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Maximizing USB Charge from Bicycle Motion

PedalCell

CyclingAbout

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Photo credit: New York Times

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Introduction

Bicycle riders have an enormous need for powering their essential USB devices, such as bike lights, GPS, smartphones, and more. Battery packs, when used alone, need charging and have limited outdoor performance + lifespans. Solar panels require extensive surface area and are sensitive to weather conditions, making them a potentially poor charging option while riding.

There are solutions that convert bicycle motion into electricity, known as “dynamos,” to provide worry-free, predictable power while a bicycle moves. While most dynamos were initially designed for lights, some can power USB devices. Yet, dynamos can also have inherent disadvantages when used for USB charging. These shortcomings force riders to live within their limited power constraints. PedalCell has developed a new bicycle power source with underlying technologies that aim to address the USB charging pitfalls of dynamos.

What We’ll Cover in This White Paper

This report provides a comprehensive overview of the bicycle dynamo charging landscape. The background showcases why some dynamo chargers experience USB charging challenges. The PedalCell section summarizes how the product approaches the existing dynamo charging challenges. Experimental test data supports PedalCell's summary and shows the product's real-world performance. Finally, an analysis of the test results is presented with a conclusion.

Today’s Dynamo Charging Realities

When users plug their USB device into a wall outlet, more times than not, charging starts without a hitch. While this process may seem simple from the outside, USB charging has a lot more going on behind the scenes. When combined with a bicycle dynamo, a multitude of issues can arise.

Power Output

It is not uncommon for a bicycle dynamo to take 6-9 hours to fully charge a smartphone on standby. Dynamos also struggle to power multiple devices, say a light and a smartphone, in-parallel due to the generators’ limited power output. Bicycle dynamos were originally designed for lights with lower power requirements than modern USB devices. For example, a typical bicycle dynamo is rated for 3 Watts (W) of power. While it is possible to extract more, sometimes 5-6W, at faster riding speeds, the output pales compared to what modern USB devices ship in the box. As a reference, an iPhone 11 Pro comes with an 18W wall charger. This problem is further exacerbated when riders use their devices while riding, running into low service areas, extreme climates, screens on high brightness, or tracking rides with GPS. These intensive activities can increase power draw up by up to 10X (source). A bicycle dynamo’s power output is rarely sufficient to charge, or even maintain, a device’s battery level when undergoing such activities.

USB Standards

USB devices charge over pre-defined standards, or "protocols." These protocols allow devices to understand a charger's capabilities and safely draw the maximum amount of power. There are dozens of these protocols, some standard and some proprietary, created by governing bodies, such as USB-IF, or private companies like Samsung or Apple. This fragmented landscape creates an uphill compatibility battle for all chargers. In particular, dynamo chargers are at a disadvantage due to their power outputs failing to meet most standards' minimum power requirements (or only

meeting them at high speeds). In most cases, dynamo chargers choose to support a limited number of standards, causing charging that can be slow and non-optimized. Sometimes, dynamo chargers decide to break the standards altogether, making charging non-existent or dangerous.

Power Stability

USB devices are designed to charge from a stable energy source, such as a wall outlet. A dynamo generator's output is not consistent. Thus, a dynamo's unregulated output can cause USB negotiation hiccups. For example, a USB device may lock its power output at a slow charge-level, ignoring available power at higher speeds. Similarly, a USB device can be forced into a charging "limp mode" when moving from a faster speed to a slower speed. These charging quirks were designed in many USB devices, such as smartphones, as a fail-safe against faulty wall chargers. However, in the dynamo case, it means that charging is almost always locked at a low level no matter the speed (typically 2.5W or lower). Some dynamo chargers implement an internal "cache" battery to mitigate these negotiation hurdles. However, these batteries have downfalls:

a) **Efficiency:** 10-20% charging efficiency loss, resulting in less power reaching the USB ports.
b) **Lifespan:** Degradation from outdoor temperatures and used charge/discharge cycles (300-500 total) over time.

The PedalCell Device

PedalCell is an entirely new bicycle power source that keeps riders safe and connected by charging their essential USB devices. While it has exterior similarities to rim dynamos of old, its underlying architecture is bespoke and patented. PedalCell has primary components designed to work alongside one another.

