# The Water Boiling Test (WBT)

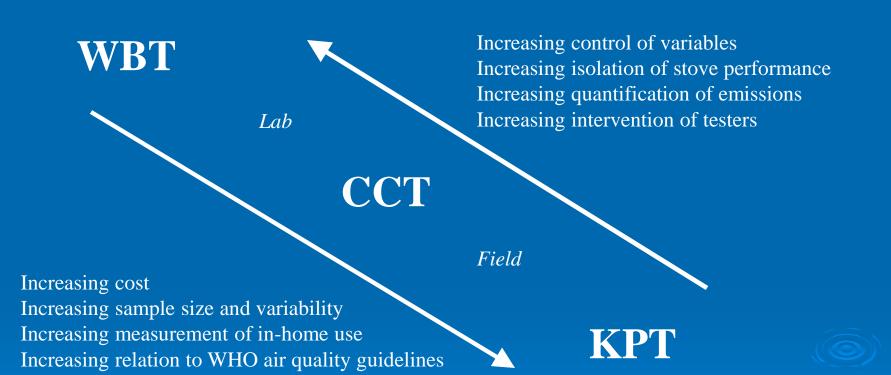
November 30, 2011 VERC Training Prepared by Ryan Thompson Lab Technician at Aprovecho Research Center With help from Nordica McCarty

#### The Water Boiling Test (WBT)

- Standardized, reproducible lab test
- Boil and simmer water
- Measure the boil time, fuel use, efficiency, and optionally emissions
- Trained tester carefully tends the fire
- > High and low power test phases
- Cold stove and hot stove test phases
- > Allows for multiple pots on one stove



### **Stove Testing Continuum**



#### Purpose of WBT

- Effective design tool to evaluate design changes of a stove
  - "...a simple method with which stoves made in different places and for different cooking applications can be compared through a standardized and replicable test."



#### Advantages of the WBT

- Reproducible, standardized
- Stoves from around the world can be compared
- A target performance level (benchmark) can be set based on comparisons
- Effects stove design changes can be observed quite clearly and relatively quickly

#### Disadvantages of the WBT

Not always reproducible When the tester or fuel changes

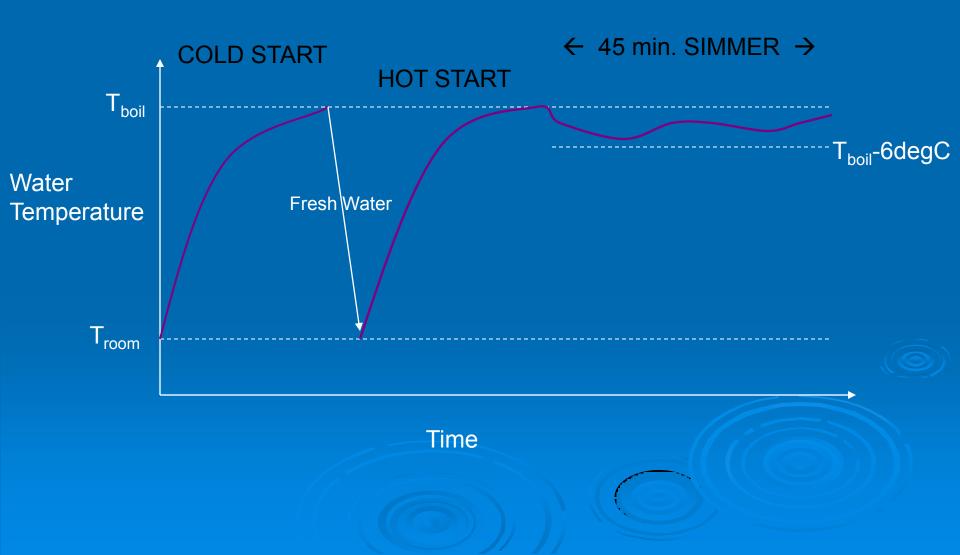
Not representative of field use Only one simulated cooking task

Hard to do for some stoves Batch-loading stoves: TLUD's, charcoal

# WBT Procedure

Phase	COLD START	HOT START	SIMMER
Task	Bring to Boil 5L in first pot	Bring to Boil fresh 5L in first pot	Simmer remaining 5L for 45 minutes
Record	Time Fuel Water Charcoal	Time Fuel Water *Assume Same Charcoal as Cold Start*	Time Fuel Water Charcoal

## **WBT Procedure**



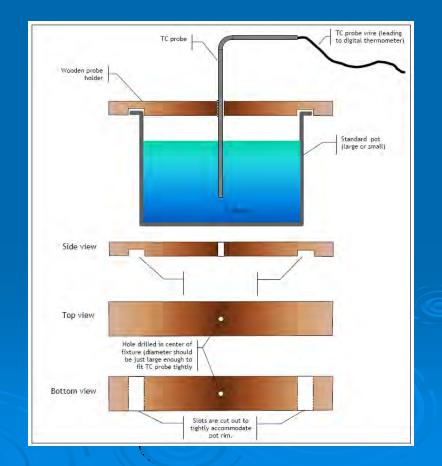
#### WBT – Preparing for the Test

#### First do a practice test to:

- Get familiar with the stove
- Determine if the stove should be tested with 2.5 or 5 liters
- Determine how much fuel is required
- Determine boiling temperature of water

#### WBT – Preparing for the Test Gather Supplies

- 1. Scale 6000g range, 1g resolution
- 2. Temperature sensor waterproof
- 3. Fixture for suspending temperature sensor
- 4. Wood moisture meter or oven for fuel MC



#### WBT – Preparing for the Test Gather Supplies

- 5. Timer or watch
- 6. Pot standard or dedicated, no lid
- 7. Heat resistant pad for scale
- 8. Charcoal scooper/tongs
- 9. Char tray
- 10. Heat resistant gloves
- 11. Water room temp,
  - at least 10 liters
- 12. Fuel air dried, uniform
  - 2 bundles ~ 2kg each

# WBT – Preparing for the Test Fill out page 1 of the Data and Calculation Sheet

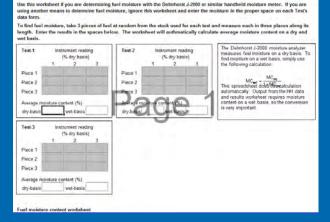
Name(s) of Tester(s) Test Number Date	Theionius 1 Feotuary 23.2				entry places in than the prima because the si	re testing a multi the simmering t ry pot are left bla immering test ca the primary pot	est for pots ank intentio n not accou	other nally
Sfove type/model Location Type of fuel Wind conditions Initial Test Conditions	Three slone fin Regional Test Average Softwoo No wind	ng Center of	Helsinki		If possible, enter the value in cell (0% MC). Use in calorific value ca	E19 if the calorif cell E22 if it is for	ic value is f moist fuel. d, choose t	or dry fuel If a local
Data		value	units	label	Data	value	units	label
Air temp	-	27.0	°C.		Dry weight of Pot # 1 (grams)	880	g	P1
verage dimensions of fi	iel (if solid)	2)4:30	.cm x cm	x cm	Dry weight of Pot # 2 (grams)	870	g	P2
Bross calorific value (dry	fuel)	20,817	kJ/kg	HHV	Dry weight of Pot # 3 (grams)	1. (1997) (1997) (1997)	g	P3
vet calorific value (dry fu	el)	19,497	kJ/kg	LHV	Dry weight of Pot #4 (grams)		g	E4
Wood moisture content (	% - wet basis)	15%	%	m	Weight of container for char (grams)	ZĎE	g	R.
Effective calorific value accounting for fuel mois	ture)	16,187	kJ/kg	Ceff	Local boiling point	100.0	°C-	Τe
Description of stove and	other comments:	<u>i</u>						

# WBT – Preparing for the Test Fill out page 1 of the Data and Calculation Sheet

#### **Determining Moisture Content**

Method 1:

-Use hand-held moisture to measure the  $MC_{dry}$ 



-Then convert to *MC<sub>wet</sub>* using the Fuel Moisture Sheet of the Excel WBT spreadsheet

Method 2:

Oven drying method





# WBT – Conducting the Test Phase 1: High Power Cold Start

- Set the pots on the stove with 5000g of water with the temp sensor suspended in the water of Pot 1.
- Record:
- Starting weight of pots with water
- Starting water temperatures
- Initial mass of the bundle of fuel
- Light the fire record start time
- Tend fire and bring water to a boil

