Final Report

Development of Improved Tobacco Curing Barn for Small Holder Farmers in Southern Africa

2007- 2008 Trials at Nature's Gift Testing Facility
Lilongwe, Malawi

Rocket Barn Field Test in Mponela and Kasungu

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Data Collection at Nature's Gift and in Kasungu was greatly assisted by the University of Twente Intern Nico Nijenhuis

The Rocket Barn project started in the season of 2005-2006. as a collaboration between Peter Scott, GTZ/ ProBEC, Department of Energy, DGIS and Limbe Leaf Tobacco Company. It has since grown to include a range of different stakeholders such as Imperial Tobacco, Alliance One, Opportunity International Bank of Malawi (OIBM), NBS Bank, Total Land Care (TLC), the Agricultural Research and Extension Trust (ARET), ATTT, TLTC , Philip Morris International (PMI), Japanese Tobacco International (JTI)

Highlights of this year's Rocket Barn Research

1. Testing at Nature's Gift Test facility 16 barns (10 different model types) were constructed. Data was collected from 65 separate cures.

2. Field tests conducted provided reliable sets of data for 41 farmers Fuel consumption data collected from 253 cures in total (148 from a Rocket Barn B, 105 from a Traditional Barn) shows that the **Rocket Barn** used an average of **12.8 m^3 / ton** of cured tobacco as compared to the **traditional barn** which used **25.1 m^3 /ton** of cured tobacco

3. Auction Floor sales data collected from 41 farmers who used both a traditional barn and a Rocket Barn shows that the Rocket Barn produced, on average, tobacco leaf with a price /kg value of $2.98 as opposed to the traditional barn which produced tobacco leaf with a price /kg value of $2.39. With an average annual yield per farmer of 2,053 kg (from these 41 farmers) we can expect the following outcome:

	Traditional Barn	Rocket Barn	Difference	Benefit	
M3 of wood / ton of tobacco	25.1	12.8	12.3	49.00%	savings
Price / kg of tobacco	$2.39	$2.98	$0.59	24.69%	increase
Value (USD)	2,053	2,053	$0.59	$1,211.27	increase
Fuel Costs	$285.00	$145.34	$139.66	$139.66	savings
				$1,350.93	

Total Annual financial benefit with Rocket Barn technology: USD 1350.93.

This analysis does **not** account for financial benefits due to increase in leaf yields, which have been estimated at 11%. Due to variation in packing rates and barn sizes it has not been possible to make definitive statements about yield increases due to the adoption of the Rocket Barn. A 10% increase in yield @ USD 2.98 would offer the farmers an additional USD 610 increase in total income. This means that the farmers one time investment of US$700 for the construction of the RB 3.0 can be easily repaid within the first year of operation

4. Field tests have also shown that the 250 stick and 500 stick Rocket Barn RB 2.1 (see table 1 for details) were a significant improvement over the Traditional barn **and** the RB 2.0.

5. Launching of Rocket Barn scale up in Malawi. Due to high demand from farmers for additional Rocket Barns, a project has been implemented to construct and sell 500 Rocket Barns in Malawi.

6. Manuals and working drawings have been completed for an improved Rocket Barn design:

7. New Designs and manuals for 2008
    i. Retrofit Rocket Barn (RBR 3.0) 250 Stick
    ii. New Rocket Barn (RBN 3.0) 250 Stick
    iii. RB3.0 TZ 250 Stick for Tanzania
    iv. RB 3.0 500 Stick

1.0 Testing at Nature's Gift testing facility

In September 2007 a number of design goals for the 2007–2008 curing season were set. Even though our curing season was cut short due to a hail storm that destroyed most of our test tobacco during the first week of March, we have met and in some cases, surpassed - these targets

Target for 2008	Outcome for 2008
Develop a 500 and 600 Stick Rocket Barn that will reduce the fuel consumption ratio to 2 kg of wood to 1 kg of cured tobacco	We increased the capacity of the 600 stick barn to 720 sticks. This Rocket Barn produced an astonishing average efficiency ratio (over two tests) of 1.5 kg of wood : 1 kg cured tobacco
Run a complete set of trials comparing the RB2.0 250 stick, 480 stick, 250 stick Venturi, and Traditional Barns	Working with ARET, we performed a minimum of 4 tests on 4 barns (Venturi 250 stick, 250 Stick Rocket, Traditional Barn 250 Stick and a 480 Stick Rocket Barn
Develop a low cost 250 Stick Rocket barn using a modified Traditional Barn structure	This years Rocket Barn Retrofit (RB3.0) of a traditional barn set a new record for a 250 stick Barn using only 2.15 kg wood:1 kg dried tobacco

Table 1: 16 separate barns were constructed at the test site. These 16 barns consisted of 10 different models. Data was collected from 65 cures. See attached excel file for details