Generator

Proprietary fork-mounted generator with maximum power output of 15-20W

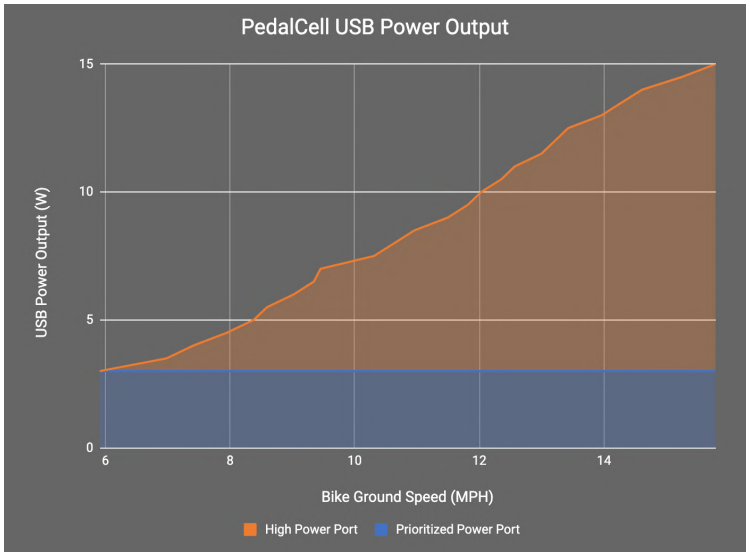
Smart Power Hub

Includes 2X USB-C ports, one safety prioritized (3W max) and one high-power (12W max). Implements patented CadenceX Technology

Value Proposition

PedalCell is proven to be the most powerful and efficient bicycle dynamo system as of November 2020 from prototype tests conducted by Fahrradzukunft. Also, the product claims to overcome challenges traditional dynamo chargers face:

1. **Power Output:** High Generator output power charges devices faster and can power more than one device at a time. In addition, more energy is available at lower speeds, leading to faster charging at any speed. See graph below for USB power available at different speeds (source).



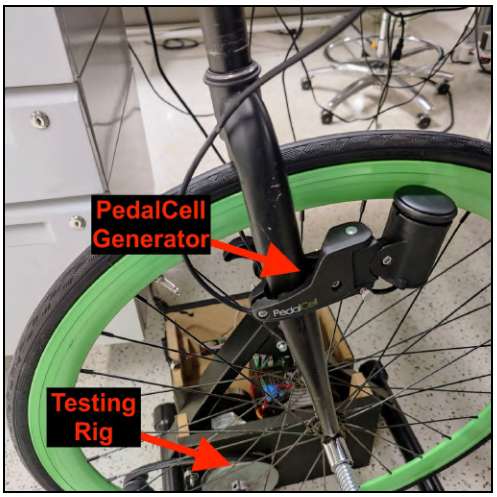
2. **USB Standards:** PedalCell's Generator output enables a variety of USB charging protocols. The supported standards on PedalCell's high-power port include:
    a. USB-C CC 5V, 3A (limited to 2.4A)
    b. Dedicated Downstream Port: 500mA + 900mA
    c. USB Battery Charging Specification BC1.2 + YD/T 1591-2009: up to 1.5A
    d. 1.2-V mode: up to 2A
    e. 2.7-V Apple device profile: up to 2.4A
3. **Power Stability:** CadenceX Technology communicates with USB devices to ensure they use the fastest charging at a given speed. PedalCell changes a device's charging speed via embedded "charging profiles" in CadenceX firmware. The profiles allow dynamic USB power output at both fast and slow speeds while staying within USB standard specifications. Furthermore, CadenceX utilizes a bank of supercapacitors, a form of energy cache, to increase its charging stability. The supercapacitors load share with generator power to provide faster charge at slower speeds for a limited time (climbing hills, slowing for turns, etc.). The supercapacitors also help maintain power for short stops and during the (rare) case of debris slippage. Supercapacitors have high charging efficiency, long lifespans (.5-1M charge/discharge cycles), and wide temperature operating ranges. Thus, a dynamo with supercapacitors can achieve power stability without a battery's pitfalls.