		COLE	) START	HIGH POWE	R	HOT STAF	rt high f	OWER (OF	TIONAL)		SIMM	ER TEST	SIMMER TEST		
		Start		Finish:		Sta	rt	Finish:		Start	when	Finish:	45 min		
	1 1			Pot #1				Pot #1			1 boils	after Po			
Measurements	Units	data	label	data	label	data	label	data	label	data	label	data	labe		
Time (in 24 hour units)	hr:min	11:16	t <sub>ci</sub>		t <sub>or</sub>		t <sub>ni</sub>		t <sub>hr</sub>		t <sub>si</sub>		t <sub>st</sub>		
Weight of wood	g	2500	fci		for		fni		fhr		fsi		fst		
Water temperature, Pot # 1	°C	25.0	T1 <sub>cl</sub>		T1 <sub>cf</sub>		T1 <sub>N</sub>		T1 <sub>nf</sub>		T1 <sub>si</sub>		T1,		
Water temperature, Pot # 2	°C	25.0	T2 <sub>cl</sub>		T2 <sub>cf</sub>		T2 <sub>h</sub>		T2 <sub>hf</sub>	T1 is	set equal to	T, because	1		
Water temperature, Pot # 3	°C		T3 <sub>cl</sub>		T3 <sub>cf</sub>		T3 <sub>hl</sub>		T3 <sub>hf</sub>		imer test st	arts after the			
Water temperature, Pot # 4	°C		T4 <sub>cl</sub>		T4 <sub>cf</sub>		T4 <sub>n</sub>		T4 <sub>hf</sub>		pot has bo	iled.			
Weight of Pot # 1 with water	g	5880	P1 <sub>cl</sub>		P1 <sub>cf</sub>		P1 <sub>N</sub>		P1 <sub>nr</sub>		P1 <sub>si</sub>		P1,		
Weight of Pot # 2 with water	g	5870	P2 <sub>cl</sub>		P2 <sub>cf</sub>		P2 <sub>h</sub>		P2 <sub>hr</sub>	P1	should be	the make	1		
Weight of Pot # 3 with water	g		P3 <sub>cl</sub>		P3 <sub>cf</sub>		P3 <sub>h</sub>		P3 <sub>hf</sub>	remain	ing in pot or	ne at the end			
Weight of Pot # 4 with water	g		P4 <sub>cl</sub>		P4 <sub>cf</sub>		P4 <sub>n</sub>		P4 <sub>nf</sub>	of th	e hot start t	est (P1 <sub>M</sub> ).			
		10 grams p	aper		-		_		_						
Fire-starting materials (if any)															
Fire-starting materials (if any) Weight of charcoal+container	g				C <sub>C</sub>	SIM				DIFFER	FROM H	GH POWE			
Weight of charcoal+container	g	COLD STA	RT	HOT STAI	RT				_	DIFFER		GH POWE	R TES		
Weight of charcoal+container Calculations/Results	g <u>Units</u>	COLD STA data	RT label	HOT STAI	RT label	Calc	ulations	Results	LATIONS		<u>Units</u>	IGH POWE	R TES		
Weight of charcoal+container Calculations/Results Wood consumed (moist)	g <u>Units</u> g	COLD STA <u>data</u> 2,500	RT label f <sub>cm</sub>	data -	RT <u>label</u> f <sub>hm</sub>	Calc Woo	ulations/ d consum	Results ned during	LATIONS	ner phase	<u>Units</u> (rr g	data -	R TES		
Weight of charcoal+container Calculations/Results Wood consumed (moist) Net change in char during test	g <u>Units</u> g	COLD STA <u>data</u> 2,500 -	RT label f <sub>cm</sub> Δc <sub>c</sub>	<u>data</u> 	RT <u>label</u> f <sub>hm</sub> Δc <sub>h</sub>	Calco Wood Net c	ulations/ d consun hange in	Results ned during char durin	LATIONS the simn g test ph	ner phase	Units (r g g	<u>data</u> 	R TES <u>lab</u> f <sub>sn</sub>		
Weight of charcoal+container Calculations/Results Wood consumed (moist) Net change in char during test Equivalent dry wood consumed	g <u>Units</u> g g	COLD STA <u>data</u> 2,500 - 2,080	RT <u>label</u> f <sub>cm</sub> Δc <sub>c</sub> f <sub>cd</sub>	data -	RT <u>label</u> f <sub>hm</sub> f <sub>hd</sub>	Calco Woo Net c Equiv	ulations/ d consun hange in /alent dry	Results ned during char durin wood con	LATIONS the simn g test ph	ner phase	Units (n g g	data -	R TES <u>lab</u> f <sub>sr</sub> f <sub>sd</sub>		
Weight of charcoal+container Calculations/Results Wood consumed (moist) Net change in char during test Equivalent dry wood consumed Water vaporized from all pots	g <u>Units</u> g g g	COLD STA data 2,500 - 2,080 11,750	RT <u>label</u> f <sub>cm</sub> Δc <sub>c</sub> f <sub>cd</sub> W <sub>ov</sub>	<u>data</u> 	RT <u>label</u> _ f <sub>hm</sub> _ Δc <sub>h</sub> _ f <sub>hd</sub> _ w <sub>hv</sub>	Calco Woo Net o Equiv Wate	ulations/ d consun hange in /alent dry er vaporiz	Results ned during char durin wood con	LATIONS the simn g test ph sumed	ner phase	Units (n g g g	<u>data</u> 	R TES <u>lab</u> f <sub>sn</sub> Δc, f <sub>sd</sub> w <sub>s</sub>		
Weight of charcoal+container Calculations/Results Wood consumed (moist) Net change in char during test Equivalent dry wood consumed Water vaporized from all pots Effective mass of water boiled	g Units g g g g g	COLD STA data 2,500 - 2,080 11,750 583	RT <u>label</u> f <sub>cm</sub> Δc <sub>c</sub> f <sub>cd</sub> W <sub>ov</sub> W <sub>or</sub>	<u>data</u> 	<b>RT</b> <u>label</u> _ f <sub>hm</sub> _ Δc <sub>h</sub> _ f <sub>hd</sub> _ W <sub>hv</sub> _ W <sub>hr</sub>	Calco Wood Net o Equiv Wate Wate	ulations/ d consun hange in valent dry er vaporiz er remaini	Results ned during char durin wood con red ing at end	LATIONS the simn g test ph sumed	ier phase ase	Units (r g g g g	<u>data</u> 	R TES <sup>'</sup> <u>lab</u> f <sub>sm</sub> f <sub>sd</sub> w <sub>s</sub>		
Weight of charcoal+container Calculations/Results Wood consumed (moist) Net change in char during test Equivalent dry wood consumed Water vaporized from all pots Effective mass of water boiled Time to boil Pot # 1	g g g g g min	COLD STA <u>data</u> 2,500 - 2,080 11,750 583 (676)	RT <u>label</u> f <sub>cm</sub> Δc <sub>c</sub> f <sub>cd</sub> W <sub>cv</sub> W <sub>cr</sub> Δt <sub>c</sub>	<u>data</u> 	RT <u>label</u> _ f <sub>hm</sub> _ Δc <sub>h</sub> _ f <sub>hd</sub> _ W <sub>hv</sub> _ W <sub>hr</sub> _ Δt <sub>h</sub>	Calci Woo Net c Equiv Wate Wate Time	ulations/ d consun hange in alent dry r vaporiz r remaini of simme	Results ned during char durin wood con red ing at end er (should	LATIONS the simn g test ph sumed	ier phase ase	Units (r g g g g min	<u>data</u> 	R TES <u>labr</u> f <sub>srr</sub> Δc, f <sub>sd</sub> w <sub>s</sub> W <sub>s</sub>		
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# WBT – Conducting the Test Phase 1: High Power Cold Start

- When Pot 1 boils record:
  - Time
  - Temperature of all pots
  - Pot plus water weights
  - Fuel remaining
    - Break char off tips of burned sticks
    - Put char on tray and record weight of char plus tray