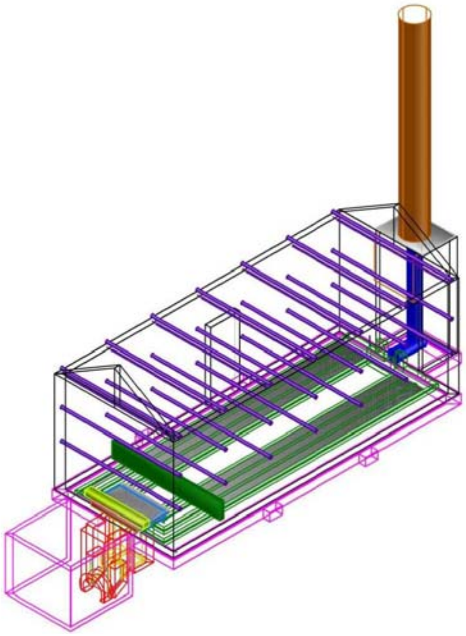
Barn	Design Features	Kg wood: Kg dried leaf ratio	% savings vs. 250 stick trad barn*	Barn Test code t
Trad 250	Traditional Barn 250 stick*	7.6 :1	0	T1-T2
Trad 180	Traditional Barn 180 Stick	7.3:1	4.2	T3
Venturi	250 Stick Conventional Venturi (ARET Barn)	4.9:1	34.7	V1
RB 2.0	250 Stick Rocket Barn (shelf furnace and all brick firebox/)	4.6:1	38.7	RB14
RB 2.1	250 Stick Rocket Barn (shelf furnace and brick/metal fireboxes	4.5:1	40.2	RB10
RB 2.2	250 Stick Rocket Barn (venturi furnace and brick/metal fireboxes	3.6:1	51.9	RB13
RB 2.1	500 Stick Rocket Barn (shelf furnace and brick/metal fireboxes)	2.9:1	62.2	RB3, 5,6
RB 1.1	500 Stick Rocket Barn (horizontal feed)	2.6:1	65.5	RB 1, RB 2
RB 2.2	500 Stick Rocket Barn (venturi furnace/ brick and metal fireboxes)	2.4:1	68.3	RB4
RB3.0	250 Stick Rocket Barn TZ (long wood)	2.2:1	71.1	TRH-4
RB3.0	250 Stick Rocket Barn MW (short wood)	2.1:1	72.3	TRH-1
RB 2.2	720 Stick Rocket Barn (venturi furnace and brick/metal fireboxes	1.5:1	80.6	RB12

*Unfortunately it was not feasible to construct a larger (250+) traditional barn to provide a meaningful comparison between 250+ Rocket Barns and 250+ traditional barns

t This column denotes the test code. It should not be confused with Barn design. For example Test code RB1-2 is not the same as RB 1.0 or RB2.0

1.1 Barn descriptions

RB1.0. A 250 stick and 480 stick model were produced during the 2005- 2006 season. This original Rocket Barn design features a:



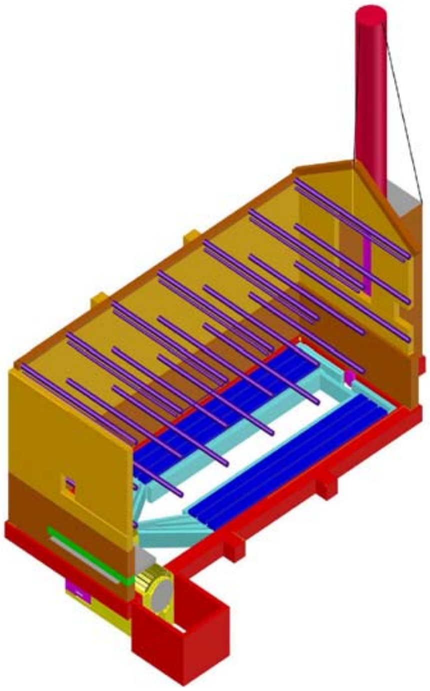
- vertical feed chamber
- submerged rocket combustion chamber
- 5 mm mild steel furnace plate
- refractory insulative bricks
- a mix of brick and metal fireboxes.

In **2007,** a new version of this barn was released (**RB1.1**Test code RB1 RB2) which featured a horizontal rocket feed chamber. 16 of these barns (480 stick version) were also disseminated in Tanzania and demonstrated favorable results . This is also the barn design that was tested at the Urambo seed farm in 2007 in Tanzania.

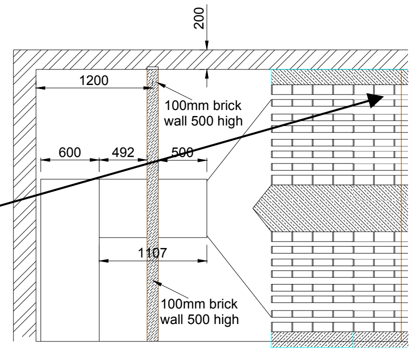
This model, although efficient, has been discontinued and is no longer recommended due to its expensive and exotic components. All testing of this barn should be discontinued in TZ.

RB 2.0. (Test code RB14) This Barn was developed in the second season of testing in Malawi (2006-2007). It featured an:

- all brick furnace
- shelf furnace design
- 6 all brick ducts of 6 cm, 7 cm ,and 8 cm wide by 30 cm deep



RB2.1 (test code RB13) . This barn is the same as RB2.0 except:

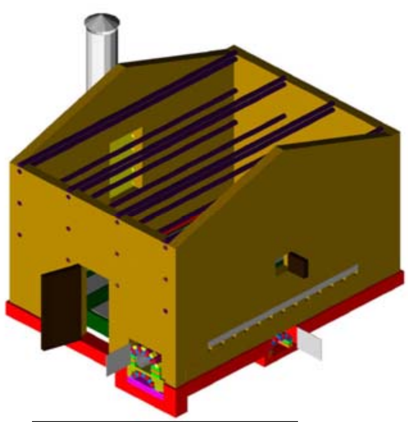


- 3.6 m from the end of the barn, the fireboxes (beyond redline shown) were reconstructed to accommodate metal sheeting. The six inner ducts under the metal sheeting were rebuilt to for 6 ducts, each duct being 17cm wide by 10 cm deep

