Power Determination Drafting and Validation

(DRAFT – 4 April, 2019)

Status and Discussion of Options

EVE-30, Stockholm

April 2019

Status of Power Determination task

- What we know:
  - We are to draft a GTR for Power Determination
  - The GTR is to be a standalone GTR and not an annex to GTR No. 15
  - A formal document is currently due in November 2019
  - A draft procedure based closely on ISO 20762 has been drafted
- What we do not know:
  - Is the draft procedure ready to become a GTR?
  - Does it need significant modification? How should it be modified?
  - Would any additional validation then be necessary?
  - When can we deliver a formal document, and the GTR?
- These questions must be resolved as soon as possible.

Summary of outstanding issues

- Known prior to validation program:
  1) Greater variation observed for TP2 than for TP1 (based on Japan testing)
  2) Proposed requirement to collect fuel flow rate for TP1 (to verify per R85)
  3) Method for assessing tire losses for TP2 (if measurement is at dyno rolls)
  4) Allowability/impact of gear shifting on maximum power
  5) Should PHEV test be in CD or CS mode, and how to determine
  6) Applicability to novel or complex powertrains (multi motor, Rex, 4WD)
- Added by results of validation program:
  7) TP1 and TP2 results differ significantly
     - Use of default K factors can contribute to the difference
     - Slippage may contribute to the difference (affecting TP2 result)
     - Engine not being at maximum power point per R85 may contribute (affecting TP1)
  8) For some vehicles, repeatability was questionable
  9) Slippage may affect identification of maximum power, due to gearshift effects

Review of TP1 and TP2

TP1

Default = 0.85

$$P_{HEV\ system}\,[kW] = ICE\ power + \left(\frac{U_{battery} \times I_{battery}}{1000} - P_{DCDC} - P_{auxiliaries}\right) \times K1$$

K1 is efficiency of [inverter + motor] during vehicle maximum power

TP2

$$P_{HEV\ system}\,[kW] = \frac{P_{wheels}}{K2}$$

Default = 0.91 to 0.98

K2 is efficiency of transmission/gearbox during vehicle max power

NOTE: K1 and K2 terminology is adopted here for convenience. In ISO 20762 it is K and $\eta_{gearbox}$

Indications of US and Canada testing

- Identifying speed of maximum power
  - Appears to be repeatable by constant speed dyno method
  - Free acceleration in road load mode might help identify the speed
- Repeatability
  - Appears to be good for both TP1 and TP2
  - Sequential pulses and different days agree well
- Procedural suggestions
  - Conditioning cycle may be insufficient for transmission oil to warm up
  - Provide guidance for how fast to conduct SOC regeneration
- Results of TP1 and TP2 differ significantly
  - TP1 <> TP2 (sometimes greater, sometimes less)
  - Use of default K factor is likely a contributing cause
  - Tire losses and slippage may be a factor (used dyno roller measurement for TP2)

Indications of JRC testing

- Identifying speed of maximum power
  - Free acceleration in road load mode might help identify the speed and gear shift strategy
- Repeatability
  - TP2 shows less variation than TP1, within the same tests and repeating the tests
- Procedural suggestions
  - Temperature of REESS and engine should be monitored
  - SOC regeneration rate or charging from the grid vs temperatures
  - Minor issues related to dyno setting in constant speed control mode
- Results of TP1 and TP2 differ significantly
  - TP1 generally greater than TP2
  - For TP1, engine should be at maximum power per R85
  - Default K factors in both TPs might have a significant impact on results
  - Correction for tire losses reduces the difference but does not eliminate it
  - Correction for slippage not easy to estimate

Indications of KATRI testing

- Identifying speed of maximum power (Hyundai Ioniq)
  - Selected to coincide with engine maximum power (3rd gear, 114 kph, 5650 rpm)
  - This differed from the speed JRC identified (100 to 105 kph)
- Repeatability
  - Results for TP1 and TP2 were quite repeatable
  - Slightly greater variation for TP2
- Procedural suggestions
  - Korea prefers TP2 sustained power for GTR
  - Recommends adding hub dyno to TP2 instrumentation options
  - Recommends excluding 1st power test to account for continued vehicle warmup
- Results of TP1 and TP2 differ significantly
  - TP1 > TP2. Not due to tire losses or slippage (hub dyno was used)
  - Default K2 factor implicated by Japan (0.97 may be too good for Ioniq hybrid)
  - Japan also notes that TP1 result varied from JRC result for same vehicle (gear shift, R85, slippage)