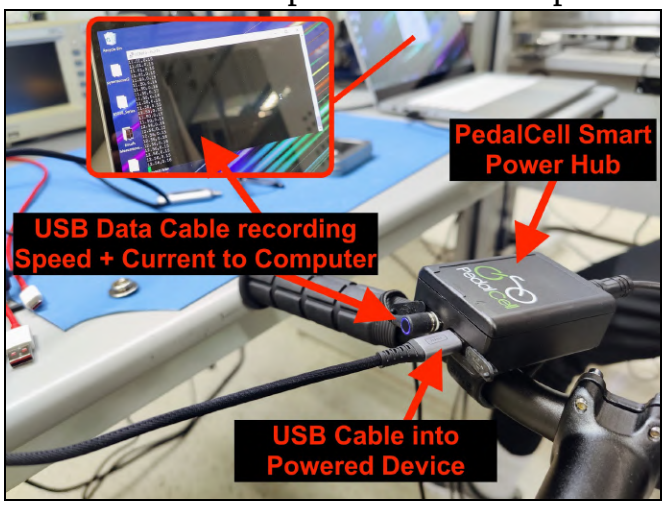
PedalCell Charging Experiment

Setup

PedalCell conducted a dynamic speed experiment to verify its charge claims. Alee Denham, founder of CyclingAbout.com, influenced the test's design, conditions, and devices used. A report from Fahrradzukunft was also referenced for the test as well.

A testing rig simulates uphill and downhill riding behavior. Speed is measured from PedalCell's Generator. The rig accelerates from 4-6 MPH to 14-16 MPH. The top speed is maintained until a peak charging profile is achieved. The wheel then slows down to 4-6 MPH. The slower speed is maintained until devices default to a slower charging profile. The speed then increases to 14-16 MPH until the peak charging profile is again achieved. PedalCell's high-power port will power USB devices. A computer records Generator speed and device charge current via PedalCell's prioritized USB-C port.





Device	Cable used
iPhone XR	Apple C-Lightning
Google Pixel XL(2016)	PedalCell C-C Charging Cable
OnePlus 8 Pro	PedalCell C-C Charging Cable
10400 mAh Battery Pack	C-C Cable

The USB devices will be powered starting within a 30%-40% charge level in two different scenarios (except the battery pack): 1) Standby with the screen off and 2) screen on with Google Maps open while playing music.

***Notes on Drag:** All bicycle dynamos add varying degrees of riding resistance to generate power. The following test was conducted to display maximum power output without care for drag. PedalCell's drag-mitigation features are not a focus of this test. These include:

1. Efficiency: PedalCell is proven to be the most efficient dynamo, meaning that it adds less drag watt-for-watt.
2. 3W lock: PedalCell's Prioritized port locks max output at 3W when used alone.
3. Dynamic output: PedalCell only provides the power that devices need. For example, if a phone is fully charged with the screen off, PedalCell will output less power.
4. Mechanical Decoupling: PedalCell can disconnect entirely from the rim when not needed, thus eliminating all mechanical drag.