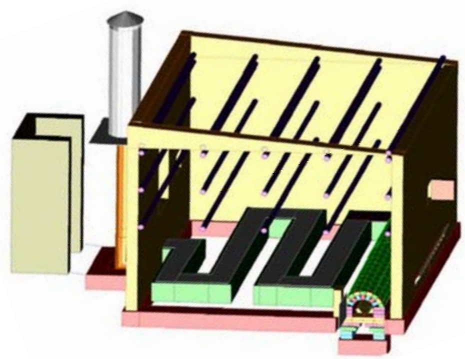
- **RB2.2** Same as above but with venturi furnace

This year we have develop three new Rocket Barns (**R.B 3.0**)

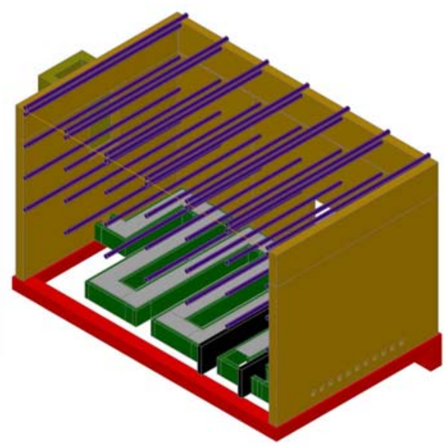
1. RB 3.0 MW 250 stick for shorter lengths of fuel wood (125 cm max length)
2. RB 3.0 TZ 250 stick for longer length of fuel wood (285 cm max length)
3. RB 3.0 MW 500 stick for shorter lengths of fuel wood (125 cm max length)



RB 3.0 250
STICK LONG



RB 3.0 250
STICK SHORT



RB 3.0 500
STICK SHORT

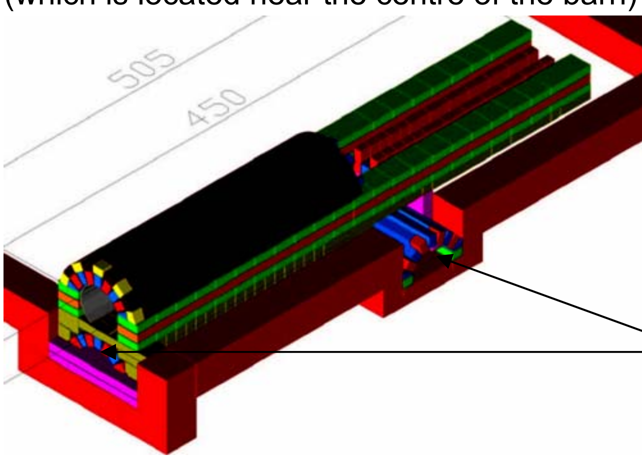
250 stick RB3.0 short

Originally the RB3.0 Long was intended for Tanzania (where processing indigenous fuel wood into shorter lengths is very difficult) and the RB3.0 Short was designed for Malawi. In reality, however, both models may be able to serve a niche that exists in either country.

Here is an outline of some of the improvements for the RB3.0 design .

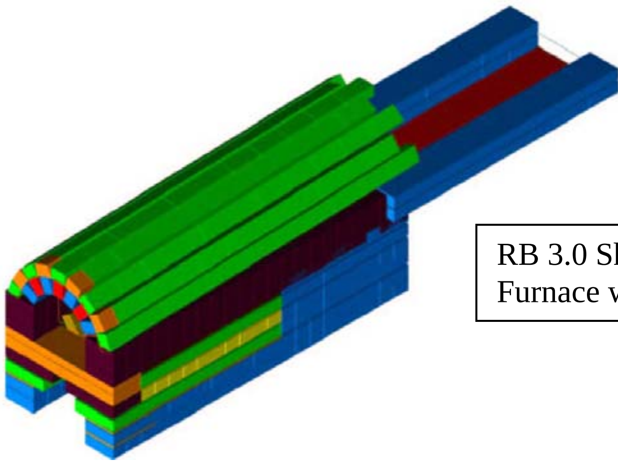
- Simplification. All exotic components have been removed. No specialized bricks, concrete lintels, or expensive 5 mm mild steel sheets are needed.
- In Malawi we are using the structure of an existing traditional barn and are ‘Rocketizing’ it which saves construction and materials. (This might not be possible to do in TZ as farmers don’t have a standard traditional barn)
- The 6 brick duct/ fireboxes of the RB2.0 – which required some complex measurement and construction- have been replaced with a single snake flue made form common bricks and flat sheet (see drawing above, RB3.0 Short) The snake system gives a greater than two fold increase in surface area as compared to the MW traditional barn.
- The height of the external metal chimney has been reduced from 3.8 m to 2.4m.
- The extended furnace (3m - 4.5m long) and the extended air inlet vent (2.5m – 3.5m long) offers greater surface area for preheating air as it enters the barn.
- Smaller footprint uses fewer bricks (4.5m by 4m as compared to 3 by 7m for the RB2.0)
- Full metal roof increases costs but ensures longevity of the barn
- Lower cost options (material and labour costs only)
    1. Retrofit with thatch roof (cost US$450)
    2. Retrofit with Metal (cost US$700)

The extended furnace (RB 3.0 Long) can accommodate wood that is 285 cm long by up to 38 cm in diameter. This design (shown below) separates the air intake (which is fixed, no door needed to regulate) and the ash cleaning pit (which is located near the centre of the barn)



RB 3.0 Long (TZ) Extended shelf furnace with separate side air intake

The extended venturi furnace (shown right) is designed to accommodate wood that is 120 cm long by up to 38 cm in diameter. These new RB 3.0 furnaces and barns, in terms of efficiency and performance, were almost identical (however , 60 kg more of wood was consumed for the longer TZ furnace). When tested at Natures gift test site this year they demonstrated a considerable savings - 2.15 kg of wood: 1kg cured tobacco as compared to last years average results of 4.3:1 for the RB2.0 .