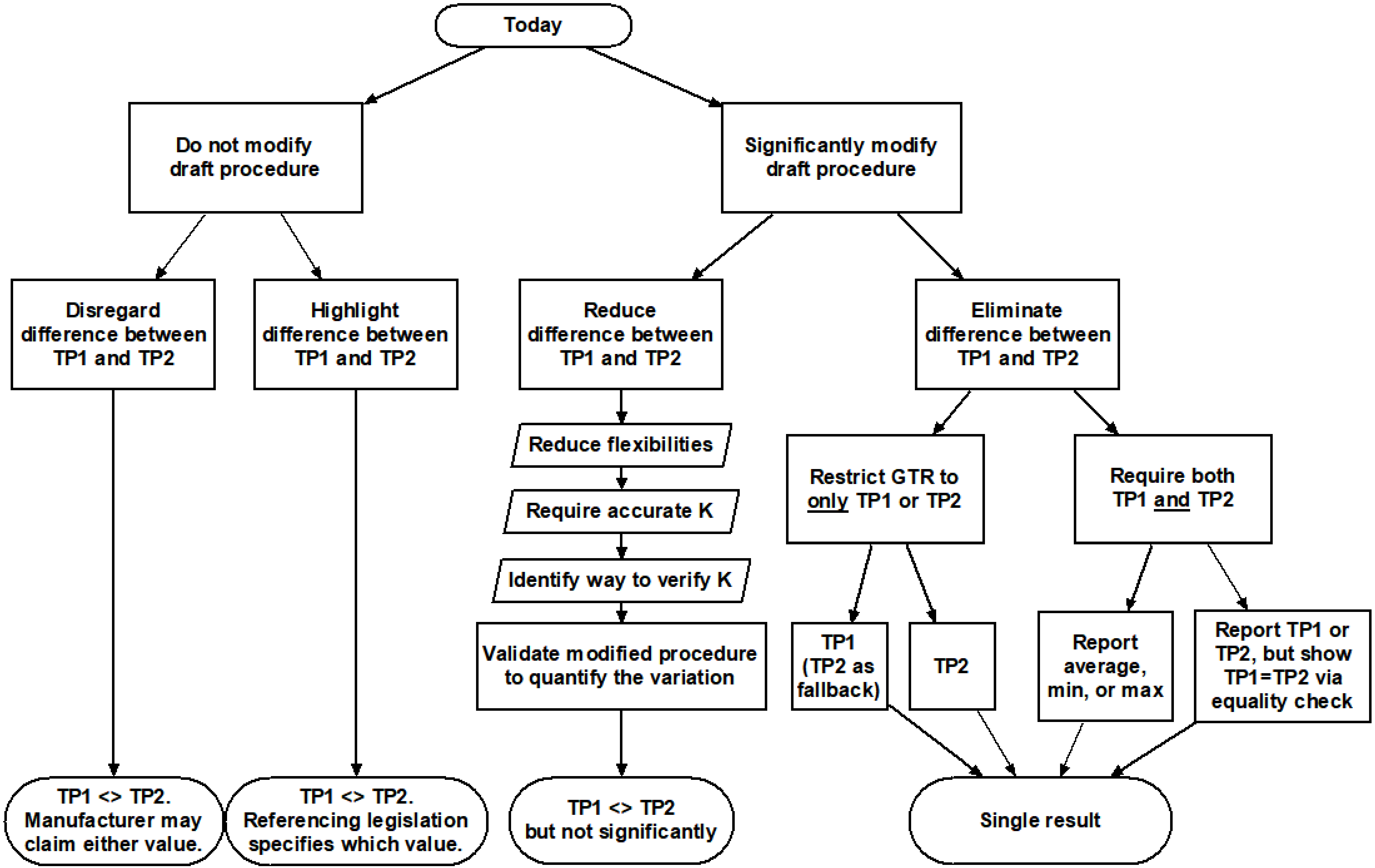
Additional uncertainties in validation tests

- All testing utilized default K factors. Accurate factors were not available.
- EPA testing relied on CAN data (TP1) and dyno roller torque (TP2)
  - For TP1, measurement accuracy is therefore not verified
  - For TP2, tire losses were accounted for, but not slippage
  - Either could contribute to the disagreement of TP1 and TP2
- Canada testing utilized a variety of sources
  - For TP1, reported results utilized Hioki measurements
  - For TP2, reported results utilized dyno roller torque, no correction for tire or slippage
  - GM CAN data for torque and power, and wheel torque sensors, was also collected
  - Torque sensors resulted in greater TP2 result by 5-7 kW. CAN was not verified.
- Ideally, follow-up testing should be conducted with sufficient lead time to allow the best possible instrumentation, and manufacturer K factors.

