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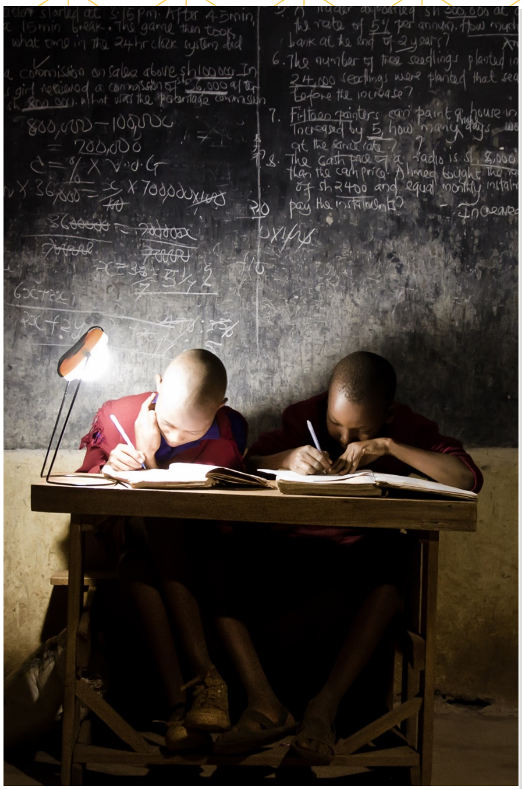
TECHNICAL NOTES



USB Charging Performance of Off-grid Products

In 2018, as part of ongoing efforts to bolster the off-grid solar market, Lighting Global Quality Assurance investigated the USB charging performance of off-grid solar products. Laboratory tests were conducted to assess the USB compatibility and charge times of product combinations. The testing demonstrated both successful charging performance and also identified problems that may occur when off-grid products are used to charge mobile devices.

Executive Summary

This Technical Note presents the results of three different phases of mobile device testing performed at the Schatz Energy Research Center (SERC) for the Lighting Global Quality Assurance Program. With guidance from industry leaders, SERC researchers purchased a set of mobile devices for evaluation. The selected phones and tablets included a number of devices that were reportedly difficult to charge using off-grid solar products (OGPs). During the research, we assessed the ability of off-grid solar products to charge these mobile devices under a range of different states of charge (SOC) for the batteries in both the mobile devices and off-grid solar products. We also evaluated how mobile device settings affected charging. Through this testing we gained insight into potential frustrations an off-grid consumer may have when charging their mobile device with a solar product. Findings include:

- While almost all the tested off-grid solar products were able to provide a charge to the selected mobile devices, one of the off-grid solar products was incompatible with a mobile device and provided no charge at all.
- The majority of off-grid solar products charged the mobile devices at a slower rate than the AC chargers that came with the phones and tablets.
- A few of the mobile devices had a larger battery capacity than the off-grid solar product that was being used to charge it, so the mobile device could not be fully charged even if the off-grid solar product began with a full charge. As smart phones and tablets become increasingly common in off-

grid areas, we anticipate this will become a more common experience for off-grid solar product consumers.

Given rapid innovation for both mobile devices and off-grid solar products along with increased use of smart phones and tablets in off-grid areas, **additional testing of newer mobile devices and off-grid solar product combinations is required to ensure up-to-date knowledge about issues consumers may experience when attempting to charge mobile devices with their off-grid solar products.**

Introduction

As the number of mobile device users increases globally in off-grid areas, mobile device charging has become an important and common feature of many off-grid solar products. Roughly 75% of products currently meeting the Lighting Global Quality Standards[1] include one or more charging ports, the majority of which are configured as USB Type A ports[2]. In order to successfully charge a mobile device, and charge it in a reasonable amount of time, an off-grid product's electronics must be properly designed to provide a sufficiently high level of charge current and also have the ability to communicate this information to the mobile device when the device is initially plugged in[3]. Failure to support a proper charging regime can result in a slow charge or no charge at all in some circumstances.

The high number of mobile device technologies currently in use means that an off-grid product will be expected to handle many different charge scenarios. The USB-IF specifications were developed to provide a standard platform that will work across a great many product combinations, and if design requirements are followed these many combinations should all work. The reality, however, suggests that USB charging is not a simple matter, and some mobile products have trouble charging when used with other manufacturers' chargers. The problem is only compounded by the additional technical challenges associated with the design of solar powered off-grid products. Lighting Global has found, in its discussions with manufacturers and other industry stakeholders, that the USB design process for an off-grid product requires a substantial investment of time and engineering resources. Proofing the development of a successful charge port design requires cross testing with many different mobile devices which can be a significant burden, but the failure to do so may result in charging failure and ultimately in consumer dissatisfaction with a particular product or manufacturer.

The tests performed by Lighting Global are aimed at assessing the current state of OGP technology and its ability to perform this essential task. The testing is not intended to identify specific product failures, and all results have been anonymized. In addition, we will outline testing details that may be useful to manufacturers formulating their own USB product design and testing procedures.

Testing Procedure and Results Overview

Three individual test phases were conducted over the course of the investigation in late 2017 and early 2018. Adjustments to test procedures and the selection of product combinations evolved as results were analyzed.

At a basic level, the testing focused on the ability of OGP's to charge mobile devices and the necessary test equipment and device configurations to make this determination (Table 1). The assessment included many different state-of-charge scenarios for both the Off-grid products and the mobile devices to simulate real world conditions, and included combinations where the mobile devices had both larger and smaller battery capacities than the OGPs.

[1] as of December 2018
[2] for a description of USB port specifications and performance details, see https://www.lightingglobal.org/resource/usb-smartphone-and-battery-charging/
[3] this process is called enumeration and is described in the Lighting Global Technical Note https://www.lightingglobal.org/resource/usb-smartphone-and-battery-charging/.

TABLE 1: SUMMARY TEST RESULTS

	pass/fail charge test result	research comments
Phase I	23 successful charge tests	Some charge rates were very slow. Charge current varied from 200-900 mA
Phase II	36 successful charge tests. 1 combination failure	Mobile device SOC did not significantly affect charge rate
Phase III	46 partially successful charge tests	A majority of mobile devices received only a partial charge

Phase I: Initial Data Collection

Phase I tested four (4) mobile products (two smartphones and two tablets) used with six (6) OGPs. Voltage and current readings were taken at the OGP battery and the OGP port to measure the power removed from the OGP battery and the charge rate delivered to the mobile device.

Phase I results summary: All OGPs were able to provide charge current to the mobile devices, but the charge rate varied from 200mA – 900mA. Only one OGP was able to maintain the higher rate of charge current across all mobile devices.

Phase II: Effects of Different Mobile Device Configurations

Phase II tested nine (9) mobile products used with two (2) OGPs. Different charge levels for the various batteries were tested: the mobile device batteries started with 0-75% states of charge (a full battery has a 100% state of charge), and the OGP batteries started with 25-100% states of charge. Each mobile product was also tested with its included AC charger.