RB 3.0 Short (MW) Venturi Furnace with extension

1.2 Findings from Nature's Gift

Making definitive statements about the efficiencies of the barns tested at Nature's Gift is a difficult undertaking. Not all barns were used throughout the season (which would not have been possible as certain designs didn't exist at the beginning of the season nor were all barns loaded with the same tobacco). Furthermore, as the season and reaping number progress all barns show a lower kg wood: kg tobacco ratio .However a few trends can be noted

- The 180 stick traditional barn (T3) performed better than the 250 stick traditional barn (T2). However, all traditional barns were nearly lost on numerous occasions due to fire. This was caused by overloading fuel in an attempt to 'push' the barns. Clerks 'pushed 'the traditional barns in an effort to 'keep up' with the improved barns. In the field, these barns would have been burnt down well before the season finished.
- The RB3.0 250 stick had a lower kg wood to kg tobacco ration than the RB2.0 500 stick.
- A considerable jump in efficiency was noted between the 500 stick and 720 stick version of the RB 2.1
- Although we still recommend the RB 2.2 Design for the 800 stick models, the new 250 and 500 stick barn require a different construction and geometry of the RB 3.0.

2.0 Rocket Barn Field Test

86 Rocket Barns (RB 2.0) were constructed in Mponela and Kasungu in 2007 Of these, 84 Barns were 250 stick Barns and the remaining 2 were 450 stick barns. Data collected provided reliable set of data from 41 farmers by 6 ProBEC data clerks. Wherever possible, data was collected from both Traditional Barns and Rocket Barns. However, many farmers refused to use their old traditional barn after using the new rocket technology. Farmers explained that due to the Rocket Barn's shorter curing interval (5.3 day average as opposed to 6.9 days) only one Rocket Barn was sufficient to cure their tobacco. Farmers commented repeatedly about how pleased they were with the quality of the Rocket Barn tobacco and that many farmers wanted to purchase a second barn. Data collected provided reliable sets of data from 253 cures in total, 148 from a Rocket Barn, and 105 from a Traditional Barn.

Table 2 : Comparison of Traditional Barns and Rocket Barn (RB 2.0) Wood consumption in Mponela and Kasungu (2008 season). See appendix A for a complete listing of results and error calculations

Barn type	m^3 wood /ton tobacco *Indigenous wood*	m^3 wood /ton of tobacco *Blue Gum*	Average m^3 wood /ton of tobacco	m^3 /ton % reduction	Avg days to cure	Barns destroyed by fire	Error calculation
Traditional 250 Stick	22.3	30.1	24.9	0%	6.9	3	4.5
Rocket Barn 250 Stick	13.6	11.4	12.6	49.5%	5.3	0	2.4
Rocket Barn 480 Stick			6.0	82.4	4.5	0	

3.0 Findings from Field test

Data collected by ProBEC in the 2008 tobacco season from farmers with reliable data sets from 6 cures or more (Nijenhuis, 2008), shows that farmers using a traditional barn consume an average of 28m^3 of stacked wood per ton of cured tobacco, the most efficient farmer using around 14.8m^3, and the least efficient around 57.8 m^3/ton tobacco. Firewood is not for free in Malawi, and a smallholder with 1 hectare of flue cured tobacco spent an average of $285 dollars last year on buying wood (Nijenhuis, 2008). Fuel wood costs accounted for almost 22% of the total average production costs of $1280 dollars last year, compared to the average income of $1575.

- The above table highlights that the Rocket Barn provided greater savings to farmers that used blue gum instead of indigenous wood.
- One farmer (Alick Banda) reduced his wood consumption from 34.3 m^3 /ton of cured tobacco with traditional 250 stick barns to 6.0 m^3/ton of cured tobacco by using a 480 stick rocket barn.

The results from the data collected in Mponela and Kasungu show that the **Rocket Barn 250 stick (RB2.0 shown left) reduces consumption by 49%** as compared to a traditional barn. Given the improved performance of this years new RB3.0 Barn we can expect even higher savings this coming season in the field.

Three different variations of the Rocket Barn were also tested:

- RB 2.0 shelf furnace / 6 all-brick ducts (121 cures)
- RB 2.1 shelf furnace/ brick and metal (14 cures)
- RB2.0 same as above but with shorter conical Chimney (13 cures)

RB 2.1 reduced farmers fuel consumption by 67.4 % as compared to the RB 2.0 (both types) which only reduced fuel consumption by 48%. The 'Crispin Pemberton Piggot chimney did not have a quantifiable effect on barn performance.

Table 3 Overall figures different types of barns, m3 wood / ton tobacco (all tests included)

Overall figures different types of barns, m3 wood / ton tobacco (all tests included)

				# of samples
RB 2.0	**Normal Rocket Barn Field Test average**		13.1	121
	All wood species	savings	48.0 %	
RB2.1	**Rocket Barn with flat sheet fireboxes average**		8.2	14
	All wood species	savings	67.4 %	
RB2.0	**Rocket Barn with modified 'Crispin' chimney**		13.1	13
	All wood species	savings	48.0 %	

4.0 Results from 41 farmers at Auction Floors:

Auction Floor data was collected from 41 farmers who used both a traditional barn and a Rocket Barn. The Rocket Barn produced, on average, tobacco leaf with a price /kg value of $2.98 as opposed to the traditional barn which produced tobacco leaf with a price /kg value of $2.39. Assuming a 2,053 kg average annual yield per farmer we can expect the following outcome:

Table 4 a comparison of the financial benefits with the adoption of the Rocket Barn technology