		COLE	D START	HIGH POWER		HOT STAF	rt high f	POWER (OPT	FIONAL)		SIMM	ER TEST	
		Start		Finish: w	hen	Star	rt	Finish:	when	Start:	when	Finish: 4	45 min
				Pot #1 b				Pot #1		Pot #		after Pot	
Measurements	Units	data	label	data	label	data	label	data	label	data	label	data	lab
Time (in 24 hour units)	hr:min	11:16	, v	11:45	~		t <sub>ni</sub>		ter		tsi		ts
Weight of wood	g	2500	f <sub>cl</sub>	1700	f <sub>cf</sub>		f <sub>hi</sub>		fnr		fsi		fs
Water temperature, Pot # 1	°C	25.0	T1 <sub>cl</sub>	100.0	T1 <sub>cf</sub>		T1 <sub>hi</sub>		T1 <sub>hr</sub>		T1 <sub>si</sub>		T1
Water temperature, Pot # 2	°C	25.0	T2 <sub>cl</sub>	86.0	T2 <sub>cf</sub>		T2 <sub>hl</sub>		T2 <sub>hf</sub>	T1.is	et equal to	T, because	1
Water temperature, Pot # 3	°C		T3 <sub>cl</sub>		T3 <sub>cf</sub>		T3 <sub>hl</sub>		T3 <sub>hf</sub>		mer test sta	arts after the	
Water temperature, Pot # 4	°C		T4 <sub>cl</sub>		$T4_{cf}$		T4 <sub>hl</sub>		T4 <sub>hf</sub>		pot has bo	iled.	]
Weight of Pot # 1 with water	g	5880	P1 <sub>cl</sub>	5030	P1 <sub>cr</sub>		P1 <sub>hl</sub>		P1 <sub>m</sub>		P1 <sub>si</sub>		P1
Weight of Pot # 2 with water	g	5870	P2 <sub>cl</sub>	5580	P2 <sub>cf</sub>		P2 <sub>hl</sub>		P2 <sub>h</sub>		should be t	he mass	1
Weight of Pot # 3 with water	g		P3 <sub>cl</sub>		P3 <sub>cf</sub>		P3 <sub>hl</sub>		P3 <sub>hf</sub>	remaini	ng in pot on	e at the end	
Weight of Pot # 4 with water	g		P4 <sub>cl</sub>		P4 <sub>cf</sub>		P4 <sub>hl</sub>		P4 <sub>hf</sub>	of the	e hot start te	est (P1 <sub>ht</sub> ).	J
			anor				-		·				
Fire-starting materials (if any)		10 grams p											
Fire-starting materials (if any) Weight of charcoal+container	 a	10 grams p	aper	250	cc				Ch				c
2 ( <i>I</i> ,	g				-	SIMM			_	DIFFER	FROM HI	GH POWER	
Weight of charcoal+container	g	COLD STA	RT	HOT STAR	T				_	DIFFER		GH POWER	R TES
Weight of charcoal+container Calculations/Results	g <u>Units</u>	COLD STA	RT label		T label	Calcu	ulations	Results	ATIONS		<u>Units</u>	GH POWER data	R TES
Weight of charcoal+container Calculations/Results Wood consumed (moist)	g <u>Units</u> g	COLD STA data 800	RT label f <sub>cm</sub>	HOT STAR	T <u>label</u> f <sub>hm</sub>	Calco Wood	ulations d consur	Results	ATIONS	er phase	<u>Units</u> (rr g		R TES
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Weight of charcoal+container Calculations/Results Wood consumed (moist) Net change in char during test Equivalent dry wood consumed	g <u>Units</u> g g	COLD STA data 800 44 600	RT <u>label</u> f <sub>cm</sub> Δc <sub>c</sub> f <sub>cd</sub>	HOT STAR	T <u>label</u> f <sub>hm</sub> ∆c <sub>h</sub> f <sub>hd</sub>	Calco Wood Net c Equiv	ulations d consun hange in valent dry	Results ned during t char during wood cons	ATIONS	er phase	<u>Units</u> (rrg g g		R TES <u>lab</u> - f <sub>s</sub> - Δα - fs
Weight of charcoal+container Calculations/Results Wood consumed (moist) Net change in char during test Equivalent dry wood consumed Water vaporized from all pots	g Units g g g	COLD STA data 800 44 600 1,140	RT <u>label</u> f <sub>cm</sub> Δc <sub>c</sub> f <sub>cd</sub> W <sub>cv</sub>	HOT STAR	T <u>label</u> f <sub>hm</sub> Δc <sub>h</sub> f <sub>hd</sub> W <sub>hv</sub>	Calco Wood Net c Equiv Wate	ulations d consum hange in valent dry er vaporiz	Results ned during t char during wood cons	ATIONS he simm ) test ph: sumed	er phase	Units (n g g g		R TES lab fsr fsr fsr fsr w
Weight of charcoal+container Calculations/Results Wood consumed (moist) Net change in char during test Equivalent dry wood consumed Water vaporized from all pots Effective mass of water boiled	g Units g g g g g	COLD STA data 800 44 600 1,140 7,981	RT <u>label</u> f <sub>cm</sub> Δc <sub>c</sub> f <sub>cd</sub> W <sub>cv</sub> W <sub>cr</sub>	HOT STAR data - - - - - - - - - -	T f <sub>hm</sub> Δc <sub>h</sub> f <sub>hd</sub> W <sub>hv</sub> W <sub>hr</sub>	Calco Wood Net c Equiv Wate Wate	ulations d consum hange in valent dry r vaporiz	Results ned during t char during wood cons red ing at end -	ATIONS he simm ) test pha sumed Pot # 1	er phase ase	Units (r g g g g		R TES <u>lab</u> - f <sub>s</sub> - f <sub>s</sub> - f <sub>s</sub> - w <sub>t</sub>
Weight of charcoal+container Calculations/Results Wood consumed (moist) Net change in char during test Equivalent dry wood consumed Water vaporized from all pots Effective mass of water boiled Time to boil Pot # 1	g g g g g min	COLD STA data 800 44 600 1,140 7,981 29	RT <u>label</u> f <sub>cm</sub> Δc <sub>c</sub> f <sub>cd</sub> W <sub>cv</sub> W <sub>cr</sub> Δt <sub>c</sub>	HOT STAR 	T <u>label</u> f <sub>hm</sub> Δc <sub>h</sub> f <sub>hd</sub> W <sub>hv</sub> W <sub>hr</sub> Δt <sub>h</sub>	Calco Wood Net c Equiv Wate Wate Time	ulations d consum hange in valent dry er vaporiz er remain of simm	Results ned during t char during y wood cons red ing at end - er (should b	ATIONS he simm ) test pha sumed Pot # 1	er phase ase	Units (r g g g g g min		R TES <u>lab</u> - Δα - f <sub>s</sub> - w <sub>t</sub> - w <sub>t</sub>
Weight of charcoal+container Calculations/Results Wood consumed (moist) Net change in char during test Equivalent dry wood consumed Water vaporized from all pots Effective mass of water boiled Time to boil Pot # 1 Temp-corr time to boil Pot # 1	g g g g g g min min	COLD STA data 800 44 600 1,140 7,981 29 29	RT $\frac{ abe }{f_{cm}}$ $\Delta c_{c}$ $f_{cd}$ $W_{cv}$ $W_{cr}$ $\Delta t_{c}$ $\Delta t_{c}$	HOT STAR data - - - - - - - - - -	T <u>label</u> f <sub>hm</sub> Δc <sub>h</sub> f <sub>hd</sub> w <sub>hv</sub> W <sub>hr</sub> Δt <sub>h</sub> Δt <sup>T</sup> <sub>n</sub>	Calco Wood Net c Equiv Wate Wate Time Ther	ulations d consum hange in valent dry er vaporiz er remain of simm mal effici	Results ned during t char during y wood cons red ing at end - er (should b	ATIONS he simm ) test pha sumed Pot # 1	er phase ase	Units g g g g min %	<u>data</u> - - - - - -	R TES <u>lab</u> f <sub>s</sub> f <sub>s</sub> w <sub>t</sub> - w <sub>t</sub> - - - - - - - - - - - - -
Calculations/Results Wood consumed (moist) Net change in char during test Equivalent dry wood consumed Water vaporized from all pots Effective mass of water boiled Time to boil Pot # 1 Themp-corr time to boil Pot # 1 Thermal efficiency	g Units g - g - g - g - g - min - min - %	COLD STA data 800 44 600 1,140 7,981 29 29 29 46%	$\begin{array}{c} \textbf{RT} \\ \underline{\textbf{label}} \\ \textbf{f}_{cm} \\ \Delta \textbf{c}_{c} \\ \textbf{f}_{cd} \\ \textbf{W}_{cv} \\ \textbf{W}_{cr} \\ \Delta \textbf{t}_{c} \\ \Delta \textbf{t}^{T}_{c} \\ \textbf{h}_{c} \end{array}$	HOT STAR 	$T \\ \frac{label}{f_{hm}} \\ \Delta c_h \\ f_{hd} \\ w_{hv} \\ W_{hr} \\ \Delta t_h \\ \Delta t_h^T \\ h_h$	Calco Wood Net c Equiv Wate Wate Time Therr Burni	ulations. d consum hange in valent dry er vaporizer remain of simm mal effici ng rate	Results ned during t char during y wood cons ted ing at end - er (should b ency	ATIONS he simm test pha umed Pot # 1 e ~45 m	er phase ase	Units g g g g min % g/min		R TES <u>lab</u> f <sub>s</sub> - f <sub>s</sub> - f <sub>s</sub> - w <sub>s</sub> - w <sub>s</sub> - Δ1 - h, - r <sub>s</sub>
Weight of charcoal+container Calculations/Results Wood consumed (moist) Net change in char during test Equivalent dry wood consumed Water vaporized from all pots Effective mass of water boiled Time to boil Pot # 1 Temp-corr time to boil Pot # 1 Thermal efficiency Burning rate	g Units g g g g min - g min - g min - g min	COLD STA data 800 44 600 1,140 7,981 29 29 29 46% 21	$\begin{array}{c} \textbf{RT} \\ \underline{\textbf{label}} \\ \textbf{f}_{cm} \\ \Delta \textbf{c}_{c} \\ \textbf{f}_{cd} \\ \textbf{W}_{cv} \\ \textbf{W}_{cr} \\ \Delta \textbf{t}_{c} \\ \Delta \textbf{t}^{T}_{c} \\ \textbf{h}_{c} \\ \textbf{r}_{cb} \end{array}$	HOT STAR 	$T \\ \frac{label}{f_{hm}} \\ \Delta c_h \\ f_{hd} \\ W_{hv} \\ W_{hr} \\ \Delta t_h \\ \Delta t_n^T \\ h_h \\ r_{hb} \\ r_{hb}$	Calco Wood Net c Equiv Wate Wate Time Therr Burni Spec	ulations d consun hange in valent dry er vaporiz er remain of simm mal effici ng rate ific fuel c	Results ned during t char during y wood cons red ing at end - er (should b	ATIONS he simm test pha umed Pot # 1 e ~45 m	er phase ase	Units (rr g g g g min % g/min g/liter	<u>data</u> - - - - - -	R TES lab $f_{er}$ $\Delta c$ $f_{sr}$ $W_{t}$
Veight of charcoal+container Calculations/Results Wood consumed (moist) Net change in char during test Equivalent dry wood consumed Water vaporized from all pots Effective mass of water boiled Time to boil Pot # 1 Temp-corr time to boil Pot # 1 Thermal efficiency Burning rate Specific fuel consumption	g g g g g min % g/min g/liter	COLD STA data 800 44 600 1,140 7,981 29 29 29 29 46% 21 75	$\begin{array}{c} \textbf{RT} \\ \hline \textbf{label} \\ \textbf{f}_{cm} \\ \Delta \textbf{C}_{c} \\ \textbf{f}_{cd} \\ \textbf{W}_{cv} \\ \textbf{W}_{cr} \\ \Delta \textbf{t}_{c} \\ \Delta \textbf{t}_{c} \\ \Delta \textbf{t}_{c} \\ \textbf{h}_{c} \\ \textbf{F}_{cb} \\ \textbf{SC}_{c} \end{array}$	HOT STAR 	$T \\ \frac{ abel }{f_{hm}} \\ \Delta c_h \\ f_{hd} \\ W_{hv} \\ W_{hv} \\ W_{hr} \\ \Delta t_h \\ \Delta t_n \\ h_h \\ r_{nb} \\ SC_h$	Calcu Wood Net c Equiv Wate Time Therr Burni Spec Firep	ulations d consum hange in valent dry er vaporiz er remain of simm mal effici ng rate ific fuel c ower	/Results ned during t char during y wood cons ted ing at end - er (should b ency consumption	ATIONS he simm test pha umed Pot # 1 e ~45 m	er phase ase	Units g g g g min % g/min	<u>data</u>	R TES <u>lab</u> - f <sub>s</sub> - Δc - f <sub>s</sub> - w <sub>t</sub> - Δt - h <sub>t</sub> - sc - Sc - FF
Weight of charcoal+container Calculations/Results Wood consumed (moist) Net change in char during test Equivalent dry wood consumed Water vaporized from all pots Effective mass of water boiled Time to boil Pot # 1 Temp-corr time to boil Pot # 1 Thermal efficiency Burning rate	g Units g g g g min - g min - g min - g min	COLD STA data 800 44 600 1,140 7,981 29 29 29 46% 21	$\begin{array}{c} \textbf{RT} \\ \underline{\textbf{label}} \\ \textbf{f}_{cm} \\ \Delta \textbf{c}_{c} \\ \textbf{f}_{cd} \\ \textbf{W}_{cv} \\ \textbf{W}_{cr} \\ \Delta \textbf{t}_{c} \\ \Delta \textbf{t}^{T}_{c} \\ \textbf{h}_{c} \\ \textbf{r}_{cb} \end{array}$	HOT STAR 	$T \\ \frac{label}{f_{hm}} \\ \Delta c_h \\ f_{hd} \\ W_{hv} \\ W_{hr} \\ \Delta t_h \\ \Delta t_n^T \\ h_h \\ r_{hb} \\ r_{hb}$	Calcu Wood Net c Equiv Wate Time Therr Burni Spec Firep	ulations d consun hange in valent dry er vaporiz er remain of simm mal effici ng rate ific fuel c	/Results ned during t char during y wood cons ted ing at end - er (should b ency consumption	ATIONS he simm test pha umed Pot # 1 e ~45 m	er phase ase	Units (rr g g g g min % g/min g/liter	<u>data</u> - - - - - -	R TES lab $f_{er}$ $\Delta c$ $f_{sr}$ $W_{t}$