Phase II results summary: One product combination was unable to charge the mobile device. Several combinations experienced erratic charging rates during the first several minutes after the mobile devices were plugged in, but subsequently charged at a steady rate for the remainder of the test. The beginning state of charge of the mobile device battery did not affect the charge rate except during the end of the charge when the mobile device battery was above 75% state of charge.

Phase III: Comparing Different Off-grid Solar Products

Phase III tested six (6) mobile devices used with four (4) OGPs. The OGPs started with 25% and 100% states of charge.

Phase III results summary: All OGPs were able to charge all mobile devices with the exception of the one case previously identified in Phase II. Many mobile devices received only a partial charge because the OGP battery was smaller than the mobile device battery.

Conclusion

Testing revealed that, on the whole, off-grid solar products appear able to successfully provide power to many different mobile devices. Consumers may, however, experience compatibility issues with some combinations such that their mobile device receives no charge from an off-grid charger. In our testing, we only observed this in one case, but anecdotal evidence from conversations with off-grid solar manufacturers indicate that there are a number of other similar cases spanning a variety of off-grid solar products and mobile devices. While we successfully tested a range of mobile devices, including a number of challenging devices recommended by industry leaders, this was not an extensive assessment of mobile device and off-grid solar product charging combinations. Further testing with different and newer mobile devices and off-grid solar products is required to expand knowledge about the experiences consumers will have when charging their mobile devices.

The size of a mobile device's battery and the amount of energy available from an off-grid solar product's battery are important parameters influencing the outcome of charging. Many of the newer mobile devices have batteries with larger storage capacity than the batteries in smaller off-grid solar products. If a consumer does not understand this relationship between battery size, they may be frustrated with the inability to fully charge their mobile device even when their off-grid solar product is fully charged. As mobile device technology continues to advance, and consumers continue to purchase larger capacity mobile devices, this is likely to become a more common experience for off-grid solar consumers.

Annex 1 below describes the testing phases in more detail and provides specific test results for each phase. All OGP names are listed anonymously.

Charge Rate and USB Battery Charging specifications

Perhaps the most significant negative finding from this research concerned charge rates. In general, the off-grid solar products in the study charged mobile devices more slowly than the original AC charger that came with the product, with the extreme example of a five-fold (5x) increase in charge time from 2.5 hours on an AC charger to 10 hours from an off-grid product. A look at the charge rates that were observed (Figure 4) suggests that mobile devices were detecting either 500mA or 900mA nominal charge rates available from off-grid products, with more falling into the 500mA and below range.

Generic specifications for USB devices are provided by the USB Implementers Forum, Inc. (USB-IF), a non-profit corporation founded by computer industry stakeholders. Many mobile devices on the market are designed with either these USB-IF specifications in mind or the manufacturer's own proprietary charge specifications (which tend to feature fast charging to minimize charge time). Manufacturers of OGP's can use the USB-IF specifications as a starting point when designing their USB charging ports and optionally include other proprietary charging sequences to increase the utility of this feature for their customers.

The USB port has evolved from a data transfer interface with limited power delivery when it was introduced in 1996 (USB 1.0) to a dual power supply/data interface capable of providing up to 100 watts of in 2012 (USB Power Delivery (PD) rev.1). USB standards continue to evolve and include USB Power Delivery rev. 3 and "Certified USB Fast Charger" definitions released in 2018 (Table 2). These specifications lay out procedures for USB hosts (in our case, the OGP) and downstream portable devices (phones and tablets) to communicate with each other and set the allowable charge current in a process called enumeration.

With the evolution of ever larger batteries, many mobile device manufacturers have moved beyond the Standard Downstream Port (SDP) power limitations and are designing their products for the higher charge currents found with USB Dedicated Charge Ports (DCP) or proprietary charge sequences at and above 1.5A. If off-grid products are to keep pace with this evolution, they will need increasingly larger batteries and will be expected to provide higher power capabilities with their USB ports.

TABLE 2: CURRENT, VOLTAGE, AND POWER LEVELS OF OFFICIAL USB-IF SPECIFICATIONS

Specification	current	voltage	Power (max)
USB 2.0 Low-power	100 mA	5 V	0.5W
USB 2.0 High-power	500 mA	5 V	2.5W
USB 3.0 Low-power	150 mA	5 V	0.75W
USB 3.0 High-power	900 mA	5 V	4.5W
USB 3.2 Gen x2	1.5 A	5 V	7.5W
USB Battery Charging (BC) 1.2	1.5 A	5 V	7.5W
Type-C	1.5 A	5 V	7.5W
Type-C	3 A	5 V	15W
Power Delivery 2.0 Micro-USB	3 A	20 V	60W
Power Delivery 2.0 Type-A/B/C	5 A	20 V	100W

Annex 1: Detailed Testing Reports

Phase I: Initial Data Collection

SERC's DAQ system, which is currently used for the IEC 62257-9-5, Annex R: Solar Charge Test, was utilized to measure voltage and current at approximately 1-minute intervals. During the initial trials, it was determined that two current and voltage measurements would be taken: one between the off-grid solar product's PCB and battery and one at the off-grid solar product's USB port (Figure 1).

A test jig was fabricated using a USB 2.0A port to allow voltage and current measurements to be taken at the USB port during device charging. The USB 2.0 has a four-pin configuration with a 5V power source (VBUS), data (D+ and D-), and ground (GND) pins (Figure 2).

FIGURE 1: DIAGRAM OF DATA ACQUISITION SYSTEM MEASUREMENT POINTS DURING PHASE I

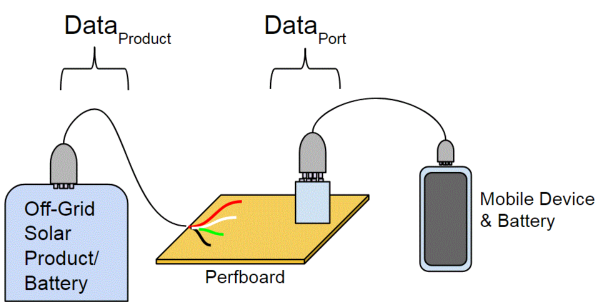
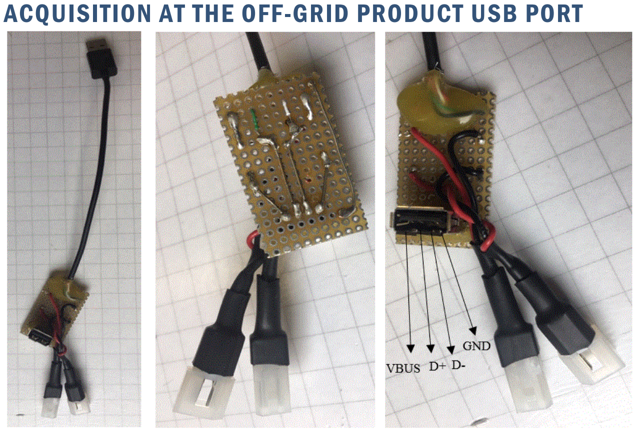