	Traditional Barn	Rocket Barn	Difference	Benefit	
M3 / ton	25.1	12.8	12.3	49.00%	savings
Price / kg	$2.39	$2.98	$0.59	24.69%	increase
Annual yield	2053		$0.59	$1,211.27	increase
Fuel Costs	$285.00	$145.34	$139.66	$139.66	savings
				$1,350.93	

Total Annual financial benefit with Rocket Barn technology: USD 1350.92

Table 4 total farmer yields and average prices with traditional barn and Rocket Barn

	Farmer Totals			ROCKET BARNS			TRADITIONAL			Difference	% of Total
Farmer Name	$	Kgs	Avg Price	Weight	VALUE	Avg Price	Weight	VALUE	Avg Price	RBR TBF	cured by RB
Average	**279,224**	**100,101**	**2.79**	**67,561**	**201,338**	**2.98**	**32,540**	**77,886**	**2.39**	**0.59**	67%
Average Excl J.banda	**5,686**	**2,053**	**2.77**	**1,455**	**4,305**	**2.96**	**613**	**1,417**	**2.31**	**0.65**	71%
ALICK K BANDA	896	450	1.99	153	345	2.25	297	551	1.86	0.40	34%
MKWEZA MSELEMA	2,443	845	2.89	345	1,112	3.22	500	1,331	2.66	0.56	41%
NELSON MAYANI	1,641	881	1.86	452	1,152	2.55	429	489	1.14	1.41	51%
W. Mphadwe	2,733	966	2.83	411	1,364	3.32	555	1,369	2.47	0.85	43%
JOSEPH MWALE	2,899	977	2.97	560	1,822	3.25	417	1,078	2.58	0.67	57%
MCSHAMU BANDA	2,252	988	2.28	622	1,720	2.77	366	532	1.45	1.31	63%
JOHN KENNEDY	2,433	1,063	2.29	984	2,283	2.32	79	150	1.90	0.42	93%
KANKHANI KAFERE	2,838	1,069	2.66	714	1,970	2.76	355	868	2.45	0.31	67%
CHAKALE DAMUBULENI	2,908	1,188	2.45	963	2,650	2.75	225	259	1.15	1.60	81%
HAROLD CHIKUSE	3,124	1,254	2.49	1,010	2,557	2.53	244	568	2.33	0.21	81%
Rabson Santhe	3,485	1,342	2.60	689	1,969	2.86	653	1,516	2.32	0.54	51%
CHARLES SITIYA	3,514	1,374	2.56	945	2,716	2.87	429	798	1.86	1.02	69%
ZELA PHILMON	3,992	1,379	2.89	1,379	3,992	2.89				NA	100%
NOEL MASAITI	4,494	1,389	3.24	861	2,894	3.36	528	1,600	3.03	0.33	62%
NAOMI BANDA	3,777	1,411	2.68	761	2,287	3.01	650	1,489	2.29	0.71	54%
HAROLD CHIPOKOSA	4,337	1,412	3.07	1,252	4,053	3.24	160	283	1.77	1.47	89%
SAMUEL CHISALE	3,433	1,414	2.43	1,224	2,856	2.33	190	577	3.04	(0.71)	87%
ANDREW JAMBO	3,855	1,480	2.60	911	2,515	2.76	569	1,340	2.36	0.41	62%
EMMANUEL JASON	4,153	1,489	2.79	1,029	3,173	3.08	460	980	2.13	0.95	69%
EDGER JEKE (Jere?)	4,957	1,540	3.22	997	3,436	3.45	543	1,521	2.80	0.64	65%
ALEX BANDA	4,697	1,703	2.76	1,142	3,484	3.05	561	1,213	2.16	0.89	67%
PAUL NYENGELE	5,626	1,743	3.23	1,215	4,263	3.51	528	1,363	2.58	0.93	70%
Kamtala Chirwa	5,086	1,797	2.83	924	2,979	3.22	873	2,107	2.41	0.81	51%
LEVISON KABOWA	3,245	1,804	1.80	943	2,112	2.24	861	1,133	1.32	0.92	52%
MACDONALD BANDA	5,032	1,811	2.78	1,338	3,976	2.97	473	1,056	2.23	0.74	74%
SAPAYILA NKHOMA	5,873	2,080	2.82	1,764	5,257	2.98	316	616	1.95	1.03	85%
ELIAVI KAPONDA SOKA	5,765	2,111	2.73	1,123	3,109	2.77	988	2,656	2.69	0.08	53%
Geral Phiri	6,472	2,143	3.02	1,452	4,541	3.13	691	1,931	2.79	0.33	68%
HAPPY CHISIDZE	5,702	2,347	2.43	1,990	4,963	2.49	357	739	2.07	0.42	85%
PAUL KHATE	6,590	2,523	2.61	1,586	4,567	2.88	937	2,022	2.16	0.72	63%
THENDO KADZITCHITE	5,941	2,525	2.35	1,155	3,265	2.83	1,370	2,676	1.95	0.87	46%
Levison Nyirongo	7,165	2,751	2.60	2,025	6,034	2.98	726	1,131	1.56	1.42	74%
STEVEN BANDA	9,040	2,999	3.01	2,709	8,248	3.04	290	791	2.73	0.32	90%
GLADSON DZOMI	6,970	3,240	2.15	2,693	6,334	2.35	547	636	1.16	1.19	83%
W MTUWA	10,357	3,600	2.88	2,349	7,150	3.04	1,251	3,208	2.56	0.48	65%
MASHATILA ZIFA	11,397	3,667	3.11	2,827	8,841	3.13	840	2,556	3.04	0.08	77%
W. MTUWA	11,595	3,957	2.93	1,908	5,998	3.14	2,049	5,597	2.73	0.41	48%
MAKONO KAYA	12,897	4,220	3.06	3,522	11,221	3.19	698	1,676	2.40	0.78	83%
Rabson Mateyu	16,960	5,344	3.17	4,174	13,684	3.28	1,170	3,276	2.80	0.48	78%
H.A Kaponda	16,868	5,829	2.89	5,095	15,289	3.00	734	1,579	2.15	0.85	87%
JACK BANDA	51,782	17,996	2.88	9,365	29,157	3.11	8,631	22,625	2.62	0.49	52%