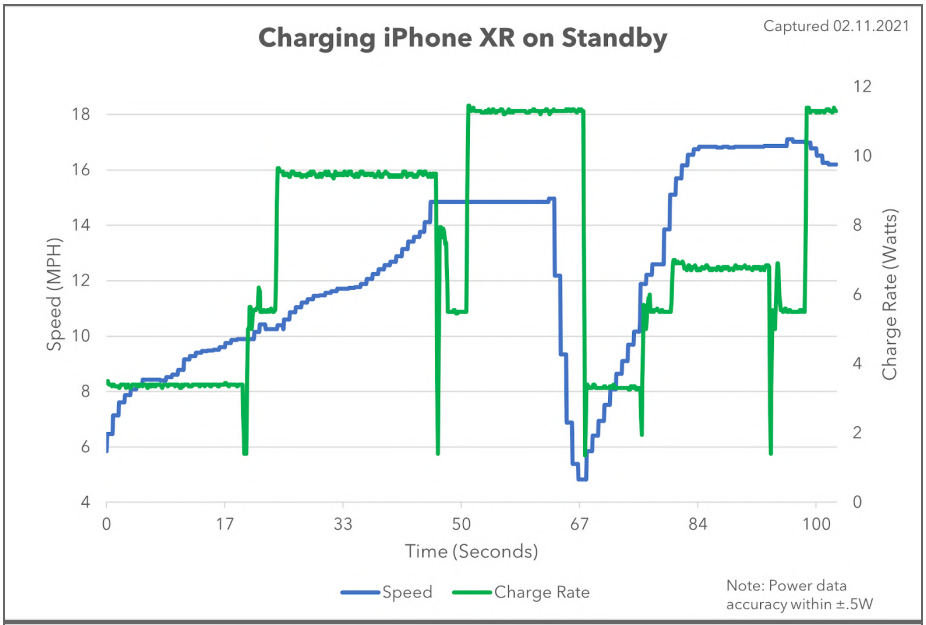
Results & Analysis

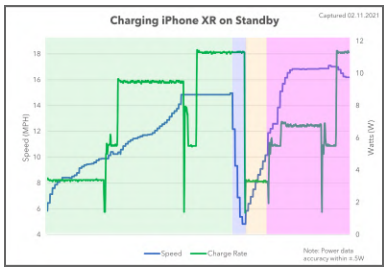
PedalCell ran seven total experiment trials. Each test displays PedalCell's Generator speed (MPH, blue) vs. device charge rate (Watts, green). Current data was converted into Watts by multiplying the captured current values by 5 Volts (PedalCell's nominal output voltage). The data is filtered to remove extraneous measurements. Each graph showcases stages of CadenceX Technology USB negotiation:

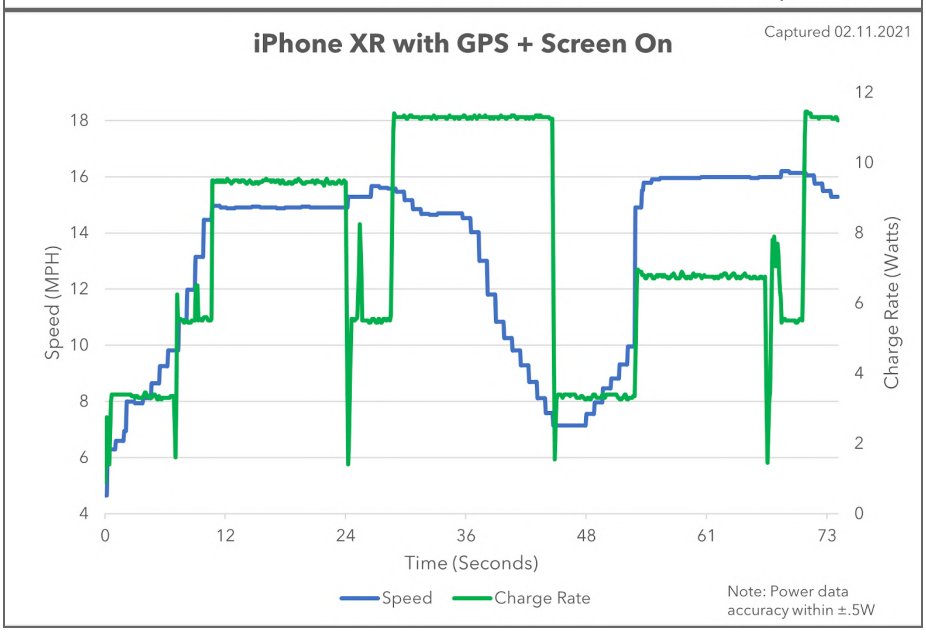
1) **Increase Speed, Increase Power:** Activate faster charge profiles as speed rises. Average speed and an embedded timer are used to select a given profile. Thus, profile activation is delayed to ensure riders stay at a given speed.
2) **Decrease Speed, Maintain Power:** Maintain fastest charge profile as speed decreases via load sharing supercapacitor and generator power.
3) **Renegotiate at Low Power Level:** Automatically renegotiate with USB devices to a lower charge profile and revert power to charging supercapacitor bank.
4) **Reinitiate Increase speed, Increase Power:** Start-over at stage 1 once supercapacitor bank is charged and average speed rises.