Enumeration of options for completing GTR

A. Do not significantly modify the draft procedure
   A. Disregard the difference between TP1 and TP2
   B. Highlight the difference as a caveat to users of the GTR

B. Modify the draft procedure
   A. Reduce the difference between TP1 and TP2
      - Reduce measurement inaccuracy (e.g., eliminate dyno rollers for TP2)
      - Reduce K factor inaccuracy (eliminate defaults, require manufacturer to provide)
      - Provide a way to verify provided K factor ← (see slide 19 for suggestion)
      - Validate the modified procedure to quantify the difference
   B. Eliminate the difference (produce only a single value)
      A. Restrict GTR to only TP1 or only TP2
         A. Perform TP1 only (possibly, fall back to TP2 if intake manifold pressure check fails)
         B. Perform TP2 only
      B. Require both TP1 and TP2
         A. Compute both. Report the average, or the lower, or the higher
         B. Compute TP1 or TP2, but collect data for both, set TP1 = TP2 and do "equality check" ← (slide 20)


Today
Do not modify draft procedure
Significantly modify draft procedure
Disregard difference between TP1 and TP2
Highlight difference between TP1 and TP2
Reduce difference between TP1 and TP2
Eliminate difference between TP1 and TP2
Reduce flexibilities
Require accurate K
Identify way to verify K
Validate modified procedure to quantify the variation
Restrict GTR to only TP1 or TP2
Require both TP1 and TP2
TP1 (TP2 as fallback)
TP2
Report average, min, or max
Report TP1 or TP2, but show TP1=TP2 via equality check
TP1 <> TP2. Manufacturer may claim either value.
TP1 <> TP2. Referencing legislation specifies which value.
TP1 <> TP2 but not significantly
Single result

Review of EPA/ECCC results

Repeatability – 2013 Malibu Eco BAS HEV (at 90 and 100 kph)

Malibu Eco TP1	TP1 (Peak)					
	90 kph			100 kph		
	Day 1	Day 2	Difference	Day 1	Day 2	Difference
First pulse	129.74	129.80	0.06	98.64	98.81	0.17
Second pulse	129.77	129.83	0.06	98.78	98.82	0.04
Difference	0.03	0.03		0.14	0.01	

Malibu Eco TP2	TP2 (Peak)					
	90 kph			100 kph		
	Day 1	Day 2	Difference	Day 1	Day 2	Difference
First pulse	118.53	120.60	2.07	92.53	93.31	0.78
Second pulse	117.82	120.51	2.69	92.66	92.98	0.32
Difference	-0.71	-0.09		0.13	-0.33	

Malibu Eco TP1	TP1 (Sustained)					
	90 kph			100 kph		
	Day 1	Day 2	Difference	Day 1	Day 2	Difference
First pulse	129.64	129.70	0.06	98.43	98.52	0.09
Second pulse	129.62	129.70	0.08	98.49	98.55	0.06
Difference	-0.02	0.0		0.06	0.03	

Malibu Eco TP2	TP2 (Sustained)					
	90 kph			100 kph		
	Day 1	Day 2	Difference	Day 1	Day 2	Difference
First pulse	118.00	119.89	1.89	92.20	92.61	0.41
Second pulse	117.60	119.56	1.96	92.16	92.55	0.39
Difference	-0.40	-0.33		-0.04	-0.06	

96% of total power is engine power. Engine power is derived only from engine speed, which has low variation, leading to low variation for TP1.

100% of total power is measured power. Larger variation in TP2 would therefore be expected, compared to TP1.