Two averages are shown in green at the top of the above table. The first represents averages for all 41 farmers. The second average represents 40 farmers and excludes Jack Banda's results. Jack Banda's high production figures (17,000 kg, or more than 8 times the farmer average) have a considerable impact on the total average price per kg. Without Jack Banda's results the actual average price per kg with the Rocket barn is USD 0.65 (USD .07 higher than the price quoted in table 4)

5.0 Inconsistencies between field data and tests at Natures gift

At nature's gift testing facility very little difference was found between RB 2.0 and 2.0 models

Table 5a Comparison of RB2.0 and RB2.1 at Nature's Gift Testing facility

Barn code	Firebox type	Barn Type	Kg wood (blue gum): kg dried leaf	% savings as compared to a 250 stick traditional barn*
RB14	All brick	250 Stick Rocket Barn RB 2.0 (shelf furnace and all brick firebox/)	4.6:1	38.7
Rb13	Brick and metal	250 Stick Rocket Barn RB 2.1 (shelf furnace and brick/metal fireboxes	4.5:1	40.2

However in the field the RB 2.1 showed a much more significant reduction.

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Table 5b Comparison of RB2.0 and RB2.1 in Kasungu and Mponela (field test)

Barn code	Firebox type	Barn Type	M3 wood: ton cured leaf	% savings as compared to a 250 stick traditional barn*
RB14	All brick	250 Stick Rocket Barn RB 2.0 (shelf furnace and all brick firebox/)	13.1	48
Rb13	Brick and metal	250 Stick Rocket Barn RB 2.1 (shelf furnace and brick/metal fireboxes	8.1	67.4

Note: Only 14 curing samples were taken for the RB 13 in the field vs 121 for RB 14

This discrepancy might be due to the farmer's lack of familiarity with an all brick furnace (slower warm up, less fuel required during mid rib drying). The new RB 3.0 utilizes a combination of brick and metal which offers a balance of responsive heat transfer and heat storage

Table 5c a comparison of barn performance in field and at Natures gift

Barn Location	% saving
Rocket at Nature's Gift	38.7
Rocket Barn in field	49.5

The fuel savings of the RB2.0 model were higher in the field than at the test site: a 49 % reduction in the field as compared to 38.7% at Natures Gift. This discrepancy could be attributed to data clerks at Natures Gift aggressively 'pushing' the traditional test barns, thereby using less wood but elevating the chance of burning the barn down. Farmers in the field know that pushing barns too quickly will lead to barn fires so they avoid pushing the barn too quickly.

6.0 Recommendations

- The 250 and 500 stick Rocket Barn should be built with the RB3.0 configuration

- The 800 stick Rocket Barn should be built with the RB 2.2 configuration (venturi furnace , Y furnace firebox interface, 6 all brick ducts leading into metal covered ducts . Similar to the RB2.1/ RB firebox configuration that was constructed in the field and Nature's Gift
- Construction of both RB 3.0 models (long and short) in Tanzania. Once these models are built (in July 2008) a decision will need to be made by ProBEC and ATTT/TLTC as to which design is deemed more suitable for Tanzania.
- Between August and November 10-50 new RB3.0 barns should be built and then tested against the traditional , Brazilian , and RB2.0 barns
- Monitoring of the new barns in Malawi , Zambia and Tanzania is required

Appendix A Methodology

Collected data

In each measurement taken, be it the average amount of leaves on a stick or the weight of wood going into a furnace, errors are involved. Assumptions have been made about these errors and are explained below, together with the mathematics involved to calculate the errors in for instance the kg's of wood per kg of tobacco.

The error in the stacked cubic meters is small. The wood is between 90cm and 110cm long, giving an extreme range of $0.9m^3$ per 'cube' if all the wood used is 90cm, which is highly unlikely, and up to $1.1m^3$ if all the wood is 110cm, which again is highly unlikely. Data clerks measure the amount of cubes used for a cure, so part of the total error will go into this and it can be stated that the error in measuring will be larger if more wood is used.
The error in the measurement of cubic meters is taken as 10% of the total amount used.

Weighing of wood happens with a few logs at a time. Thus it happens that a cure can have between 20 and 40 measurements. The digital scale used is accurate to one digit, however some of the wood will loose its bark before entering the furnace and will thus loose weight.
The error in the weight of wood is taken as 0.2kg's per measurement.

The correct positioning of the sticks have been marked in most of the barns, however the workers loading the barns can put more sticks on a pole if they are not paying attention. Thus the total number of sticks is counted. However, small mistakes in counting can be made. Assumptions are made here about the difference between errors in a 250-stick barn and larger barns.

The error in the number of sticks going into a 250-stick barn is taken as 5. For a 480-stick barn this number is taken to be 10, for a 780-stick barn it is taken to be 15 sticks. The same errors apply to the number of cured sticks coming out of a barn.