FIGURE 2: PERFBOARD FABRICATION USED FOR DATA ACQUISITION AT THE OFF-GRID PRODUCT USB PORT



In Phase I, two smartphones and two tablets were each tested with six off-grid solar products. Table 3 presents the specifications of the mobile devices and off-grid solar products associated with this phase of testing, and Figure 3 provides a summary of the battery capacities of these devices and products. The goals of this phase were to test the DAQ equipment and connections, identify whether any of the off-grid solar products had issues charging the mobile devices, and compare the average charging currents for each off-grid solar product and mobile device combination. During this phase of testing, the smartphones started at a 0% state-of-charge (SOC), the tablets were at various SOCs, and the off-grid solar products were at 100% SOC. No basic or feature phones were tested during this phase of the research. Voltage and current measurements were taken between each off-grid solar product's printed circuit board (PCB) and battery and at its USB port. Time intervals for the measurements spanned from a minimum of 20 minutes to a maximum of 110 minutes.

Phase I Results

In these initial trials, all the selected off-grid solar products were able to charge the mobile devices. However, the current each mobile device received varied depending on the off-grid solar product charging it (Figure 4). Other than the variations in current, the only other notable observation was that the Pico B off-grid product provided oscillating current when charging the Tecno smartphone (Figure 5). Based on these results, we chose to include this off-grid solar product / mobile device combination in future phases of testing.

From this phase of the testing, we determined that adding a third voltage and current measurement between the mobile device's PCB and battery to log energy accumulated at the mobile device's battery would provide information on the final SOC of the mobile device's battery.

TABLE 3: MOBILE DEVICES AND OFF-GRID SOLAR PRODUCTS TESTED IN PHASE I

Model	Abbreviation	Type	Nominal Voltage [V]	Rated Battery Capacity [mAh]
Mobile Device				
Samsung Duos	Duos	Smart	3.7	1000
Tecno Y2	Tecno	Smart	3.8	2800
Samsung Tablet	Samsung	Tablet	3.7	4000
Asus Nexus	Asus	Tablet	3.7	4325
Off-Grid Solar Products				
Off-grid Product	Pico A	Pico	3.6	750
Off-grid Product	Pico B	Pico	3.2	2300
Off-grid Product	Pico C	Pico	6.4	2000
Off-grid Product	Pico D	Pico	3.6	3000
Off-grid Product	Pico E	Pico	3.2	1720
Off-grid Product	Pico F	Pico	3.7	8800