Repeatability – 2013 Chevy Volt (at 70 and 90 kph)

Chevy Volt TP1	TP1 (Peak)					
	70 kph			90 kph		
	Day 1	Day 2	Difference	Day 1	Day 2	Difference
First pulse	93.96	93.96	0.00	91.99	91.56	-0.43
Second pulse	93.56	93.77	0.21	91.39	91.85	0.46
Difference	-0.40	-0.19		-0.61	0.29	

Chevy Volt TP2	TP2 (Peak)					
	70 kph			90 kph		
	Day 1	Day 2	Difference	Day 1	Day 2	Difference
First pulse	100.14	100.17	0.03	99.89	99.89	-0.01
Second pulse	100.41	100.90	0.49	99.43	100.03	0.60
Difference	0.27	0.72		-0.47	0.14	

Chevy Volt TP1	TP1 (Sustained)					
	70 kph			90 kph		
	Day 1	Day 2	Difference	Day 1	Day 2	Difference
First pulse	92.42	92.75	0.33	91.09	91.09	-0.01
Second pulse	92.71	92.53	-0.19	90.50	91.48	0.99
Difference	0.29	-0.22		-0.60	0.39	

Chevy Volt TP2	TP2 (Sustained)					
	70 kph			90 kph		
	Day 1	Day 2	Difference	Day 1	Day 2	Difference
First pulse	98.95	99.58	0.62	99.46	99.29	-0.17
Second pulse	98.99	99.74	0.75	99.17	99.03	-0.14
Difference	0.03	0.16		-0.29	-0.26	

For Chevy Volt, TP1 has similar variation to TP2 because 100% of the power is measured power.

Difference in TP1 and TP2 results

2013 Malibu Eco

	Peak power			Sustained power		
	TP1	TP2	Difference	TP1	TP2	Difference
First pulse	130.73 kW	121.07 kW	-9.66 kW	129.57 kW	120.15 kW	-9.42 kW
Second pulse	130.04 kW	119.87 kW	-10.17 kW	129.54 kW	118.99 kW	-10.55 kW
Difference	-0.69 kW	-1.2 kW		-0.03 kW	-1.16 kW	

2013 Chevy Volt

	Peak power			Sustained power		
	TP1	TP2	Difference	TP1	TP2	Difference
First pulse	94.31 kW	103.29 kW	+8.98 kW	92.91 kW	101.00 kW	+8.09 kW
Second pulse	93.21 kW	102.31 kW	+9.10 kW	92.67 kW	101.19 kW	+8.51 kW
Difference	-1.10 kW	-0.98 kW		-0.24 kW	+0.18 kW	

2016 Chevy Volt

	Peak power			Sustained power		
	TP1	TP2	Difference	TP1	TP2	Difference
Repeat 1	103.9 kW	115.6 kW	+11.7 kW	103.3 kW	104.3 kW	+1.0 kW
Repeat 2	103.2 kW	113.6 kW	+10.4 kW	102.9 kW	103.0 kW	+0.1 kW
Difference	-0.7 kW	-2.0 kW		-0.4 kW	-1.3 kW	

Difference in downstream efficiency check

- No matter which TP, we know power at wheels (from dyno rolls)
- We can compare the computed TP value to the power at wheels
  - Suppose TP1 or TP2 result = 100 kW, and 90 kW was measured at rolls
  - Implied downstream efficiency (IDE) = 90 / 100 = 90%
- IDE should always be < 100%, and should be similar for either TP

	Sustained		
	TP1	TP2	Difference
First pulse	87.0%	93.8%	+6.8
Second pulse	86.2%	93.8%	+7.6
Difference	-0.8	0.0	

Implied downstream efficiency, 2013 Malibu Eco

TP1 result was smaller than power measured at wheels

	Sustained		
	TP1	TP2	Difference
First pulse	103.7%	95.4%	-8.3
Second pulse	104.1%	95.4%	-8.7
Difference	+0.4	0.0	

Implied downstream efficiency, 2013 Chevy Volt

Implications and discussion

General observations

- In theory, both TP1 and TP2 should deliver the same result (TP1 = TP2)
  - IF the respective measurements are accurate
  - IF the respective K factors are accurate
- Measurement accuracy is controllable
  - TP1 measures engine speed, battery power out (and manifold pressure as a check)
    - Accuracy additionally depends on engine being at WOT per R85
    - No guidance or tolerance is currently provided for judging this requirement.
  - TP2 measures wheel torque and speed
    - If measured at rollers, accuracy also depends on tire losses and wheel slippage
    - No guidance is currently provided for accurately accounting for either.
- K factors are influential
  - The default K factors are typical, but are rarely accurate for any specific vehicle
  - Without an accurate K factor for both TP1 and TP2, we should not expect the two results to be the same for any specific vehicle
- The GTR would be much stronger if TP1 = TP2, or very close