# WBT – Conducting the Test Phase 2: High Power Hot Start

- Refill the pots with cool water and repeat the boil procedure starting with a hot stove
- Use a new bundle of wood
- This time, when Pot 1 boils keep the char in the combustion chamber. DO NOT WEIGH THE CHAR
- Weight the pots and place them back on the stove
- Weigh the wood, place it back in the combustion chamber, then re-light it.

				HIGH POWER				POWER (OPT	ONAL)		SIMM	ER TEST	
		Star	t	Finish: w		Start	t	Finish: w		Start:		Finish: 4	
	I			Pot #1 b				Pot #1 k		Pot #1		after Pot	
Measurements	Units	data	label	data	label	data	label	data	label	data	label	data	lab
Time (in 24 hour units)	hr:min	11:16		11:45	~	11:51	t <sub>ni</sub>	12:16			tsi		ts
Weight of wood	g	2500		1700	~	2500	f <sub>hi</sub>	1710	fnr		fsi		fs
Water temperature, Pot # 1	°C	25.0	T1 <sub>cl</sub>	100.0	T1 <sub>cf</sub>	26.0	T1 <sub>h</sub>	100.0	T1 <sub>hr</sub>		T1 <sub>sl</sub>		T1
Water temperature, Pot # 2	°C	25.0	T2 <sub>cl</sub>	86.0	T2 <sub>cf</sub>	26.0	T2 <sub>hl</sub>	100.0	$T2_{\rm hf}$	T1. is s	et equal to	T, because	
Water temperature, Pot # 3	°C		T3 <sub>cl</sub>		T3 <sub>cf</sub>		T3 <sub>hl</sub>		T3 <sub>hf</sub>	the sim	mer test sta	arts after the	
Water temperature, Pot # 4	°C		T4 <sub>cl</sub>		T4 <sub>cf</sub>		T4 <sub>n</sub>		$T4_{\rm hf}$	L	pot has bo	iled.	
Weight of Pot # 1 with water	g	5880	P1 <sub>cl</sub>	5030	P1 <sub>cf</sub>	5880	P1 <sub>h</sub>	5167	P1 <sub>hf</sub>		P1 <sub>si</sub>		P1
Weight of Pot # 2 with water	g	5870	P2 <sub>cl</sub>	5580	P2 <sub>cf</sub>	5870	P2 <sub>h</sub>	5650	P2 <sub>hf</sub>		should be f	he mase	-
Weight of Pot # 3 with water	g		P3 <sub>cl</sub>		P3 <sub>cf</sub>		P3 <sub>h</sub>		P3 <sub>hf</sub>	remainin	ng in pot or	e at the end	
Weight of Pot # 4 with water	g		P4 <sub>cl</sub>		P4 <sub>cf</sub>		P4 <sub>hl</sub>		P4 <sub>hf</sub>	of the	e hot start t	est (P1 <sub>ht</sub> ).	
Fire-starting materials (if any)		10 grams p	aper			none							
								0.50					c
Weight of charcoal+container	g			250	Cc			250	ch				Ľ
Weight of charcoal+container			DT			SIMM	ER TES			DIFFER		GH POWER	
-	Ĩ	COLD STA		HOT STAR	T			T (CALCULA		DIFFER			RTES
Calculations/Results	Units	data	label	HOT STAR	T label	Calcu	lations	T (CALCUL/	ATIONS		<u>Units</u>	GH POWEF data	R TES
Calculations/Results Wood consumed (moist)	Units g	<u>data</u> 800	label f <sub>cm</sub>	HOT STAR data 790	T <u>label</u> f <sub>hm</sub>	Calcu Wood	lations consur	T (CALCUL/ Results	ATIONS le simm	er phase	<u>Units</u> (n g		R TES
Calculations/Results Wood consumed (moist) Net change in char during test	<u>Units</u> g	<u>data</u> 800 44	<u>label</u> f <sub>om</sub> Δc <sub>o</sub>	HOT STAR <u>data</u> 790 44	T <u>label</u> f <sub>hm</sub> Δc <sub>h</sub>	Calcu Wood Net ch	lations consur hange ir	T (CALCUL/ /Results ned during th a char during	ATIONS le simm test pha	er phase	<u>Units</u> (mg g		R TES
Calculations/Results Wood consumed (moist) Net change in char during test Equivalent dry wood consumed	<u>Units</u> g g	<u>data</u> 800 44 600	<u>label</u> f <sub>cm</sub> ∆c <sub>c</sub> f <sub>cd</sub>	HOT STAR <u>data</u> 790 44 591	T <u>label</u> f <sub>hm</sub> ∆c <sub>h</sub> f <sub>hd</sub>	Calcu Wood Net ch Equiva	lations consur hange in alent dr	T (CALCULA /Results ned during th o char during y wood consu	ATIONS le simm test pha	er phase	<u>Units</u> (mg g		R TES lab - f <sub>s</sub> - Δα
Calculations/Results Wood consumed (moist) Net change in char during test Equivalent dry wood consumed Water vaporized from all pots	Units g g g	<u>data</u> 800 44 600 1,140	label f <sub>cm</sub> Δc <sub>c</sub> f <sub>cd</sub> W <sub>cv</sub>	HOT STAR <u>data</u> 790 <u>44</u> 591 933	T <u>label</u> f <sub>hm</sub> Δc <sub>h</sub> f <sub>hd</sub> W <sub>hv</sub>	Calcu Wood Net ch Equiva Water	lations consum nange in alent dr	T (CALCUL/ /Results ned during th o char during y wood consu	ATIONS le simm test pha umed	er phase	Units (mg g g	<u>data</u> - - - -	R TES $\frac{ ab }{f_{el}}$ $- \int_{f_{el}}$ $- f_{e}$ $- w_{f}$
Calculations/Results Wood consumed (moist) Net change in char during test Equivalent dry wood consumed Water vaporized from all pots Effective mass of water boiled	Units g g g g	data 800 44 600 1,140 7,981	label f <sub>cm</sub> Δc <sub>c</sub> f <sub>cd</sub> W <sub>cv</sub> W <sub>cr</sub>	HOT STAR <u>data</u> 790 <u>44</u> 591 933 9,067	T f <sub>hm</sub> ∆c <sub>h</sub> f <sub>hd</sub> W <sub>hv</sub> W <sub>hr</sub>	Calcu Wood Net ch Equiva Water Water	lations consur hange in alent dr vaporiz remain	FT (CALCUL/ /Results ned during th n char during y wood consu zed ing at end - F	ATIONS le simm test pha umed	er phase ase	Units (n g g g g	<u>data</u> - - - - -	R TES <u>lab</u> - f <sub>s</sub> - f <sub>s</sub> - f <sub>s</sub> - w <sub>t</sub>
Calculations/Results Wood consumed (moist) Net change in char during test Equivalent dry wood consumed Water vaporized from all pots Effective mass of water boiled Time to boil Pot # 1	Units g g g g g min	data 800 44 600 1,140 7,981 29	Iabel f <sub>cm</sub> Δc <sub>c</sub> f <sub>cd</sub> W <sub>ov</sub> W <sub>or</sub> Δt <sub>c</sub>	HOT STAR <u>data</u> 790 <u>44</u> 591 933 9,067 25	T f <sub>hm</sub> Δc <sub>h</sub> f <sub>hd</sub> W <sub>hv</sub> W <sub>hr</sub> Δt <sub>h</sub>	Calcu Wood Net ch Equiva Water Water Time o	lations consur ange in alent dr vaporiz remain of simm	FT (CALCUL/ /Results ned during th n char during y wood consu zed ing at end - f er (should be	ATIONS le simm test pha umed	er phase ase	Units (n g g g g min	<u>data</u> - - - -	R TES <u>lab</u> - f <sub>s</sub> - f <sub>s</sub> - g - w <sub>t</sub> - w <sub>t</sub> - Δt
Calculations/Results Wood consumed (moist) Net change in char during test Equivalent dry wood consumed Water vaporized from all pots Effective mass of water boiled Time to boil Pot # 1 Temp-corr time to boil Pot # 1	Units g g g g min min	data 800 44 600 1,140 7,981 29 29	label       f <sub>cm</sub> Δc <sub>c</sub> f <sub>cd</sub> Wov       Wor       Δt <sub>c</sub> Δt <sub>c</sub>	HOT STAR <u>data</u> 790 <u>44</u> 591 933 9,067 <u>25</u> 25	T <u>label</u> f <sub>hm</sub> ∆c <sub>h</sub> f <sub>hd</sub> W <sub>hv</sub> W <sub>hr</sub> ∆t <sub>h</sub>	Calcu Wood Net ch Equiva Water Water Time o Therm	lations consur nange in alent dr vaporiz remain of simm nal effici	FT (CALCUL/ /Results ned during th n char during y wood consu zed ing at end - f er (should be	ATIONS le simm test pha umed	er phase ase	Units g g g g min %	<u>data</u> - - - - -	R TES <u>lab</u> - Δα - f <sub>s</sub> - w <sub>t</sub> - w <sub>t</sub> - w <sub>t</sub> - Δt