FIGURE 3: SUMMARY OF RATED BATTERY CAPACITIES FOR PRODUCTS USED IN PHASE I

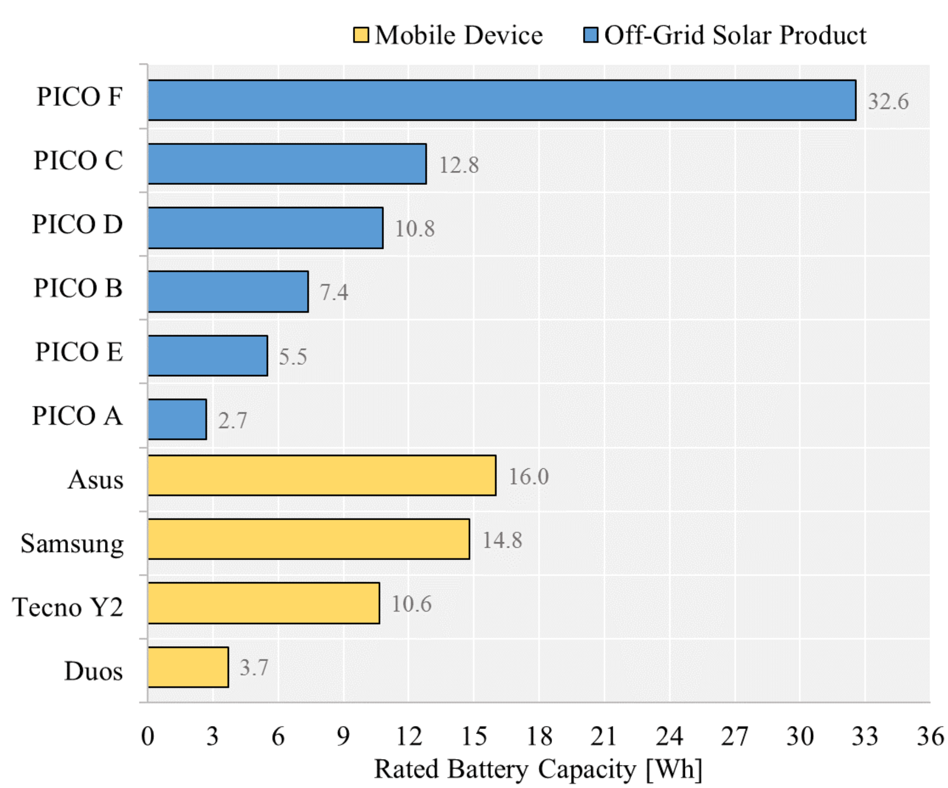


FIGURE 4: AVERAGE CHARGING CURRENT FOR PRODUCTS USED IN PHASE I

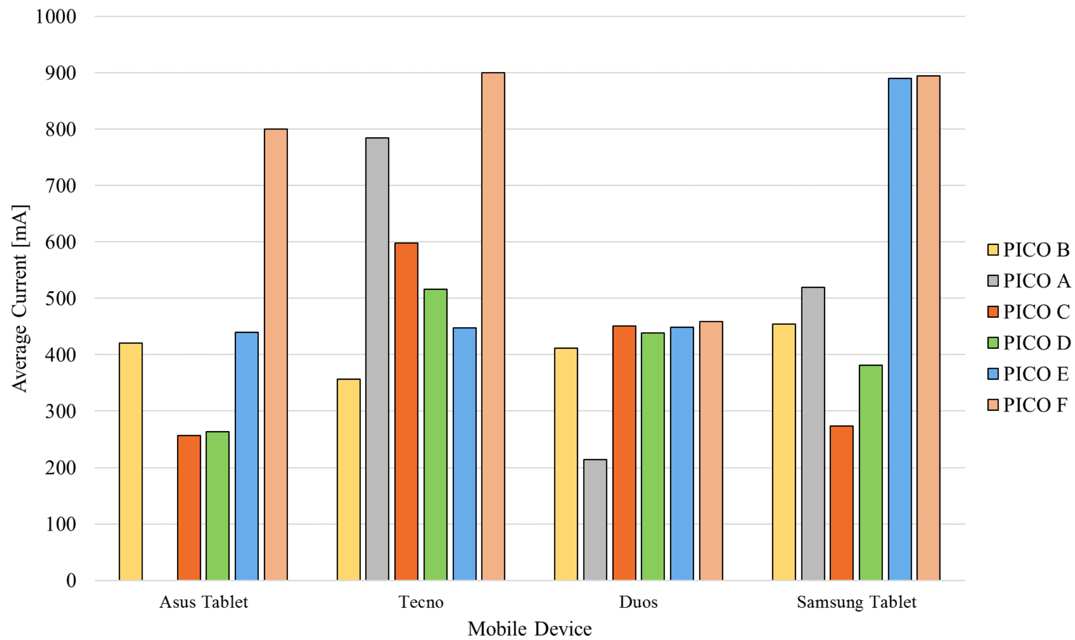
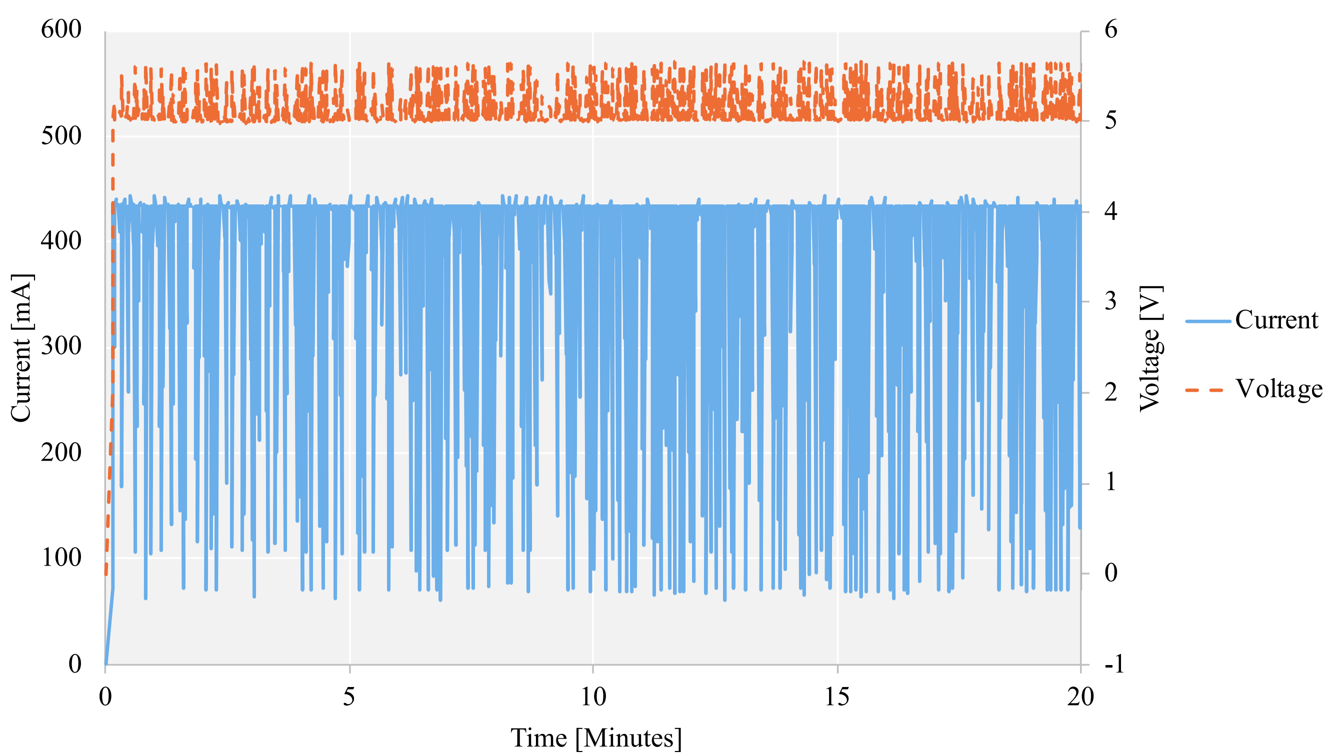


FIGURE 5: ERRATIC CHARGING BEHAVIOR FOR PICO B AND TECHNO Y2 PRODUCT COMBINATIO



Phase II: Effects of Different Mobile Device Configurations

Phase II focused on investigating how different device settings and configurations affected charging. These scenarios included charging the mobile device in both the on and off state, charging with varying state of charge levels for the mobile device, and charging with varying off-grid solar product states of charge. In addition to these scenarios, we ran a trial where the mobile device was charged using its provided AC charger and an AC power supply (set to 240 V, 50 Hz to match the standard grid voltage and frequency in most Sub Saharan African and South Asian countries). The AC charging data provided a baseline for comparison with the off-grid solar product charging results. For this phase, OGP manufacturers recommended mobile devices that they deemed challenging from a compatibility perspective, and the Nokia 1100, Nokia 530, Nokia 222, Samsung Duos, and Micromax 2A106 were purchased and included in this phase of testing.

Nine mobile devices, including basic, feature, and smart phones and tablets were tested by charging each device using one of two different off-grid solar products. A spot check was done to confirm that each mobile device could be charged with both off-grid solar products, and then half of the mobile devices were tested with the Pico B product, and the other half were tested with the Pico G product. Table 4 provides a summary of the specifications associated with the devices and products tested during this phase. Figure 6 provides a summary of the battery capacities for each of the products and devices used during this phase of testing. Table 5 provides an overview of each scenario that was run. All trials were run for 30 minutes except for trials where the mobile phone was at a 75% state of charge; these trials were run until the mobile device reached a full charge or stopped charging.

Results

The results of Phase II are summarized as follows:

- both of the off-grid solar products were able to charge all of the mobile devices regardless of configuration except for the Nokia 1100.
- Irregular charging behavior was observed during the first few minutes for many tests
- All mobile devices were charged successfully whether they were turned ON or OFF
- All mobile devices were charged successfully at battery SOC levels of 0%, 50%, and 75%

There was often irregular charging behavior at the mobile device's battery when initially connected to the off-grid solar product. Since this charging behavior was not representative of the rest of the trial, we decided to omit the first two minutes of data in our calculations in Phase II, and this was also omitted in all Phase III calculations. Figure 7 provides examples of data where there were oscillations in current within the first two minutes of charging.

One OGP was unable to charge the Nokia 1100. It should be noted that this product did not have the proper barrel plug charge cable for the Nokia 1100. We used other cables to attempt charging but this was not successful (Figure 8).

All other mobile devices were charged successfully using their respective off-grid solar product whether they were turned off or turned on. The measured difference between the current delivered at the USB port when the phone was switched off and when the phone was switched on was less than 4% (Table 6). In these trials, the phone started at a 50% SOC, the off-grid solar product was at 100% SOC, and the measurements were taken over a 20-minute period.

All mobile devices were charged successfully by their designated off-grid solar product at starting state of charge levels of 0%, 50% and 75%. The average currents delivered to the battery when the mobile device as set to different state of charge levels were usually similar. There was a notable drop in current for the Micromax, Tecno Y2, Nokia 1100 and Nokia 222 when comparing the 75% SOC to the 0% and 50% SOC (Table 7). However, for these mobile devices, we suspect that as they neared a full-charge, the internal circuitry lowered the current allowed to enter the battery. This was further investigated in Phase III.