History of default K factors

- Default K factors are inherited from ISO procedure
- They are useful if vehicle-specific K factors are not known
- ISO does not assume a specific application for its power rating
- The potential inaccuracy introduced by use of a default factor is therefore *not necessarily* a problem for ISO 20762.
- However, default K factors may not be appropriate for a GTR
  - Varying accuracy may lead to unfairness or cherry picking opportunities
  - For type approval, manufacturer has an interest in providing accurate factor
  - **But the factor provided should also be verifiable**

Verification possibility #1: Bench testing

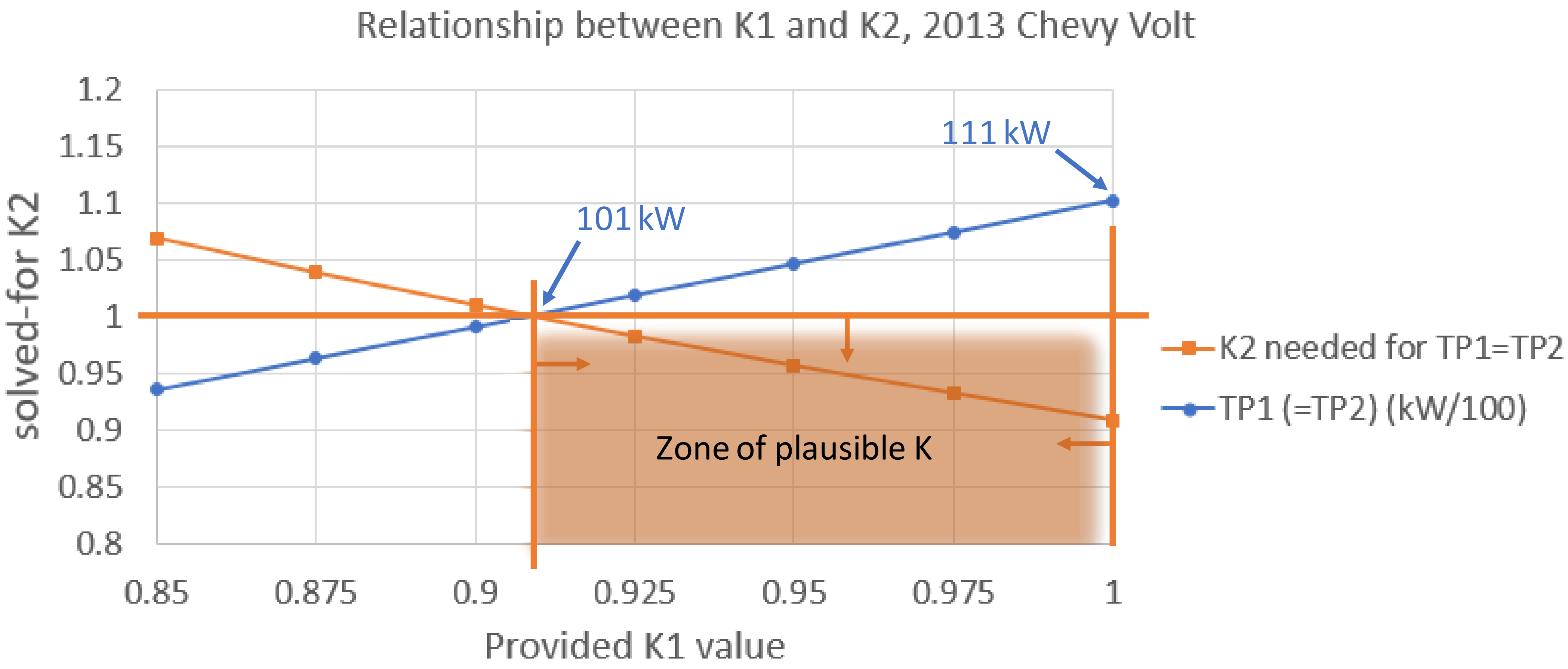
- Motor+inverter efficiency (K1) can be verified by independent testing
- Transmission efficiency (K2) is more difficult to test directly
- However, if both K1 and K2 are accurate, then TP1=TP2
- K2 can then be verified indirectly:
    1. Conduct accurate vehicle measurements for TP1 and TP2
    2. Conduct bench test to determine K1 accurately under observed conditions
    3. Compute TP1. Set TP2 = TP1, and solve for K2.
    4. See if solved-for K2 is close to what the manufacturer provided

Verification possibility #2: “Equality check”