Calculations/Results Wood consumed (moist) Net change in char during test Equivalent dry wood consumed Water vaporized from all pots Effective mass of water boiled Time to boil Pot # 1 Thermal efficiency	Units g_ g_ g_ g_ min _ min _ %	data 800 44 600 1,140 7,981 29 29 29 46%	$\begin{array}{c} \underline{label} \\ f_{cm} \\ \Delta c_{o} \\ f_{cd} \\ W_{ov} \\ W_{or} \\ \Delta t_{c} \\ \Delta t_{c} \\ \Delta t_{c}^{\top} \\ h_{c} \end{array}$	HOT STAR <u>data</u> 790 44 591 933 9,067 25 25 45%	T <u>label</u> f <sub>hm</sub> Δc <sub>h</sub> f <sub>hd</sub> w <sub>hv</sub> W <sub>hr</sub> Δt <sub>h</sub> Δt <sub>h</sub>	Calcu Wood Net ch Equiva Water Time o Therm Burnin	lations consur- nange in alent dr. vaporiz remain of simm nal effici ng rate	T (CALCULA /Results ned during th a char during y wood consu- zed ing at end - f er (should be ency	ATIONS le simm test pha umed	er phase ase	Units g g g g min % g/min	<u>data</u> - - - - -	R TES <u>lab</u> - f <sub>s</sub> - f <sub>s</sub> - f <sub>s</sub> - w <sub>t</sub> - w <sub>t</sub> - w <sub>t</sub> - h <sub>s</sub>
Calculations/Results Wood consumed (moist) Net change in char during test Equivalent dry wood consumed Water vaporized from all pots Effective mass of water boiled Time to boil Pot # 1 Temp-corr time to boil Pot # 1 Thermal efficiency Burning rate	Units g g g g min min g/min	data 800 44 600 1,140 7,981 29 29 29 46% 21	$\begin{array}{c} \underline{label} \\ f_{cm} \\ \Delta c_{o} \\ f_{cd} \\ W_{ov} \\ W_{or} \\ \Delta t_{c} \\ \Delta t_{c} \\ \Delta t_{c} \\ h_{c} \\ r_{ob} \end{array}$	HOT STAR <u>data</u> 790 44 591 933 9,067 25 25 45% 24	$T \\ \underline{label} \\ f_{hm} \\ \Delta c_h \\ f_{hd} \\ w_{hv} \\ W_{hr} \\ \Delta t_h \\ \Delta t_h \\ \Delta t_h \\ h_h \\ r_{hb} $	Calcu Wood Net ch Equiva Water Time o Therm Burnin Specif	lations consur- nange in alent dr vaporia remain of simm nal effici ng rate fic fuel o	FT (CALCUL/ /Results ned during th n char during y wood consu zed ing at end - f er (should be	ATIONS le simm test pha umed	er phase ase	Units (rr g g g g min % g/min g/liter	<u>data</u> - - - - -	R TES $\frac{ ab}{f_{sr}}$ $f_{sr}$ $f_{sr}$ $f_{sr}$ $h_{rs}$ SC
Calculations/Results Wood consumed (moist) Net change in char during test Equivalent dry wood consumed Water vaporized from all pots Effective mass of water boiled Time to boil Pot # 1 Temp-corr time to boil Pot # 1 Thermal efficiency Burning rate Specific fuel consumption	Units g g g g min min g/min g/liter	data 800 44 600 1,140 7,981 29 29 46% 21 75	$\begin{array}{c} \underline{label} \\ f_{cm} \\ \Delta c_{c} \\ f_{cd} \\ W_{cv} \\ W_{cr} \\ \Delta t_{c} \\ \Delta t_{c} \\ \Delta t_{c} \\ h_{c} \\ r_{cb} \\ SC_{c} \end{array}$	HOT STAR <u>data</u> 790 44 591 933 9,067 25 25 45% 24 65	T <u>label</u> f <sub>hm</sub> Δc <sub>h</sub> f <sub>hd</sub> w <sub>hw</sub> w <sub>hw</sub> w <sub>hr</sub> Δt <sub>h</sub> Δt <sup>T</sup> <sub>n</sub> h <sub>n</sub> SC <sub>h</sub>	Calcu Wood Net ch Equiva Water Time o Therm Burnin Specit Firepo	lations consum ange in alent dr vaporiz remain of simm nal effici ng rate fic fuel o ower	T (CALCUL/ Results ned during th c har during y wood consu zed ing at end - f er (should be ency consumption	ATIONS le simm test pha umed	er phase ase	Units g g g g min % g/min	<u>data</u> - - - - -	$= \frac{ at }{f_{e}}$ $= \Delta i$ $= 0$ $= 0$ $= 0$ $= 0$ $= 0$ $= 0$ $= 0$
Calculations/Results Wood consumed (moist) Net change in char during test Equivalent dry wood consumed Water vaporized from all pots Effective mass of water boiled Time to boil Pot # 1 Temp-corr time to boil Pot # 1 Thermal efficiency Burning rate Specific fuel consumption Temp-corr sp consumption	Units g g g min min g/min g/liter g/liter	data 800 44 600 1,140 7,981 29 29 46% 21 75 75	$\begin{array}{c} \underline{label} \\ \mathbf{f}_{cm} \\ \Delta \mathbf{C}_{c} \\ \mathbf{f}_{cd} \\ \mathbf{W}_{ov} \\ \mathbf{W}_{or} \\ \Delta \mathbf{t}_{c} \\ \Delta \mathbf{t}_{c} \\ \Delta \mathbf{t}^{T}_{c} \\ \mathbf{h}_{c} \\ \mathbf{SC}_{c} \\ \mathbf{SC}_{c}^{T}_{c} \end{array}$	HOT STAR <u>data</u> 790 44 591 933 9,067 25 25 45% 24 66 66	T <u>label</u> f <sub>hm</sub> Δc <sub>h</sub> f <sub>hd</sub> W <sub>h</sub> νν W <sub>h</sub> νν Δt <sub>h</sub> Δt <sup>T</sup> <sub>h</sub> h <sub>n</sub> SC <sub>h</sub> SC <sup>T</sup> <sub>n</sub>	Calcu Wood Net ch Equiva Water Time o Therm Burnin Specit Firepo	lations consur- nange in alent dr vaporia remain of simm nal effici ng rate fic fuel o	T (CALCUL/ Results ned during th c har during y wood consu zed ing at end - f er (should be ency consumption	ATIONS le simm test pha umed	er phase ase	Units (rr g g g g min % g/min g/liter	<u>data</u> - - - - -	$= \frac{ at }{f_{e}}$ $= \Delta i$ $= 0$ $= 0$ $= 0$ $= 0$ $= 0$ $= 0$ $= 0$
Calculations/Results Wood consumed (moist) Net change in char during test Equivalent dry wood consumed Water vaporized from all pots Effective mass of water boiled Time to boil Pot # 1 Temp-corr time to boil Pot # 1 Thermal efficiency Burning rate Specific fuel consumption	Units g g g g min min g/min g/liter	data 800 44 600 1,140 7,981 29 29 46% 21 75	$\begin{array}{c} \underline{label} \\ f_{cm} \\ \Delta c_{c} \\ f_{cd} \\ W_{cv} \\ W_{cr} \\ \Delta t_{c} \\ \Delta t_{c} \\ \Delta t_{c} \\ h_{c} \\ r_{cb} \\ SC_{c} \end{array}$	HOT STAR <u>data</u> 790 44 591 933 9,067 25 25 45% 24 65	T <u>label</u> f <sub>hm</sub> Δc <sub>h</sub> f <sub>hd</sub> w <sub>hw</sub> w <sub>hw</sub> w <sub>hr</sub> Δt <sub>h</sub> Δt <sup>T</sup> <sub>n</sub> h <sub>n</sub> SC <sub>h</sub>	Calcu Wood Net ch Equiva Water Time o Therm Burnin Specit Firepo	lations consum ange in alent dr vaporiz remain of simm nal effici ng rate fic fuel o ower	T (CALCUL/ Results ned during th c har during y wood consu zed ing at end - f er (should be ency consumption	ATIONS le simm test pha umed	er phase ase	Units (rr g g g g min % g/min g/liter	<u>data</u> - - - - -	