TABLE 4: DEVICES AND OFF-GRID SOLAR PRODUCTS TESTED IN PHASE II

Model	Abbreviation	Type	Nominal Voltage [V]	Rated Battery Capacity [mAh]
Mobile Device				
Nokia 1100	--	Basic	3.7	1120
Itel 6800	Itel	Feature	3.7	1000
Nokia 222	--	Feature	3.7	1100
Samsung Galaxy Duos	Duos	Smart	3.7	1000
Nokia 530	--	Smart	3.7	1430
Micromax 2A106	Micromax	Smart	3.7	2000
Tecno L8	--	Smart	3.8	2500
Tecno Y2	--	Smart	3.8	2800
Asus Nexus	Asus	Tablet	3.7	4325
Products				
Off-grid Product	Pico B	Pico	3.3	2300
Off-grid Product	Pico G	Pico	12.8	3000

FIGURE 6: SUMMARY OF RATED BATTERY CAPACITIES FOR PRODUCTS AND MOBILE DEVICES TESTED IN PHASE II

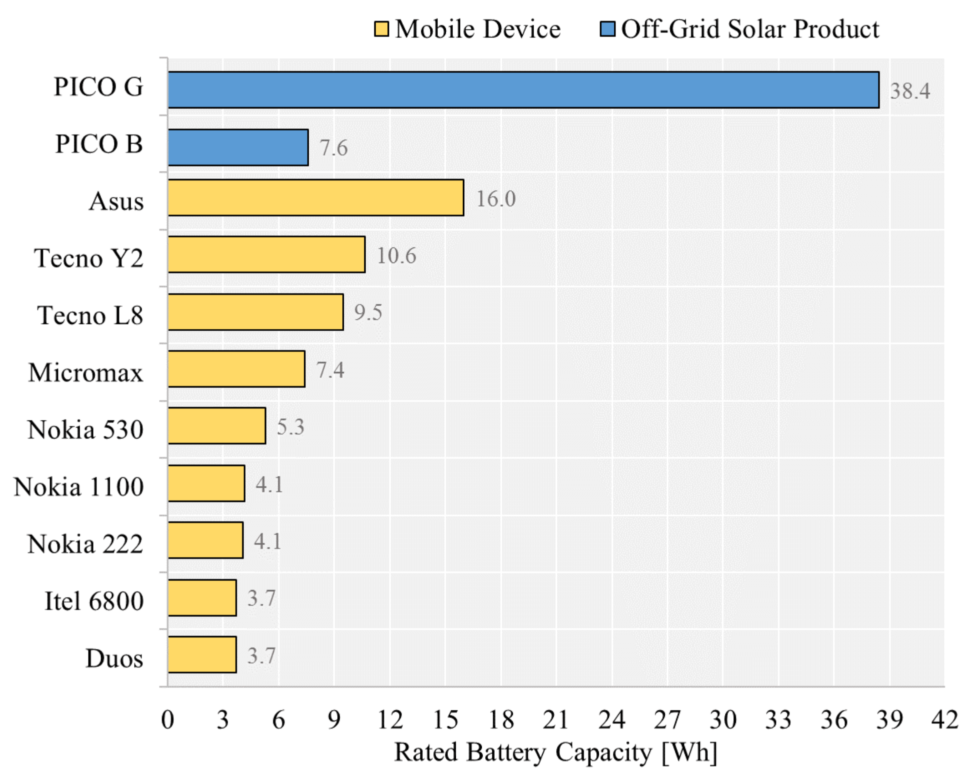


TABLE 5: TRIALS RUN FOR EACH MOBILE DEVIDE AND OFF-GRID SOLAR PRODUCT COMBINATION

Test Plan		
Off-Grid Product SOC	Mobile Device On/Off	Mobile Device SOC
100%	Off	0%
100%	Off	50%
100%	On	50%
100%	Off	75%
25%	Off	75%