The weighing of green tobacco going into a barn happens in two weighings of 10 sticks. This happens on a digital scale with an accuracy of one digit. However, the occasion might happen that one or two of about 80 leaves per stick might fall off before the sticks enter the barn so it is not enough to state the error as being only 0.1kg per 10 sticks.
The error in the weight of 20 sticks of green tobacco entering a barn is therefore 0.3kg.

When the tobacco is cured, it is weighed separately from the sticks it was on. Since the cured tobacco is much lighter than the green tobacco, it looses about 85% of its weight, this measurement is assumed to be accurate. The tobacco coming from the 20 sticks is weighted in one batch, and will still have a small chance of loosing leaves along the way. The 20 sticks are weighed on the digital scale as well, separate from the tobacco. These sticks don't have the chance of loosing any part of their weight, so the accuracy of the scale determines the error in this case.
The error in the measurement of 20 sticks of green tobacco 0.15kg. The error in the weight of 20 sticks is 0.1kg.

It is hard to make any assumption about the error in the weight of slatpacks, since there is no control or insight over this part of the tobacco farm. Workers might mix tobacco from one cure with another, or misread the mechanical scales used.
Therefore, the error in slatpack weight of tobacco is taken to be 15% of the weight.

The number of leaves per stick varies, but a deviation of 5 leaves per stick is assumed. To minimize the error in the average leaves per stick going into a barn, 5 sticks are counted and the average is taken. Even though, this average will have an error since data clerks can make a mistake in counting, and different workers from the farm put the leaves on sticks, thus resulting in a different spread per worker.
Therefore, the error in average leafs per stick is taken as 5 leafs if only one stick has been counted. It is taken as 3 leafs if the leafs on 5 sticks have been counted.

Ashes are weighed as an indication of the efficiency of the barn. The error is substantial, since it is hard to get all the ashes out. Some will mix with earth while cleaning the ash pit and will not be useable, some will blow away if there is a strong wind.
The error in the weight of ashes is therefore taken to be 20% of the weight.

All the errors summed up, where the 'Δ' stands for 'error':

$$\Delta cubes\_used = 10\%$$
$$\Delta weight\_wood = 0.2kg \ \ per \ measurement$$
$$\Delta sticks = 5 \ \ for \ 250 - stick \qquad errors \ apply \ to \ \Delta cured\_sticks \ as \ well$$
$$= 10 \ \ for \ 480 - stick$$
$$= 15 \ \ for \ 780 - stick$$
$$\Delta green\_tobacco = 0.3kg \ \ for \ 20 \ sticks \ weighted$$
$$\Delta cured\_tobacco = 0.15kg \ \ for \ 20 \ strings \ weighted$$
$$\Delta weight\_sticks = 0.1kg \ \ for \ 20 \ sticks \ weighted$$
$$\Delta slatpack = 15\%$$
$$\Delta leafs\_stick = 3 \ if \ 5 \ sticks \ are \ counted$$
$$= 5 \ if \ 1 \ stick \ is \ counted$$
$$\Delta ash = 20\%$$

Calculated data

When calculating a function, where this function is dependent on one or more variables that carry an error in them, the error in the function itself can be calculated as follows:

$$f(g,h,j) \rightarrow \Delta f = \left|\frac{\delta f}{\delta g}\right| \cdot \Delta g + \left|\frac{\delta f}{\delta h}\right| \cdot \Delta h + \left|\frac{\delta f}{\delta j}\right| \cdot \Delta j \qquad (1)$$

Where $\left|\frac{\delta f}{\delta g}\right|$ stands for absolute value of the partial derivative of the function f to the variable g and Δg stands for the error in the variable g. This example shows a function f of three variables g, h, and j but one could extend this formula to an infinite amount of variables if needed.

Looking at the calculation for the total amount of green tobacco going into a barn, the formula is as follows:

$$tobacco\_in = \frac{green\_tobacco}{20} \cdot sticks - \frac{weight\_sticks}{20} \cdot sticks \qquad (2)$$

And thus the corresponding error for the total amount of green tobacco entering the barn, can be calculated in the following way:

$$\Delta tobacco\_in = \left|\frac{green\_tobacco - weight\_sticks}{20}\right| \cdot \Delta sticks + \left|\frac{sticks}{20}\right| \cdot \Delta green\_tobacco + \left|\frac{-sticks}{20}\right| \cdot \Delta weight\_sticks$$

(3)

The cured tobacco coming out of a barn is weighed without the sticks, so one loses a part of the formulas (2) and (3) and what remains is the following:

$$tobacco\_out = \left(\frac{cured\_tobacco}{20}\right) \cdot cured\_sticks$$

(4)

$$\Delta tobacco\_out = \left|\frac{cured\_tobacco}{20}\right| \cdot \Delta cured\_sticks + \left|\frac{cured\_sticks}{20}\right| \cdot \Delta cured\_tobacco$$

(5)

For the ratio of the kgs of wood per kg of cured tobacco, the formulas take the shape of:

$$wood/tobacco\_out = \frac{wood\_used}{tobacco\_out}$$

(6)

$$\Delta wood/tobacco = \left|\frac{1}{tobacco\_out}\right| \cdot \Delta wood\_used + \left|\frac{-wood\_used}{(tobacco\_out)^2}\right| \cdot \Delta tobacco\_out$$

(7)

The *wood_used* is the total amount of wood used, and the error in this is 0.2kg times the number of times logs have been weighted during the cure as described earlier.