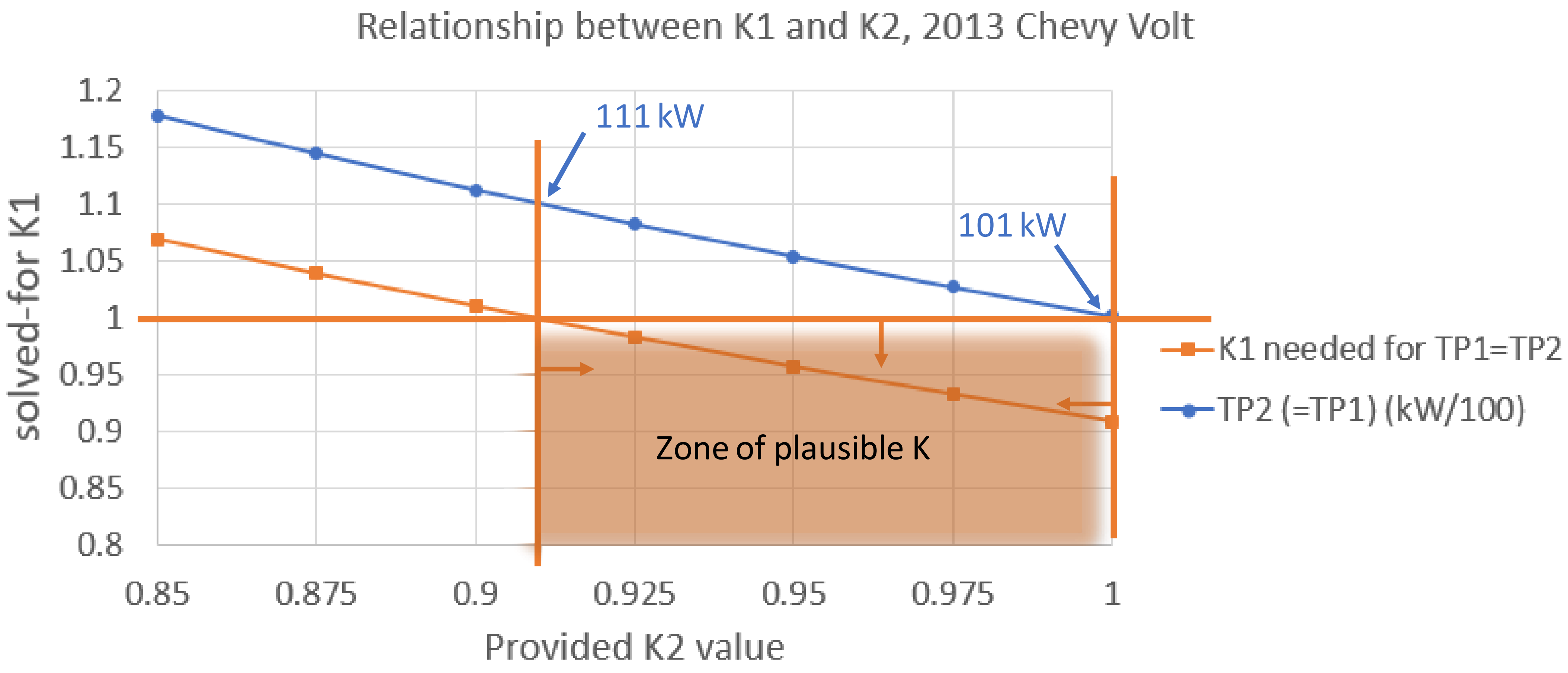
- Manufacturer selects TP1 [or TP2], and provides K1 [or K2]
- Lab instruments the vehicle for both TP1 and TP2**
- Compute TP1 [or TP2] using provided K1 [or K2]
- Set up calculations also for the other TP, but assume TP1 = TP2
- Then solve for the missing K (the K value that would make TP1 = TP2)
- The manufacturer-provided K value is verified if the solved-for K value is “reasonable” for the vehicle’s powertrain.
- I.e. for a TP result to be accepted, it must be internally consistent with the other TP if it were performed instead.