FIGURE 7: PLOTS DISPLAYING IRREGULAR BEHAVIOR DURING THE FIRST MINUTES OF MOBILE DEVICE CHARGING

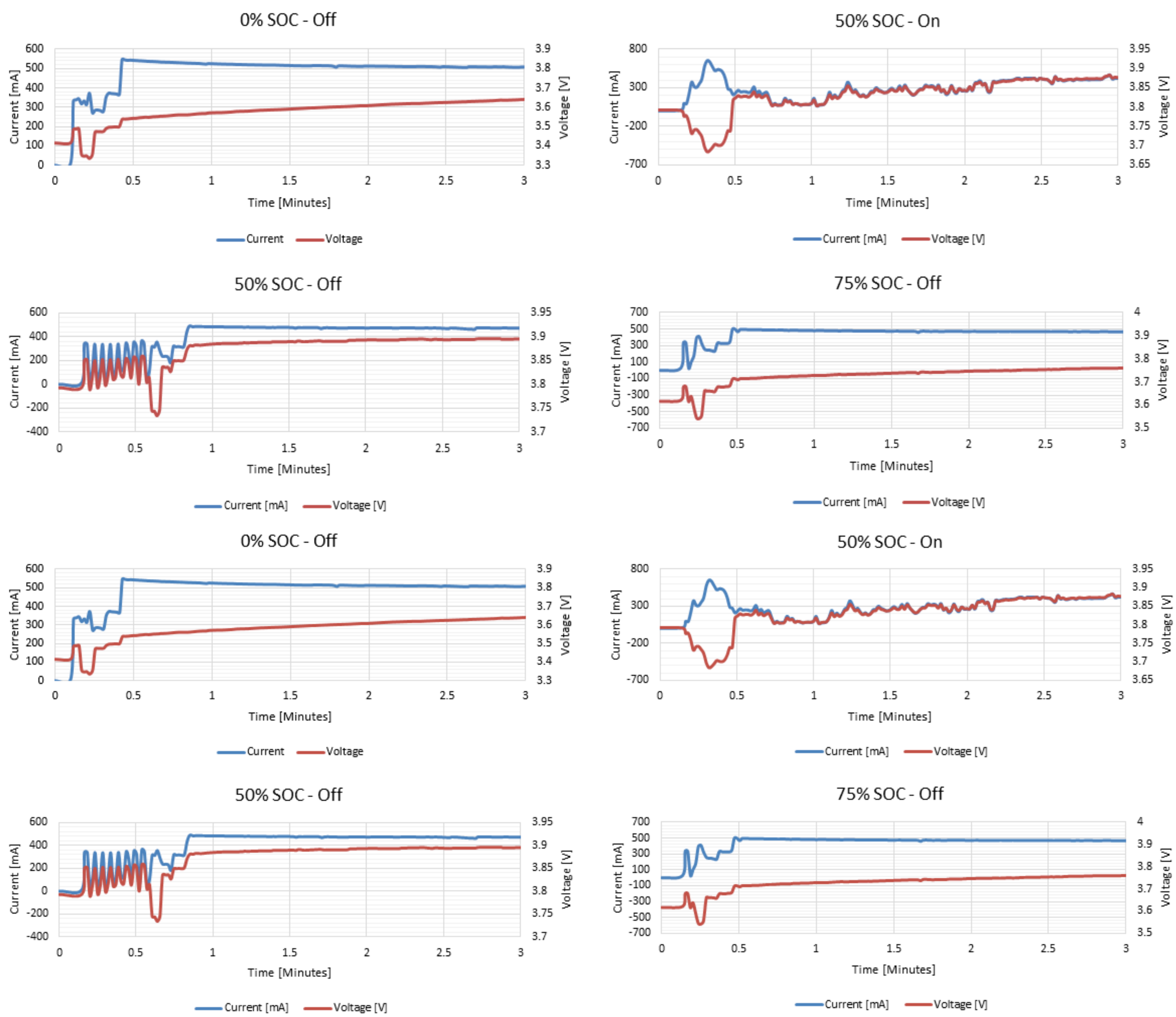


FIGURE 8: PLOTS DISPLAYING IRREGULAR CHARGING BEHAVIOR DURING THE FIRST MINUTES OF MOBILE DEVICE CHARGING

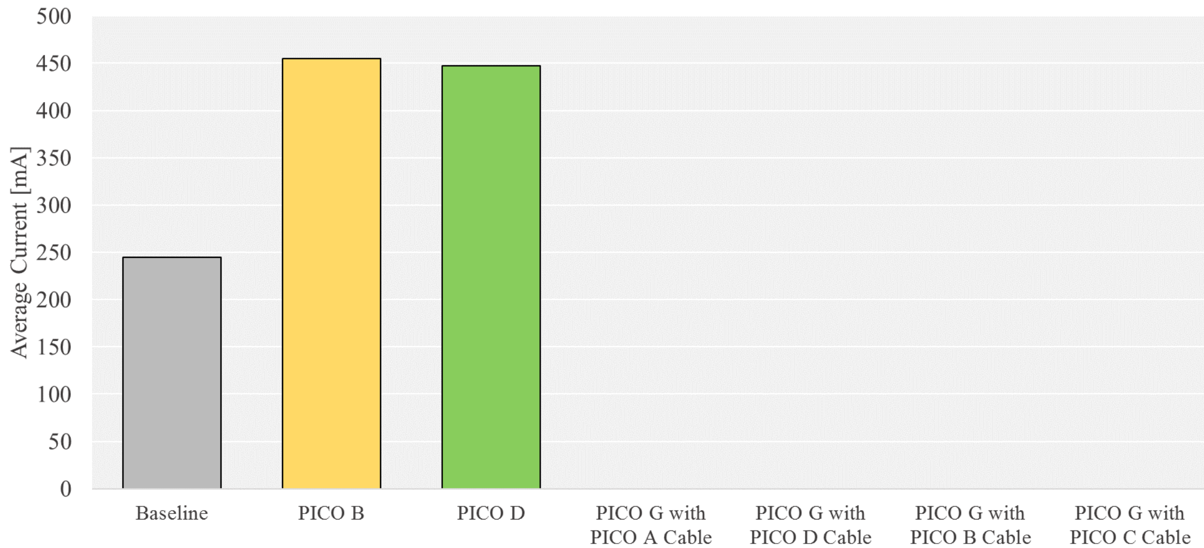


TABLE 6: MOBILE DEVICE ON/OFF AVERAGE CURRENT CONSUMPTION

Off-Grid Solar Product	Mobile Device	Off USB Current [mA]	On USB Current [mA]	% Difference from Off Setting [%]
Pico G	Nokia 530	464	463	-0.2%
	Micromax 2A106	474	471	-0.6%
	Itel 6800	303	313	3.2%
	Tecno Y2	464	470	1.3%
Pico B	Nokia 1100	414	420	1.4%
	Nokia 222	318	326	2.5%
	Samsung Duos	439	450	2.4%
	Tecno L8	469	467	-0.4%

TABLE 7: COMPARISON OF AVERAGE CHARGING CURRENT AT EACH MOBILE DEVICE'S BATTERY AT DIFFERENT SOC

Off-Grid Solar Product	Mobile Device	Current at Baseline [mA]	Current at 0% SOC [mA]	Current at 50% SOC [mA]	Current at 75% SOC [mA]
Pico G [100% SOC]	Nokia 530	304	281	268	243
	Micromax 2A106	333	509	489	312
	Itel 6800	245	301	300	316
	Tecno Y2	666	451	449	387
Pico B [100% SOC]	Nokia 1100	237	457	423	262
	Nokia 222	321	313	324	218
	Samsung Duos	452	457	452	453
	Tecno L8	714	480	466	435
	Asus Tablet	512	492	448	440

Phase III: Comparing Different Off-Grid Solar Products

This phase of testing focused on comparing mobile device charging behavior when charged by several different off-grid solar products. Based on guidance from an industry representative, we decided to test the off-grid solar products' ability to charge mobile devices at a high state of charge (100% SOC) and a low state of charge (25% SOC). The industry representative indicated that high and low states of charge could create extreme voltages at the USB port and prevent some mobile devices from charging. In this round of testing, four off-grid solar products were used to charge six mobile devices. Table 8 provides a summary of the specifications associated with the devices and products tested during this phase, and Figure 9 provides a summary of the battery capacities for each of the solar products and mobile devices used during this phase of testing. Of the off-grid solar products chosen, one was an older style lantern pico-product (Pico C), two were relatively new pico-solar products (Pico B and Pico D), and one was a pico-solar product with a larger, 12.8 V battery (Pico G). We included a range of mobile devices, including one basic phone (Nokia 1100), two feature phones (Itel 2060 and Nokia 222), two smart phones (Micromax 2A106 and Tecno Y2), and one tablet (Asus). All of the mobile devices except for the Asus tablet and the Tecno Y2, which was procured in the field, were identified as problematic devices. In the trials with the Pico G and the Nokia 1100, a OEM charging cable was used since the Pico G product does not come with an older style Nokia charging connector. Also, for this testing we utilized a three-channel Yokogawa power meter which enabled the simultaneous logging of voltage, current, power, and energy accumulated for all three measurement points.

Phase III Results

Other than the Pico G / Nokia 1100[4] combination, which demonstrated compatibility issues in Phase II, all the off-grid solar products were able to provide a partial or full charge to the mobile devices regardless of their state of charge (Table 9).