The ratio of kg's of wood per kg of tobacco can also be calculated using the slatpack information from the farm. Formulas (6) and (7) will remain identical, except for the fact that *tobacco_out* gets replaced by *slatpack* everywhere:

$$wood/slatpack = \frac{wood\_used}{slatpack}$$

(8)

$$\Delta wood/slatpack = \left|\frac{1}{slatpack}\right| \cdot \Delta wood\_used + \left|\frac{-wood\_used}{(slatpack)^2}\right| \cdot \Delta slatpack$$

(9)

The last calculated number is the cubic meters of wood per ton of tobacco. Again, the *tobacco_out* information can be used as well as the *slatpack* information, basics of the formula do not change:

$$cub\_wood / ton\_tobacco = \left(\frac{1000}{tobacco\_out}\right) \cdot cubes\_used$$

(10)

$$\Delta cub\_wood / ton\_tobacco = \left|\frac{1000}{tobacco\_out}\right| \cdot \Delta cubes\_used + \left|\frac{-1000}{(tobacco\_out)^2}\right| \cdot \Delta tobacco\_out$$

(11)

$$cub\_wood / ton\_slatpack = \left(\frac{1000}{slatpack}\right) \cdot cubes\_used$$

(12)

$$\Delta cub\_wood / slatpack = \left|\frac{1000}{slatpack}\right| \cdot \Delta cubes\_used + \left|\frac{-1000}{(slatpack)^2}\right| \cdot \Delta slatpack$$

(13)

2. Results

250- and 180-stick Traditional Barns

$\Delta cubes\_used = 10\%$

$\Delta weight\_wood = 0.2kg \ \ per\ measurement$

$\Delta sticks = 5 \ \ for\ 250-stick \qquad errors\ apply\ to\ \Delta cured\_sticks\ as\ well$

$= 10 \ \ for\ 480-stick$

$= 15 \ \ for\ 780-stick$

$\Delta green\_tobacco = 0.3kg \ \ for\ 20\ sticks\ weighted$

$\Delta cured\_tobacco = 0.15kg \ \ for\ 20\ strings\ weighted$

$\Delta weight\_sticks = 0.1kg \ \ for\ 20\ sticks\ weighted$

$\Delta slatpack = 15\%$

$\Delta leafs\_stick = 3\ if\ \ 5\ sticks\ are\ counted$

$= 5\ if\ \ 1\ stick\ is\ counted$

$\Delta ash = 20\%$

$$f(g,h,j) \rightarrow \Delta f = \left|\frac{\delta f}{\delta g}\right| \cdot \Delta g + \left|\frac{\delta f}{\delta h}\right| \cdot \Delta h + \left|\frac{\delta f}{\delta j}\right| \cdot \Delta j$$

$$tobacco\_out = \left(\frac{cured\_tobacco}{20}\right) \cdot cured\_sticks$$

$$\Delta tobacco\_out = \left|\frac{cured\_tobacco}{20}\right| \cdot \Delta cured\_sticks + \left|\frac{cured\_sticks}{20}\right| \cdot \Delta cured\_tobacco$$

$$wood/slatpack = \frac{wood\_used}{slatpack}$$

$$\Delta wood/slatpack = \left|\frac{1}{slatpack}\right| \cdot \Delta wood\_used + \left|\frac{-wood\_used}{(slatpack)^2}\right| \cdot \Delta slatpack$$

$$cub\_wood\,/\,ton\_slatpack = \left(\frac{1000}{slatpack}\right) \cdot cubes\_used$$

$$\Delta cub\_wood\,/\,slatpack = \left|\frac{1000}{slatpack}\right| \cdot \Delta cubes\_used + \left|\frac{-1000}{(slatpack)^2}\right| \cdot \Delta slatpack$$

Please see attached excel for specific data on individual barn curing efficiencies

Appendix B Wood weights.

Although we would expect that indigenous wood would be denser than the Blue gum , the tendency to poorly stack indigenous wood accounts for its low kg/m3 rating

Indigenous wood

Weight of wood	Number of cubes	**Weight per cube**
1418	3.5	**400.6**
1554	4.4	**351.6**
1036	3.0	**345.3**
1033	4.4	**236.9**
948	3.4	**280.5**
1300	2.9	**456.1**
2033	3.5	**589.3**
1998.7	3.0	**666.2**
2176	5.6	**392.1**
1558	4.3	**361.5**
2939	6.5	**452.2**
2306	6.6	**352.1**
989	4.7	**210.2**
2812	4.0	**703.0**
2460	6.0	**410.0**
970	3.0	**323.3**
1010	2.8	**360.7**
590	1.4	**421.4**
1470	4.3	**338.7**

Average: **403**

Weighted average: **427**

Blue Gum

Weight of wood	Number of cubes	**Weight per cube**
998	2.8	**352.4**
1770	6.1	**289.6**
1243	3.5	**353.1**
849	1.4	**589.6**
991	1.6	**635.3**
1159	2.4	**482.9**
1160	2.4	**483.3**
2268	4.1	**555.9**
1062	1.8	**590.0**
869	1.4	**603.5**
2708	4.8	**564.2**

Average: **500**

Weighted average: **485**

Unknown wood type

Weight of wood	Number of cubes	**Weight per cube**
857	1.3	**659.2**
1544	2.4	**643.3**
1475	1.4	**1053.6**
1731	2.6	**665.8**
904	2.5	**361.6**
1183	2.2	**537.7**
800	3.0	**266.7**
894	1.5	**596.0**
1000	2.9	**344.8**
755	2.3	**331.1**
785	2.4	**327.1**
762	1.7	**448.2**
966	2.4	**402.5**
960	2.4	**400.0**
1783	3.4	**522.9**
610	1.7	**369.7**
450	1.3	**340.9**
890	3.0	**299.7**
500	1.4	**349.7**
980	2.8	**356.4**
855	1.4	**597.9**

Average: **470**

Weighted average: **452**