### WBT – Conducting the Test Phase 3: Low Power Simmer

- Record the start time once the fire is lit
- Transfer over the fuel weight, pot and water weight, and water temp from the results column at the end of the hot start
- Tend the fire to keep the water temp of Pot 1 at 3 degrees C below boiling for 45 min
- After 45 min of simmer record:
  - Final water temperature
  - Weight of Pot 1 plus water
  - Final weight of fuel and char remaining

	_			HIGH POWER				POWER (OPT				ER TEST	
		Start		Finish: w		Star	t	Finish: v		Starts		Finish: 4	
Measurements	Units	data	label	Pot #1 b data	label	data	label	Pot #1 t data	label	Pot #1 data	label	after Pot	#1 bo la
Time (in 24 hour units)	hr:min	11:16		11:45		11:51		12:16		12:1		13:02	
Weight of wood		2500	fci	1700	ler fer	2500		12.10		12.1		700	
	g ℃				T1 <sub>cr</sub>		1				01		
Water temperature, Pot # 1	°C	25.0		100.0		26.0		100.0		100.0	, 's	95.0	Т
Water temperature, Pot # 2	-	25.0		86.0	T2 <sub>cf</sub>	26.0		100.0				T <sub>b</sub> because	
Water temperature, Pot # 3	°C		T3 <sub>cl</sub>		T3 <sub>cf</sub>		T3 <sub>hl</sub>		T3 <sub>hf</sub>		ner test st pot has bo	arts after the siled	
Water temperature, Pot # 4	°C		T4 <sub>cl</sub>		T4 <sub>cf</sub>		T4 <sub>hl</sub>		T4 <sub>nr</sub>	L			
Weight of Pot # 1 with water	g	5880		5030	P1 <sub>cf</sub>	5880		5167		516	7 P1 <sub>si</sub>	4380	P
Weight of Pot # 2 with water	g	5870	·	5580	P2 <sub>cf</sub>	5870		5650		P1.	should be	the mass	
Weight of Pot # 3 with water	g		P3 <sub>cl</sub>		P3 <sub>cf</sub>		P3 <sub>hl</sub>		P3 <sub>hf</sub>	remainir	ng in pot o	ne at the end	
Weight of Pot # 4 with water	g		P4 <sub>cl</sub>		P4 <sub>cf</sub>		P4 <sub>hl</sub>		P4 <sub>hf</sub>	or the	not start t	est (P1 <sub>ht</sub> ).	
		10	anor			10 grams	paper			none			
Fire-starting materials (if any)		10 grams p	aper										
Fire-starting materials (if any) Weight of charcoal+container	g			250	-			250				280	
Weight of charcoal+container	g	COLD STA	RT	HOT STAR	T	SIMM	IER TES	T (CALCUL			FROM H	280 IGH POWER	
Weight of charcoal+container Calculations/Results		COLD STA	RT label	HOT STAR	T <u>label</u>	SIMM Calcu	IER TES	T (CALCUL	ATIONS	DIFFER	<u>Units</u>	IGH POWER	TE:
Weight of charcoal+container Calculations/Results Wood consumed (moist)	g	COLD STA	RT	HOT STAR data 790	T <u>label</u> f <sub>hm</sub>	SIMM Calcu Wood	IER TES	T (CALCUL /Results med during th	ATIONS	S DIFFER	<u>Units</u>	IGH POWER data 1,010	TES
Weight of charcoal+container Calculations/Results Wood consumed (moist) Net change in char during test	g <u>Units</u>	COLD STA	RT label	HOT STAR	T <u>label</u>	SIMM Calcu Wood Net cl	IER TES Ilations I consur hange ir	T (CALCUL) /Results med during th n char during	ATIONS ne simm test ph	S DIFFER	<u>Units</u>	IGH POWER	TES
Weight of charcoal+container Calculations/Results Wood consumed (moist) Net change in char during test Equivalent dry wood consumed	g <u>Units</u> g	COLD STA data 800	RT label f <sub>om</sub>	HOT STAR <u>data</u> 790 44 591	T <u>label</u> f <sub>hm</sub>	SIMM Calcu Wood Net cl	IER TES Ilations I consur hange ir	T (CALCUL /Results med during th	ATIONS ne simm test ph	S DIFFER	<u>Units</u> (rr g	IGH POWER data 1,010	tes <u>la</u> f
Weight of charcoal+container Calculations/Results Wood consumed (moist) Net change in char during test	g <u>Units</u> g g	COLD STA <u>data</u> 800 44	RT label f <sub>cm</sub> Δc <sub>c</sub>	HOT STAR <u>data</u> 790 44	T <u>label</u> f <sub>hm</sub> Δc <sub>h</sub>	SIMM Calcu Wood Net cl Equiv	IER TES Ilations I consur hange ir	T (CALCUL) /Results med during th n char during y wood conse	ATIONS ne simm test ph	S DIFFER	<u>Units</u> (r g g	IGH POWER <u>data</u> 1,010 30	t TES <u>lai</u> f <sub>t</sub> Δ
Weight of charcoal+container Calculations/Results Wood consumed (moist) Net change in char during test Equivalent dry wood consumed	g <u>Units</u> g g	COLD STA data 800 44 600	RT <u>label</u> f <sub>om</sub> Δc <sub>c</sub> f <sub>od</sub>	HOT STAR <u>data</u> 790 44 591	T <u>label</u> f <sub>hm</sub> Δc <sub>h</sub> f <sub>hd</sub>	SIMM Calcu Wood Net cl Equiv Wate	IER TES Ilations I consur hange ir alent dr r vapori:	T (CALCUL) /Results med during th n char during y wood conse	ATIONS ne simm test ph umed	S DIFFER	Units (r g g g	IGH POWER <u>data</u> 1,010 <u>30</u> 795	tes <u>lai</u> f <sub>e</sub> Δ
Weight of charcoal+container Calculations/Results Wood consumed (moist) Net change in char during test Equivalent dry wood consumed Water vaporized from all pots	g <u>Units</u> g g g g	COLD STA data 800 44 600 1,140	RT <u>label</u> f <sub>cm</sub> Δc <sub>c</sub> f <sub>cd</sub> W <sub>cv</sub> W <sub>cr</sub> Δt <sub>c</sub>	HOT STAR <u>data</u> 790 <u>44</u> 591 933	T <u>label</u> f <sub>hm</sub> Δc <sub>h</sub> f <sub>hd</sub> W <sub>hv</sub> W <sub>hr</sub> Δt <sub>h</sub>	SIMM Calcu Wood Net cl Equiv Wate Wate	IER TES Ilations I consur hange ir alent dr r vapori: r remain	T (CALCUL) /Results med during th n char during y wood consi zed	ATIONS ne simm test ph umed Pot # 1	6 DIFFER her phase ase	Units (mg g g	IGH POWER <u>data</u> 1,010 30 795 787	tes <u>lai</u> f <sub>e</sub> Δ - f <sub>e</sub> - w
Weight of charcoal+container Calculations/Results Wood consumed (moist) Net change in char during test Equivalent dry wood consumed Water vaporized from all pots Effective mass of water boiled	g <u>Units</u> g g g g	COLD STA data 800 44 600 1,140 7,981	RT <u>label</u> f <sub>cm</sub> Δc <sub>c</sub> f <sub>cd</sub> W <sub>cv</sub> W <sub>cr</sub>	HOT STAR <u>data</u> 790 <u>44</u> 591 933 9,067	T <u>label</u> f <sub>hm</sub> ∆c <sub>h</sub> f <sub>hd</sub> W <sub>hv</sub> W <sub>hr</sub>	SIMM Calcu Wood Net cl Equiv Wate Wate Time	IER TES Ilations I consur hange ir alent dr r vapori: r remain	T (CALCUL) (Results med during th a char during y wood consi zed ing at end - 1 ier (should be	ATIONS ne simm test ph umed Pot # 1	6 DIFFER her phase ase	Units (mg g g g	IGH POWER <u>data</u> 1,010 30 795 787 3,500	ETE: <u>lai</u> f <sub>e</sub> Δ - f <sub>i</sub> - w
Weight of charcoal+container Calculations/Results Wood consumed (moist) Net change in char during test Equivalent dry wood consumed Water vaporized from all pots Effective mass of water boiled Time to boil Pot # 1	g Units g g g g g g min	COLD STA data 800 44 600 1,140 7,981 29	RT <u>label</u> f <sub>cm</sub> Δc <sub>c</sub> f <sub>cd</sub> W <sub>cv</sub> W <sub>cr</sub> Δt <sub>c</sub>	HOT STAR <u>data</u> 790 <u>44</u> 591 933 <u>9,067</u> <u>25</u>	T <u>label</u> f <sub>hm</sub> Δc <sub>h</sub> f <sub>hd</sub> W <sub>hv</sub> W <sub>hr</sub> Δt <sub>h</sub>	SIMM Calcu Wood Net cl Equiv Wate Wate Time Therm	IER TES Ilations I consur hange ir alent dr r vapori: r remain of simm	T (CALCUL) (Results med during th a char during y wood consi zed ing at end - 1 ier (should be	ATIONS ne simm test ph umed Pot # 1	6 DIFFER her phase ase	Units (r g g g g min	IGH POWER <u>data</u> 1,010 30 795 787 3,500 45	R TES <u>la</u> - f <sub>i</sub> - γ <sub>i</sub> - ν <sub>i</sub> - ν <sub>i</sub>
Weight of charcoal+container Calculations/Results Wood consumed (moist) Net change in char during test Equivalent dry wood consumed Water vaporized from all pots Effective mass of water boiled Time to boil Pot # 1 Temp-corr time to boil Pot # 1	g g g g g min min	COLD STA data 800 44 600 1,140 7,981 29 29	RT $f_{cm}$ $\Delta c_c$ $f_{cd}$ $W_{cv}$ $W_{or}$ $\Delta t_c$ $\Delta t_c^T$	HOT STAR <u>data</u> 790 44 591 933 9,067 25 25	T <u>label</u> f <sub>hm</sub> Δc <sub>h</sub> f <sub>hd</sub> W <sub>hv</sub> W <sub>hr</sub> Δt <sub>h</sub>	SIMM Calcu Wooo Net cl Equiv Wate Wate Time Thern Burnin	IER TES Ilations I consur hange ir alent dr r vaporiz r remain of simm nal effici ng rate	T (CALCUL) (Results med during th a char during y wood consi zed ing at end - 1 ier (should be	ATIONS ne simm test ph umed Pot # 1	6 DIFFER her phase ase	Units (n g g g g min %	IGH POWER <u>data</u> 1,010 30 795 787 3,500 45 11%	RTE: <u>la</u> f, Δ
Weight of charcoal+container Calculations/Results Wood consumed (moist) Net change in char during test Equivalent dry wood consumed Water vaporized from all pots Effective mass of water boiled Time to boil Pot # 1 Temp-corr time to boil Pot # 1 Thermal efficiency	g g g g g min min %	COLD STA data 800 44 600 1,140 7,981 29 29 29 46%	$\begin{array}{c} \textbf{RT} \\ \underline{\textbf{label}} \\ \textbf{f}_{cm} \\ \Delta \textbf{c}_{c} \\ \textbf{f}_{cd} \\ \textbf{W}_{cv} \\ \textbf{W}_{cv} \\ \boldsymbol{W}_{cr} \\ \Delta \textbf{t}_{c} \\ \Delta \textbf{t}_{c} \\ \textbf{h}_{c} \end{array}$	HOT STAR <u>data</u> 790 44 591 933 9,067 25 25 45%	T <u>label</u> $f_{hm}$ $\Delta c_h$ $f_{hd}$ $W_{hv}$ $W_{hr}$ $\Delta t_h$ $\Delta t_h$ $\Delta t_h$ $h_h$	SIMM Calcu Wooo Net cl Equiv Wate Wate Time Thern Burnin	IER TES Ilations I consur hange ir alent dr r vapori: r remain of simm nal effici ng rate fic fuel o	ST (CALCUL/ /Results med during th a char during y wood consi zed ing at end - I ier (should be iency	ATIONS ne simm test ph umed Pot # 1	6 DIFFER her phase ase	Units g g g g min % g/min	IGH POWER <u>data</u> 1,010 30 795 787 3,500 45 11% 18	₹TE:  a f, 
Weight of charcoal+container Calculations/Results Wood consumed (moist) Net change in char during test Equivalent dry wood consumed Water vaporized from all pots Effective mass of water boiled Time to boil Pot # 1 Temp-corr time to boil Pot # 1 Thermal efficiency Burning rate	g Units g g g g min min % g/min	COLD STA data 800 44 600 1,140 7,981 29 29 29 46% 21	$\begin{array}{c} \textbf{RT} \\ \underline{\textbf{label}} \\ f_{em} \\ \Delta c_{e} \\ f_{ed} \\ W_{ov} \\ W_{ov} \\ W_{or} \\ \Delta t_{e} \\ \Delta t_{e} \\ h_{e} \\ r_{eb} \end{array}$	HOT STAR <u>data</u> 790 44 591 933 9,067 25 25 45% 24	$T \\ \frac{label}{f_{hm}} \\ \Delta c_h \\ f_{hd} \\ w_{hv} \\ W_{hr} \\ \Delta t_h \\ \Delta t_n \\ h_h \\ r_{hb} $	SIMM Calcu Wooc Net cl Equiv Wate Wate Time Therr Burnii Speci Firepo	IER TES Ilations I consur hange ir alent dr r vapori: r remain of simm nal effici ng rate fic fuel o	FT (CALCULI /Results med during th c char during y wood consized ining at end - I ining at end - I inining at end - I ining at end - I ining at end - I ining a	ATIONS ne simm test ph umed Pot # 1	6 DIFFER her phase ase	Units g g g min % g/min g/liter	IGH POWER <u>data</u> 1,010 30 795 787 3,500 45 11% 18 227	RTE: <u>lai</u> - Δ - f, - w - Λ - γ - Γ - Γ
Weight of charcoal+container Calculations/Results Wood consumed (moist) Net change in char during test Equivalent dry wood consumed Water vaporized from all pots Effective mass of water boiled Time to boil Pot # 1 Temp-corr time to boil Pot # 1 Thermal efficiency Burning rate Specific fuel consumption	g Units g g g g g min min % g/min g/liter	COLD STA data 800 44 600 1,140 7,981 29 29 29 29 46% 21 75	RT $\frac{ abe }{f_{em}}$ $\Delta c_c$ $f_{od}$ $W_{ov}$ $W_{or}$ $\Delta t_c$ $\Delta t_c$ $h_c$ $F_{ob}$ $SC_c$ $SC_c^{-}$	HOT STAR <u>data</u> 790 44 591 933 9,067 25 25 45% 24 65	$T \\ \frac{label}{f_{hm}} \\ \Delta c_h \\ f_{hd} \\ w_{hv} \\ W_{hr} \\ \Delta t_h \\ \Delta t_n \\ h_h \\ r_{hb} \\ SC_h$	SIMM Calcu Wooc Net cl Equiv Wate Wate Time Therr Burnii Speci Firepo	IER TES Ilations I consur hange ir alent dr r vaporiz r remain of simm nal effici ng rate fic fuel o ower	FT (CALCULI /Results med during th c char during y wood consized ining at end - I ining at end - I inining at end - I ining at end - I ining at end - I ining a	ATIONS ne simm test ph umed Pot # 1	6 DIFFER her phase ase	Units g g g min % g/min g/liter	IGH POWER <u>data</u> 1,010 30 795 787 3,500 45 11% 18 227 5,743	R TES <u>lai</u> - Δ - f <sub>t</sub> - w - w