The Pico G product at a high state of charge was able to provide a full charge to all of the mobile devices faster or close the time required to fully charge the mobile device with their provided AC charger (except the Nokia 1100). At the low state of charge, many of the off-grid solar products' batteries were depleted before they could provide a full charge to the mobile devices. Overall, almost all of the mobile device and off-grid solar products were able to provide a charge regardless of the SOC, but the mobile devices were charged at a slower rate than they would have if they were connected to the grid. It is notable that while the Pico C product was able to provide current to each mobile device, it was not able to fully charge the Tecno Y2, Itel 2060, or Micromax 2A106 at a high state of charge despite having a large enough battery to fully charge all of these devices. Figure 10 displays curves showing the energy accumulated by each mobile device and off-grid solar product combination. In these graphs, once the mobile device reached its highest accumulated energy, the data were extended from this point to help compare the maximum energy accumulated for each mobile device and off-grid solar product combination. The average current provided at each USB port is shown in Figure 11 and the average off-grid solar product efficiencies are shown in Figure 12.

[4] The Nokia 1100 was discontinued in 2009 and decreased usage, as existing models fail and are retired, will make charge compatibility with this phone less important with time. At least one OGP manufacturer has removed the Nokia 1100 from its charge compatibility testing.

TABLE 8: MOBILE DEVICE AND OFF-GRID SOLAR PRODUCTS TESTED IN PHASE III

		Mobile Device		
Nokia 1100	--	Basic	3.7	850
Nokia 222	--	Feature	3.7	1100
Itel 2060	Itel	Feature	3.7	1000
Micromax 2A106	Micromax	Smart	3.7	1000
Tecno Y2	--	Smart	3.8	2800
Asus Nexus	Asus	Tablet	3.7	4325
		Products		
Off-grid Product	Pico B	Pico	3.3	2300
Off-grid Product	Pico C	Pico	6.4	2000
Off-grid Product	Pico D	Pico	3.2	3000
Off-grid Product	Pico G	Pico	12.8	3000

FIGURE 9: SUMMARY OF RATED BATTERY CAPACITIES FOR PRODUCTS AND MOBILE DEVICES TESTED PHASE III

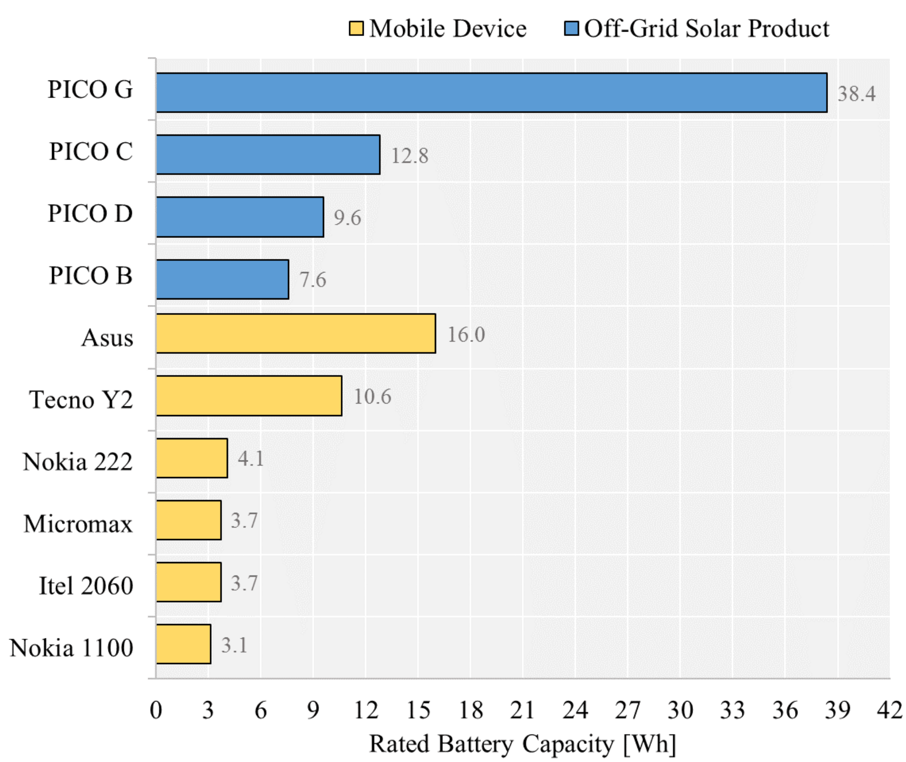
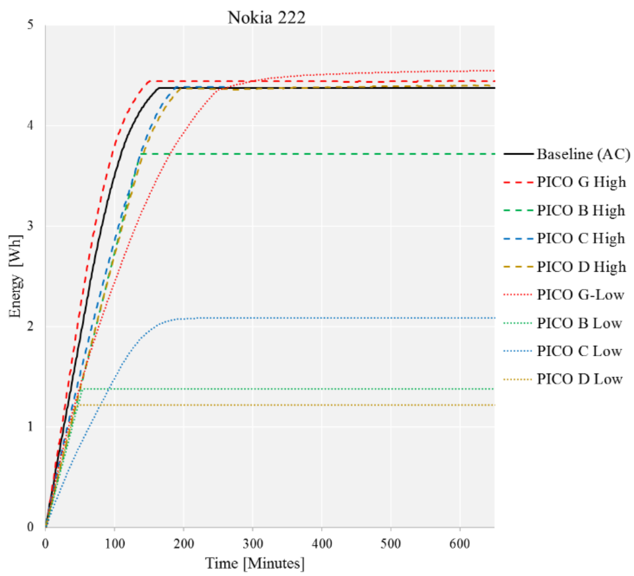


TABLE 9: CHARGING RESULTS FROM PHASE III TESTING

SOC	Product	Nokia 1100	Itel 2060	Nokia 222	Micromax	Tecno Y2	Asus Tablet
100%	Pico G	no charge	full charge	full charge	full charge	full charge	full charge
	Pico D	full charge	full charge	full charge	partial charge	partial charge	partial charge
	Pico B	full charge	partial charge	partial charge	partial charge	partial charge	partial charge
	Pico C	full charge	full charge	full charge	partial charge	partial charge	partial charge
25%	Pico G	no charge	full charge	full charge	partial charge	partial charge	partial charge
	Pico D	partial charge	partial charge	partial charge	partial charge	partial charge	partial charge
	Pico B	partial charge	partial charge	partial charge	partial charge	partial charge	partial charge
	Pico C	partial charge	full charge	partial charge	partial charge	partial charge	partial charge