*** If TP1 is selected, to reduce instrumentation burden, use dyno rollers for TP2 and perform approximate correction for tire losses.*

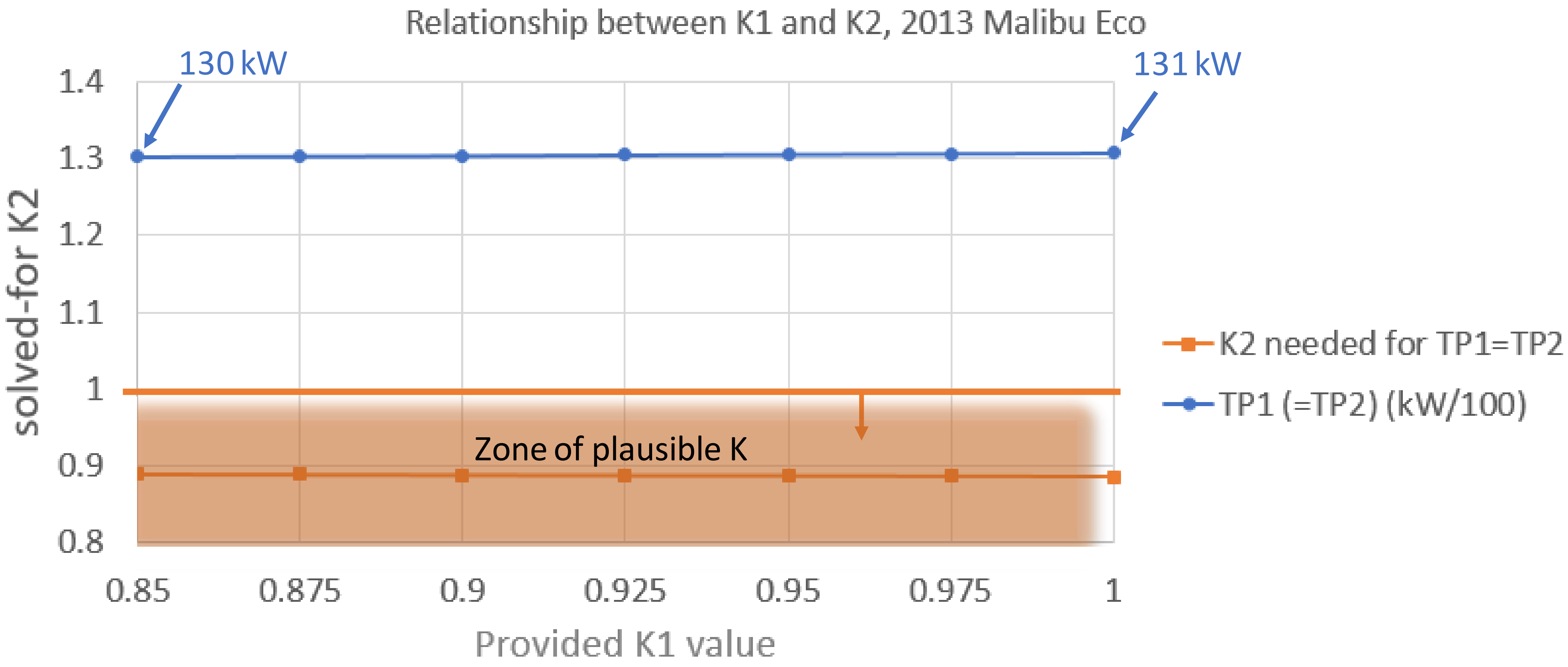
Example: 2013 Volt equality check (K1 provided)