Once you have tested the stove 3 times, copy the data from your data sheet to the Excel spreadsheet.

The performance metrics are listed on the Results sheet for each of the three phases: The important ones are:

St

- 1. Time to Boil (temp corrected)
- 2. Thermal Efficiency
- 3. Specific Fuel Consumption (temp corrected)
- 4. Firepower
- 5. Turndown Ratio

ve type/model	Three s	tone fire				
ation	Region	al Testing (	Center of H	elsinki		
od species (specify if different for each test)	Average	e Softwood	(Conifer)			
d conditions (specify if different for each test)	No wind					
1. HIGH POWER TEST (COLD START)	units	Test 1	Test 2	Test 3	Average	St Dev
Time to boil Pot # 1	min	29	27	30	28.5	1.6
Temp-corrected time to boil Pot # 1	min	29	27	30	28.5	1.6
Burning rate	g/min	21	23	21	21.9	1.3
Thermal efficiency	%	46%	44%	43%	45%	2%
Specific fuel consumption	g/liter	75	78	81	78.0	2.7
Temp-corrected specific consumption	g/liter	75	78	81	78.0	2.7
Firepower	watts	6,765	7,593	6,963	7107	432.0
2. HIGH POWER TEST (HOT START)	units	Test 1	Test 2	Test 3	Average	St Dev
Time to boil Pot # 1	min	25	26	25	25.3	0.6
Temp-corrected time to boil Pot # 1	min	25	26	25	25.7	0.6
Burning rate	g/min	24	22	24	23.5	0.9
Thermal efficiency	%	45%	46%	44%	45%	1%
Specific fuel consumption	g/liter	65	64	67	65.5	1.2
Temp-corrected specific consumption	g/liter	66	65	68	66.4	1.2
Firepower	watts	7,685	7,306	7,880	7624	291.8
3. LOW POWER (SIMMER)	units	Test 1	Test 2	Test 3	Average	St Dev
Burning rate	g/min	18	16	15	16.0	1.6
Thermal efficiency	%	11%	12%	13%	12%	1%
Specific fuel consumption	g/liter	227	201	187	205.2	20.3
Firepower	watts	5,743	5,082	4,734	5186	512.7
Turn down ratio		1.18	1.49	1.47	1.38	0.2

#### Temperature Corrected Time to Boil (min)

$$=\frac{75}{T_{boil}-T_{init}}*(t_{boil}-t_{start})$$

Normalized to a standard change in temperature of 75 C

#### Thermal Efficiency (%)

=  $\frac{energy to heat water + energy to evap water}{energy released by fuel}*100$ 

#### High efficiency $\neq$ low fuel consumption

because high power stoves evaporate lots of water and also use lots of fuel

Temperature Corrected Specific Fuel Consumption (g/L)

 $= \frac{75}{T_{boil} - T_{init}} * \frac{eqvivalent \, dry \, wood \, consumed \, (g)}{liters \, of \, water \, remaining \, (L)}$ 

Eq. dry wood consumed = dry w

dry wood mass –

wood mass that was consumed to evaporate the moisture in the wood

equivalent mass of
 wood stored as char

#### Best indicator of fuel consumption

#### Average Firepower (W)

total energy released by fuel during the test period (Joules) length of test period (seconds)

Turndown Ratio

average boil firepower(W)

average simmer firepower (W)

