove, which is designed for burning charcoal (Figure 33). Since then four companies have been making the TChar TLUD-ND designs: Wisdom Stoves' Malaika Jiko (Kenya), Jiko Bomba by Bjarne Laustsen (Tanzania), Betembo TChar (DR Congo) and Awamu (Uganda) (Roth, 2014, pp. 126-130).

More than a decade after Ron Larson's early interest in char-making stoves, the topic of biochar (using charcoal as a soil amendment) started to emerge around 2007 and has been gaining momentum worldwide since 2010. The quest for char quickly linked with the char-making capabilities of TLUD devices, and that mutually-beneficial association continues to bring significant interest for TLUD projects. Char production (for carbon sequestration) is also of extreme interest to the discussions of climate change, global warming, and atmospheric CO_2 increases. Plants remove atmospheric CO_2, and then 50% of that carbon can be captured for hundreds of years in pyrolytic charcoal placed into soil. Therefore, char production by TLUD methods represent carbon sequestration at low cost with appropriately-simple technology that can be readily available in potentially millions of small installations for cooking or for other uses of clean, renewable, sustainable energy utilizing what Karl Frogner calls "thinly distributed feedstock". Frogner, Ron Larson, Paul Anderson, Art Donnelly, Hugh McLaughlin, Paul Taylor and many others frequently make presentations about the char-making characteristics and capacities of TLUD devices at biochar and climate change meetings. They actively support the "quad-fecta" of symbiotic efforts for 1) healthy kitchens, 2) thermal energy, 3) biochar for agriculture/food production, and 4) climate care. Also to be recognized are the educational efforts of Kelpie Wilson (http://www.greenyourhead.com), Jock Gill, and many others who are incorporating topics of biochar, TLUD gasifiers and combustion into school curricula.

The Toucan TLUD device (Figure 34) is an excellent example of TLUD pyrolysis being used for char-making purposes. This device is also an excellent example of a "Tincanium" cookstove. More about Toucan TLUDs (including detailed construction plans) can be found in Hugh McLaughlin's paper, *1G Toucan TLUD for Biochar Production* (McLaughlin, 2010).

FIGURE 34: SEVERAL TOUCAN TLUD DEVICES

Early examples of TLUD stoves which were intended to produce char for biochar purposes include the Moto TLUDs by ACON in Kenya and the Estufa Finca (Figure 35) by Art Donnelly's SeaChar project in Costa Rica (http://www.seachar.org) (James, 2012). Both projects received funding from the National Geographic Society in the early 2010s, specifically for their production of biochar. Anderson was a technical adviser and visitor/reviewer to both projects. The rapidly growing interest in biochar since 2007 has called wider attention to the char-making capabilities of the TLUD technology, including barrel-size units.

The important impacts of biochar, carbon sequestration, and renewable energy are far more significant than what the two paragraphs above can convey. Those impacts could drive and finance the adoption of TLUD stoves for impoverished people who will gain, as a substantial bonus, the health benefits of lower harmful emissions.

FIGURE 35: ESTUFA FINCA FARM STOVE

As of late 2015 and early 2016, modern "industrial" production of TLUD stoves is rather limited, but making progress as noted previously for efforts mainly in India, China, and Indonesia. In South Africa, David Lello's Ekasi Energy company has the FAABulous™ Home Power 2-in-1 Appliance that provides electrical and thermal energy with its modular fan-assisted air-base and separate TLUD reactor that have many similarities with Anderson's previously-mentioned Juntos B prototype (Anderson, 2004).

Production in large quantities with very low costs can also be accomplished with the use of clay/ceramic in the TLUD components. In 2015 two efforts with particular promise are being conducted by Joshua "Jed" Guinto (Philippines) and Mahbubul Islam (Bengladesh).

Throughout the 15 years of ETHOS conference meetings, the number of TLUD efforts mentioned in presentations each year has grown from one to twenty, with the most significant rise in the last five years. At the ETHOS 2012 conference, Anderson gave the Keynote Presentation (Anderson, 2012) and made two declarations that are still true today:

1. Only 20% (approx.) of what can be learned about TLUD micro-gasification was then known (and in 2015 that percentage might be 25 or 30%), with much additional progress expected soon.

2. TLUD stoves are projected to account for 30 million of the 100 million-stoves target by the GACC for improved cookstoves by the year 2020.

[Note: In addition to the Microsoft PowerPoint slides of Anderson's ETHOS keynote presentation (Anderson, 2012), there is also a five-part video series of the event at the Dr TLUD YouTube channel (http://www.youtube.com/user/drtlud).]

Since 2011 there has been a website named Dr TLUD (www.drtlud.com) which is devoted to TLUD technology and stoves. It is under the creative and technical care of writer and website developer, James S. Schoner.