FIGURE 10: ENERGY ACCUMULATED BY MOBILE DEVICES DURING PHASE III TESTING



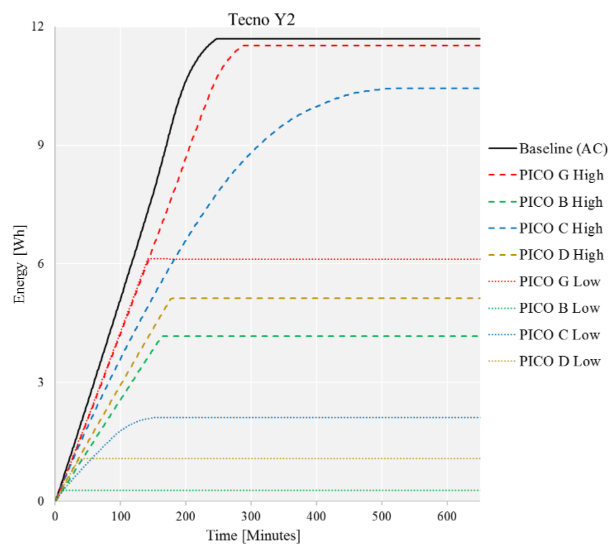


FIGURE 10 (CONT): ENERGY ACCUMULATED BY MOBILE DEVICES DURING PHASE III TESTING

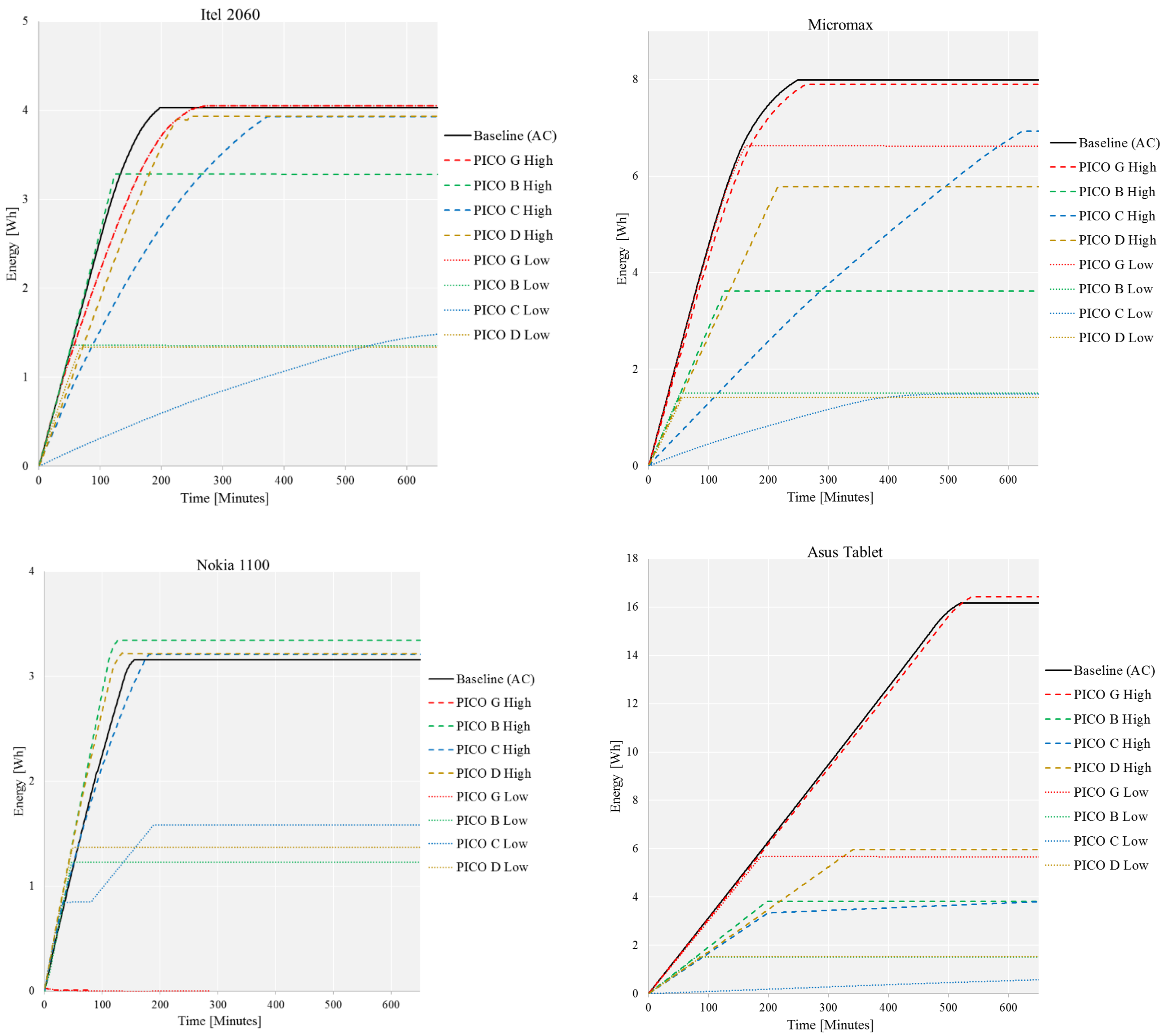


FIGURE 11: AVERAGE CURRENT PROVIDED AT USB PORT

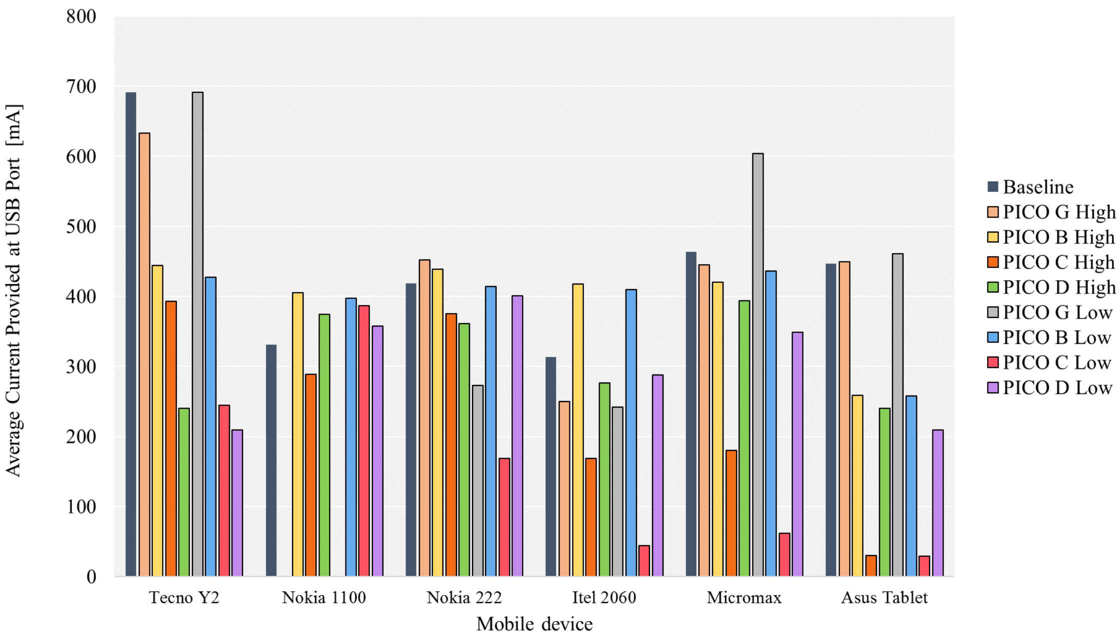


FIGURE 12: AVERAGE OFF-GRID PRODUCT CHARGING EFFICIENCY