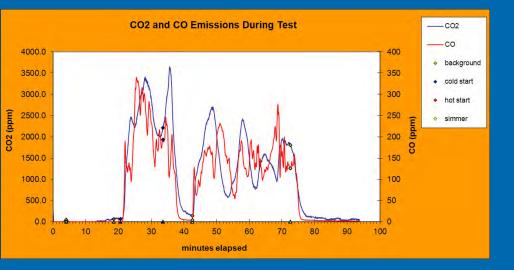
Indicates a stove's ability to adjust the firepower to match low power and high power cooking tasks

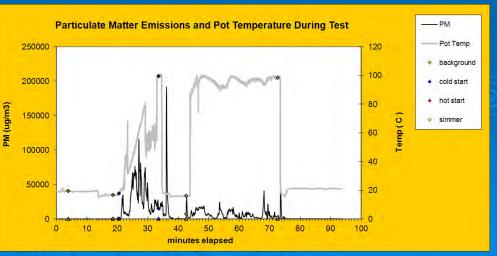
# WBT Measuring Emissions PEMS

- Portable Emissions Measurement System collects and measures real-time emissions
- This data is processed using the PEMS spreadsheet to provide WBT results in the form of:
  - Total Emissions (grams)
  - Emission Factors (grams emission per kg fuel burned)
  - Pollutant/CO<sub>2</sub> ratios
  - Specific Emissions (grams of emissions per liter of water cooked)
  - Emissions to Complete the WBT (grams) used for benchmarking

#### WBT Results Emissions

Total Emission	<u>د</u>		
COLD START	3		(cold start)
CO		grams	16.52
CO2		grams	293
appx PM		mg	2220
SIMMER			(simmer)
со		grams	27.75
CO2		grams	449
appx PM		grams	1172
Specific Emiss	ions (Corrected	d for starting	temp, moistu
COLD START	Correction Facto	or	0.2421
СО		gr/liter	4.0
CO2		gr/liter	71.0
appx PM mg		mg/liter	537.5
SIMMER	Correction Factor	r	0.6169
CO		gr/liter	25.7
CO2		gr/liter	415.9
appx PM mg		mg/liter	1084.4
Other Emission	n Measures		
COLD START			
Wood (g) based or		g	174
CO/CO2 Ratio (mol	,	%	8.8%
EF-CO (g/kg) base		g/kg	94.85
EF-CO2 (g/kg) bas		g/kg	1684
EF-PM (g/kg) base	d on Carbon	g/kg	12.75
SIMMER	Carban	-	200
Wood (g) based on		g %	269
CO/CO2 Ratio (mol	,	, .	9.7% 103.21
EF-CO (g/kg) base		g/kg	
EF-CO2 (g/kg) bas		g/kg	1671 4.36
EF-PM (g/kg) base		g/kg	4.30 3stone 3.5in
Standard Perfo			
CO to Cook 5L (20)	,	g	84.2
PM to Cook 5L (15 CO2 to Cook 5L	00)	mg	5398.6
COZ IO COOK OL		g	1394.7





# WBT Sample Size

- At least three full tests per stove design are recommended
- Then do more tests if necessary to achieve the desired statistical significance measured by the COV (Coefficient of Variation)

$$COV = \frac{standard\ deviation}{average\ value} * 100 \quad (\%)$$

COV is a measure of how much your results vary

COV indicates how good you are at getting repeatable results

For stove testing

COV = 5% COV = 10% or 25% is very good .is-also acceptable

## WBT Sample Size COV Example

#### Do more tests to lower the COV

Results of	three water boiling tests - <u>all cells are linke</u>	d to data w	orksheets	, no entrie	s are requ	ired		
Stove type/	model	Three st	one fire					
Location		Regiona	al Testing (	Center of H	lelsinki			
Wood spec	ies (specify if different for each test)	Average	Softwood	(Conifer)				
Wind condi	tions (specify if different for each test)	No wind						
	1. HIGH POWER TEST (COLD START)	units	Test 1	Test 2	Test 3	Average	St Dev	COV (%)
	Time to boil Pot # 1	min	29	27	30	28.5	1.6	5.66559
	Temp-corrected time to boil Pot # 1	min	29	27	30	28.5	1.6	5.66559
	Burning rate	g/min	21	23	21	21.9	1.3	6.07892
	Thermal efficiency	%	46%	44%	43%	45%	2%	3.5326
	Specific fuel consumption	g/liter	75	78	81	78.0	2.7	3.50325
	Temp-corrected specific consumption	g/liter	75	78	81	78.0	2.7	3.50325
	Firepower	watts	6,765	7,593	6,963	7107	432.0	6.07892
	2. HIGH POWER TEST (HOT START)	units	Test 1	Test 2	Test 3	Average	St Dev	COV (%)
	Time to boil Pot # 1	min	25	26	25	25.3	0.6	2.27901
	Temp-corrected time to boil Pot # 1	min	25	26	25	25.7	0.6	2.27901
	Burning rate	g/min	24	22	24	23.5	0.9	3.82698
	Thermal efficiency	%	45%	46%	44%	45%	1%	1.85487
	Specific fuel consumption	g/liter	65	64	67	65.5	1.2	1.86681
	Temp-corrected specific consumption	g/liter	66	65	68	66.4	1.2	1.86681
	Firepower	watts	7,685	7,306	7,880	7624	291.8	3.82698
	3. LOW POWER (SIMMER)	units	Test 1	Test 2	Test 3	Average	St Dev	COV (%)
	Burning rate	g/min	18	16	15	16.0	1.6	9.88486
	Thermal efficiency	%	11%	12%	13%	12%	1%	9.64316
	Specific fuel consumption	g/liter	227	201	187	205.2	20.3	9.88486
	Firepower	watts	5,743	5,082	4,734	5186	512.7	9.88486
	Turn down ratio		1.18	1.49	1.47	1.38	0.2	12.7572

e type/modei	Three 5	tone fire						
tion	Region	al Testing (	Center of H	etsinki				
d species (specify it different for each test)	Average	Softwood	(Conifer)					
a conditions (specify if different for each test)	No wind	E <sup>1</sup>						_
1. HIGH POWER TEST (COLD START)	units	Test 1	Test 2	Test 3	Test 4	Average	St Dev	COV (%)
Time to boil Pot # 1	min	29	27	30	23	28.4	1.3	4,74155
Temp-corrected time to boil Pot # 1	min	29	27	30	28	28.4	1.3	4.74155
Burning fate-	gimin	.21	23	21	22	21.9	11	4.96483
Thermal efficiency	96	46%	44%	43%	43%	44,3%	7.5%	3 4818
Specific fuel consumption	0/lifer	75	78	81	80	78.5	24	3.10232
Temp-corrected specific consumption	g/iter	75	78	81.	80	78.5	24	3 10232
Firepower	watts	6,765	7,593	6,963	7,000	7080.3	356.6	5,03925
2. HIGH POWER TEST (HOT START)	units	Test 1	Test 2	Test 3	Test 4	Average	St Dev	COV (%
Time to boil Pot # 1	tniri	25	26	25	25	25.3	0.5	1.9802
Temp-corrected time to boil Pot # 1	man	25	26	25	25	25 5	0.6	2,29411
Burning rate	ĝ/min	24	22	24	24	23.6	0.6	3,30944
Thermal efficiency	15	45%	46%	44%	45%	45.0%	0.7%	1.51479
Specific fuel consumption	gitter	65	64	67	65	65.4	1.0	1,57765
Temp-corrected specific consumption	g/tter	65	65	68	66	66.3	1.0	1-5646
Pirepower	watts	7.585	7,306	7,680	7.400	7568.0	263.2	3.47832
3. LOW POWER (SIMMER)	units	Test 1	Test 2	Test 3	Test 4	Average	St Dev	COV (%)
Burning rate	g/min	13	15	15	17	16.2	1.4	8,56375
Thermal efficiency	-56	11%	12%	13%	15%	12,9%	1.7%	13 1724
Specific fuel consumption	griter	227	201	787	250	216.4	27.9	12.0719
Firepower	watts	5,743	5,082	4,734	5,800	5339.8	519.0	971945
Turn down ratio	_	1.18	1.49	1.47	1.20	1.5	0.2	12 7227

#### Sample size = 3

#### Sample size = 4

After doing a 4<sup>th</sup> test, the variation decreased for the cold start and hot start but not for the simmer

#### Regional Water Boiling Test (RWBT)

- Same control of variables as the WBT (same repeatability as WBT)
- Change the cooking task to be more realistic
  - Local pot (and lid)
  - Local fuel (as long as it doesn't increase variability)
  - Simulate local cooking tasks

# Stove Testing Continuum

Lab 🦊

Increasing control of variables Increasing isolation of stove performance Increasing quantification of emissions Increasing intervention of testers

CCT

Increasing cost

Field

Increasing sample size and variability Increasing measurement of in-home use Increasing relation to WHO air quality guidelines

**KPT** 

Regional Water Boiling Test (RWBT) Advantages

- A lab test that is more representative of field results
  - better approximation of actual cooking
- Same repeatability as the WBT

Prepares stoves for the CCT better

Regional Water Boiling Test (RWBT) Disadvantages

Not internationally comparable

 Could be abused as a substitute for field data

## Regional Water Boiling Test (RWBT) Example: RWBT for West Africa

Difference from WBT protocol: RWBT uses a pot has lid because cooks in West Africa usually use a lid to cook rice or beans.

During the WBT, simmering without a lid requires 1000 W firepower due to heat loss by evaporation During the RWBT, simmering with a lid requires 100 W firepower by blocking evaporation

Excess firepower = wasted fuel. RWBT shows us which stoves can save fuel at low power. WBT does not test stove at low power.

The WBT does not evaluate the stove performance below 1000 W, so the RWBT is a more appropriate test for that cooking task.

#### Documentation

www.aprovecho.org/lab/pubs/testing

#### Download testing protocols