The Dr TLUD website

The Dr TLUD website (www.drtlud.com) was established on 04 July 2011 by Paul S. Anderson, PhD as a place to publish and make freely available documents, videos, news articles, slideshow presentations, and other electronic resources containing information about TLUD technology and projects around the world. Soon thereafter, Anderson acquired the former Biomass Energy Foundation (BEF) website (www.woodgas.com) and all related publications. Rather than maintain two closely-related websites, Anderson chose to re-publish all of the content of the former BEF website as resource items and other content formats as part of the Dr TLUD website. That re-publishing effort continues in 2016. [Note: The woodgas.com Internet domain name is reserved by Paul Anderson for future use.]

Today, the Dr TLUD website is a responsive website (friendly to the smaller screens of mobile devices) and receives hundreds of visitors daily from around the world. Some of its features include periodic news posts, an archive of resource items with a search utility, a list of Quick Picks (links to featured resource items), an Event Calendar, and Dr TLUD's featured projects by geographic area.

Website visitors who wish to engage in TLUD-related discussions are invited to join the Stoves Listserv and participate in the discussions there. Please visit http://lists.bioenergylists.org/mailman/listinfo/stoves_lists.bioenergylists.org for more information.

FIGURE 36: THE DR TLUD WEBSITE

The final comment about acceptance of TLUD stove technology relates to the changing demographics of stove developers and promoters (the people who can call themselves “Stovers”). There are long-established Stovers with credentials dating back before 2007, some for several decades; they often have commitments to the earlier stove technologies. TLUD stoves came to them new and unproven, and over the past thirty years (since 1985), TLUDs have gradually risen in acceptance and/or gained equal footing with older, established stove technologies and with older Stovers who do not want to be left behind. And, certainly, all are welcome.

But the “new” Stovers (not by age, but by when they began working with cookstove research after 2007) were generally exposed to micro-gasification topics before selecting preferences for specific stove technologies. They were uninhibited by preconceptions about what works and what does not work in combustion for small cookstoves. Many of them have more easily embraced TLUDs and have brought fresh vigor to develop these stoves. Three of these new Stovers are over 50: Kirk Harris, Dr. Julien Winter, and David Lello. And they will be joined by the young researchers now in graduate school or starting their careers.

TLUD stoves are like “the new kid on the block” who has finally gained some recognition and traction for further advancement. So 2015-2016 is a fitting time to declare the success of TLUD’s quest for acceptance amongst peers. The ESMAP/GACC Technical Report 007/2015 on *The State of the Global Clean and Improved Cooking Sector* (ESMAP, 2015, pp. 90-91) makes clear statements:

a. Section title: “High-Potential Newcomer: Gasifier Stoves”

b. “**The most exciting technology trend in the biomass cookstove sector is the growing range of forced draft and natural draft gasifier stoves**. These stoves have shown the greatest potential to improve health and environmental outcomes, at least under laboratory conditions.”

c. “At the very apex of cookstove technological innovation are fan gasifiers and fan jet stoves…”

d. “These gasifier technologies have great untapped potential. … now [2015] there are more than a dozen existing stove models in this category.”

The focus of TLUD efforts can now shift from efforts to gain acceptance by stove specialists and funding sources to efforts for gaining TLUD stove acceptance by household users around the world.

Evolution of the Fundamentals in TLUD Stove Design

Several important evolutionary breakthroughs mentioned and illustrated in this chronological history document are separated by many years and therefore by many pages of text, so a summary can be useful. TLUD micro-gasification technology has a migratory pyrolytic front (MPF) that produces charcoal separately from the combustion of the charcoal (a significant difference from fan-jet stoves). There are two main branches: natural draft (ND) and forced air (FA, which also can mean fan-assisted). Both relate to the fact that TLUDs (and most gasifiers) are air controlled, not fuel controlled. The early Hottenroth patent (Figure 5) and the Zmart Ztove (Figure 7) have the MPF, but were lacking in height above the gas-combustion zone. And when height was added to increase the draft in the Reed-Larson stove (Figure 9), the gases were intentionally forced out to the sides by the "gas wick," resulting in undesirable cooling of gases and separation of areas of flames when the gas flow was low. Reed concluded in the late 1990s that natural draft was not feasible in residential-size TLUD/IDD gasifiers. Reed, Walt, Punchibanda and others overcame the difficult combustion challenges with forced secondary air directly into the zone of rising hot combustible gases (Figure 11).

For natural draft units, one key to the solution was to bring together (concentrate) the gases and the secondary air through a central hole that forces mixing, higher heat, and cleaner combustion. Wendelbo, in 1993, and Anderson, in 2005, independently derived the concentrator disk solution (Figures 18 and 26). Anderson also incorporated a riser or "internal chimney" below the pot for height to strengthen the natural draft (Figures 18 and 26). Refinements are continual and very important, but the basic fundamentals of successful TLUD micro-gasification were identified by 2005.