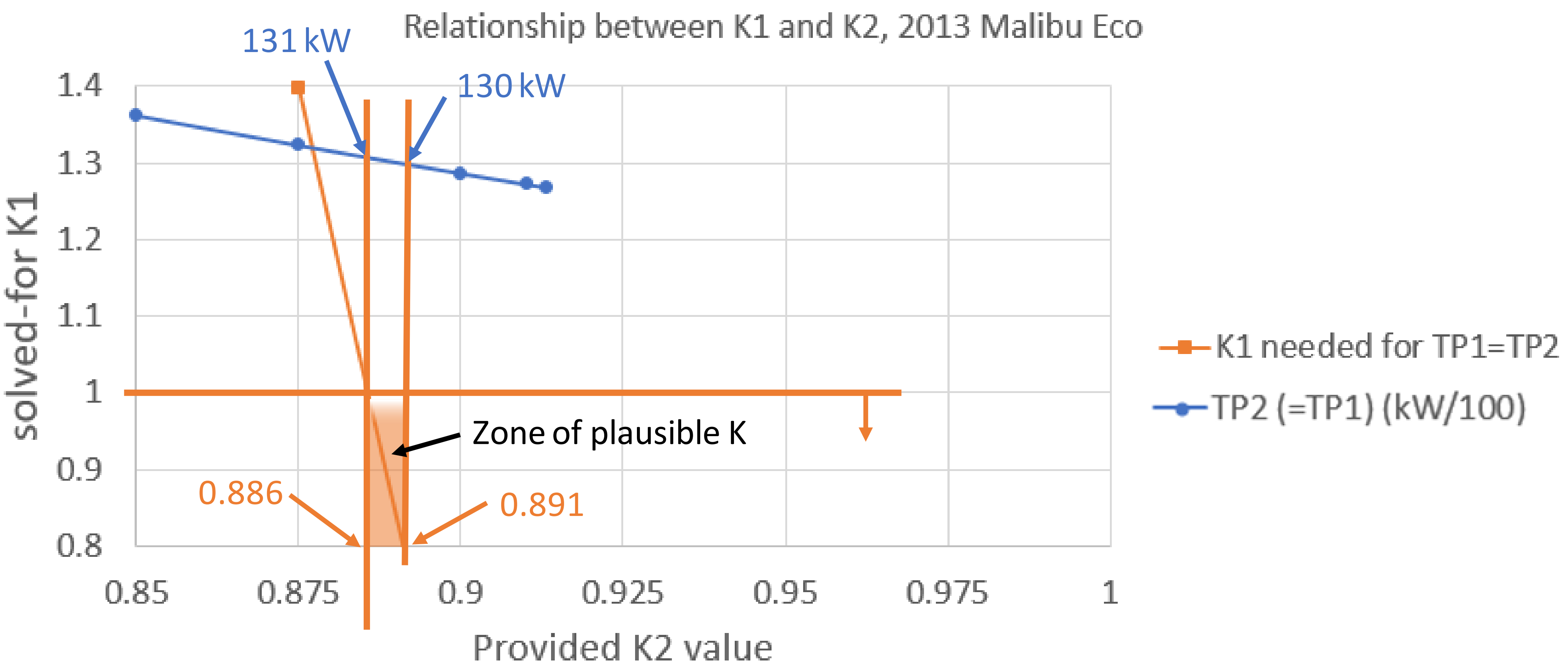
2013 Volt equality check (K2 provided)



Malibu Eco equality check (K1 provided)



Malibu Eco equality check (K2 provided)



EVS-32 paper

- Submitted to EVS-32, Lyon France, May 2019
- Outlines highlights of validation testing performed at EPA and ECCC
- Also provides background of the draft procedure and how the testing is informing its development

32nd Electric Vehicle Symposium (EVS32)
Lyon, France, May 19 - 22, 2019

Development and Validation of a Test Procedure for Determining the System Power of Hybrid and Plug-In Hybrid Electric Vehicles

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Summary

The World Harmonized Light Vehicles Test Procedure (WLTP) determines vehicle classification and cycle downscaling based on engine power rating. However, it does not specify a method for determining an equivalent system power rating for electrified vehicles that have more than one source of propulsion, such as an internal combustion engine and one or more electric motors. This paper describes the development and initial validation of a draft test procedure being considered by the United Nations Economic Commission for Europe (UN ECE) Informal Working Group (IWG) on Electric Vehicles and the Environment (EVE). This paper reports on a first exploratory phase of testing, in which hybrid vehicles were tested at laboratories in North America and Europe to support initial assessment of the draft procedure and to generate relevant information and experience to assist its further development by the EVE IWG.

Keywords: testing processes, power, vehicle performance, regulation, HEV (hybrid electric vehicle)

1 Introduction

The United Nations Economic Commission for Europe (UNECE) World Forum for Harmonization of Vehicle Regulations (WP.29) is a regulatory forum within the UNECE Inland Transport Committee. Several working parties exist under WP.29, including the Working Party on Pollution and Energy (GRPE) which develops emission and energy requirements for vehicles. Several informal working groups (IWGs) exist under GRPE, including the Electric Vehicles and the Environment (EVE) IWG. Under the second of two mandates, the EVE IWG has been tasked with several initiatives related to vehicle electrification, one of which is the development of a test procedure for determining the combined system power of hybrid electric vehicles (HEVs) and pure electric vehicles (PEVs) with more than one propulsion motor.

This paper outlines the structure of the draft test procedure and preliminary results of HEV testing performed in 2018 at the U.S. Environmental Protection Agency (EPA), Environment and Climate Change Canada (ECCC) and European Commission Joint Research Centre (JRC).