FIGURE 37: EVOLUTION OF THE FUNDAMENTALS IN TLUD STOVE DESIGN

View to the Future (2016 and Beyond)

2016 ~ 2020: Onward for Dissemination and Acceptance by Users

To attain user acceptance, it is necessary to have sufficient production and sufficient varieties of stoves so that users have opportunities to try them and give feedback. Sufficient production numbers of several major designs and size variations are possible in the coming two years (2016 – 2017). This coincides with Phase 2 of the GACC strategic plan that targets 40 million new, appropriately-improved (low emissions) cookstoves of all types by 2017 (GACC, 2014). Of these, 5 to 15 million should be TLUD gasifier stoves.

Four major shifts are envisioned for the next two years.

1. Fuels for TLUD stoves will become more eco- and user-friendly, acceptable to the public, more plentiful, cleaner to handle, and more economical in price per cooking task. The associated fuel industries (making pellets and other fuels, including pre-processed, semi-processed, or not-processed fuels) will increasingly utilize inexpensive biomass, even feedstocks for which the industry is paid or subsidized to extract and process, such as invasive plants or essential thinning of forests.

2. TLUD stove designs will evolve to become less costly and more friendly to households. This includes industrial mass production of high-quality, light-weight, long-lasting, appealing gasifiers and associated stove products as well as components that are attractive, sturdy, and available with such variety that most cultural preferences will be accommodated and exceeded.

3. Fan-assisted forced air will be widely embraced, helping make TLUD stoves sought-after, prestige stoves for households with modest or higher affluence, especially in urban and peri-urban communities, with favorable impacts down into the lower income levels. TLUD-FA stoves will match the fan-jet stoves in operations and will be much more affordable and more easily maintained due to decreased failure of parts and ease of repair when needed.

4. The carbon-related and environmental aspects of TLUD stoves will be further recognized as coming from a) low emissions, b) less fuel use through improved efficiencies, c) more fuel sources that do not involve killing trees, d) TLUD pyrolytic production of charcoal, and e) optional uses of char as biochar. That recognition will attract carbon credits and environment-minded funding to the producers and distributors of TLUD stoves, with the final beneficiaries being the stove-using public and the environment.

FIGURE 38: BIOCHAR

Taken together, the four shifts should create a groundswell of interest and acceptance of TLUD stoves in each separate society, with very different combinations of each of the four shifts according to the societal situations. As each of these shifts gains momentum, the other three shifts will be facilitated, even into Phase 3 (2018 ~ 2020) of the GACC plans for an additional 40 million stoves (GACC, 2014) with increasingly better characteristics. Maybe half of them could be micro-gasifiers with TLUD or related technological advancements.

To reach the very poorest households in extreme poverty, TLUD-ND stoves (plus some with minimal electrical power for fan-assisted TLUD-FA operation with a few LED lights) will be shown to yield many benefits in health, environment and education. When the benefits are so numerous and substantial and eventually documented, governments will be in a position to leverage sufficient financial gains in public services to offset the costs of national programs to bring this technology to all of the people. Furthermore, when the full impact of biochar (charcoal into soil) is understood and appreciated, the char-making TLUD stoves will become an integrated part of the improvement of societies at all levels, and of the world as a whole.

The advancement of micro-gasifier stoves must not and will not stop in 2020. The GACC goal of one hundred million improved cook stoves by 2020 (GACC, 2014) is only one-fifth (and the easiest fifth) of the need for improved cookstoves around the world. Another hundred million are needed at least by 2025, plus replacement stoves and the continual need for fuel supply. Indeed, clean cookstoves and renewable biomass fuels are big businesses that can impact the smallest of households and benefit every nation.

Thirty percent of the eventual 500 million households would require 150 million TLUD stoves to be in use, plus replacements. If the major components could last for 5 years, that would result in an annual replacement of 30 million stoves. But the projected thirty percent could be considerably higher. By that time, this short history will be a much longer story, and written by younger Stovers.

Conclusion (Primary Author's Comment)

For Paul Anderson (the primary author of this document), 2015 was a turning point. TLUD micro-gasifiers have attained recognition and sufficient critical mass to proceed with less of his efforts for research and technology acceptance among the community of "Stovers" and program advocates. He expects to continue as "Dr TLUD" to support new and ongoing efforts by many others. But now he can more easily shift his emphasis, probably in two ways:

First, major efforts for awareness and high-volume cookstove production are needed to attain widespread acceptance of truly clean stoves by the diverse households that need them, and

Second, the issues and advantages of char-production by TLUDs and related pyrolysis technologies are yet to be widely known and accepted. This includes all of the issues of biochar, soil health, food production, re-forestation, atmospheric CO_2 reduction, sustainable development, and societal progress with peace, justice and caring. That should keep Anderson busy for a few more years.

And one last thought: Collectively on behalf of stove users everywhere, we express our sincere appreciation and thanks to everyone who has contributed to the journey of TLUD micro-gasifiers during these first thirty years of organized and shared efforts. It is gratifying that this technology for renewable clean energy is freely shared, unencumbered by issues of ownership, and with truly worldwide accessibility and potential impact. Numerous challenges still remain, but a tipping point has been reached, and the benefits of IDD / TLUD / MPF technology for cooking, heating, and char-making can now flow to everyone, especially to those most in need.

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