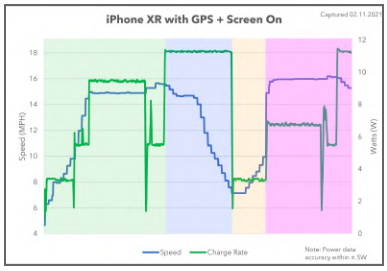
iPhone XR

~12W PeakPower, Standby and GPS + Screen on





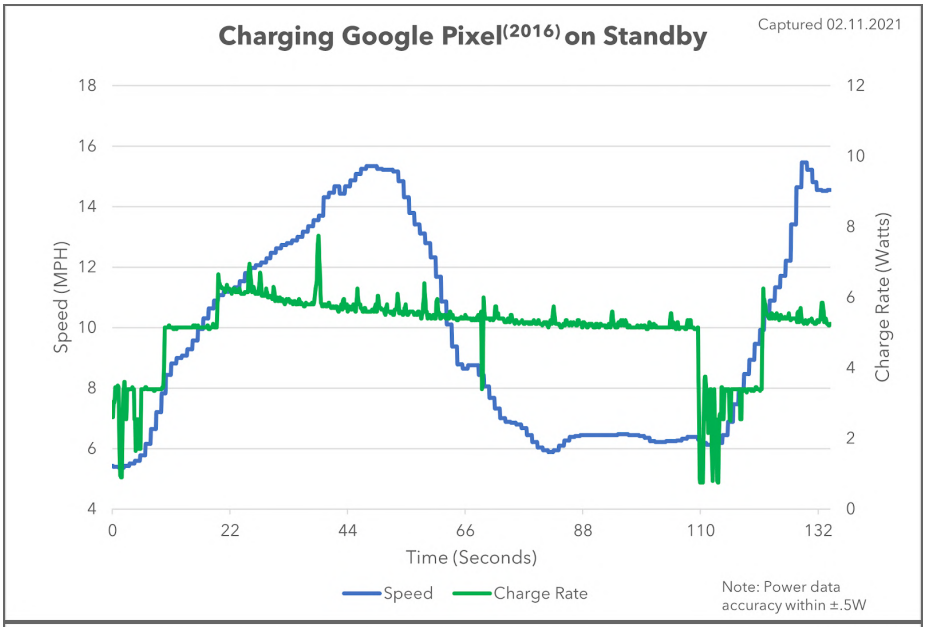


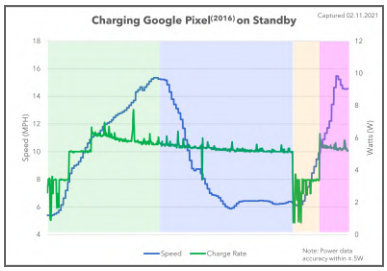


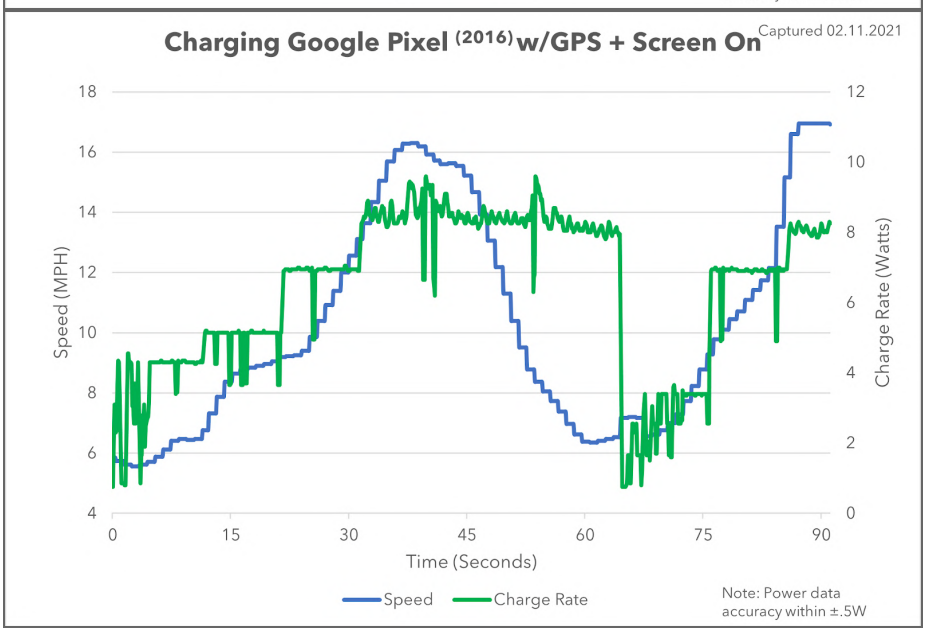
1) **Increase Speed, Increase Power:** Dynamically negotiated to fastest 12W charge profile. Apple devices require a "forced" negotiation with interrupts between faster charging profiles.
2) **Decrease Speed, Maintain Power:** Maintained 12W profile as speed decreased via supercapacitor load sharing. Less abrupt change in speed led to longer load sharing in "GPS + Screen on" trial.
3) **Renegotiate at Low Power Level:** Charged iPhone at 3.5W profile as supercapacitors charged.
4) **Reinitiate Increase speed, Increase Power:** Dynamically negotiated back to peak 12W profile once supercapacitors were charged and speed rose.

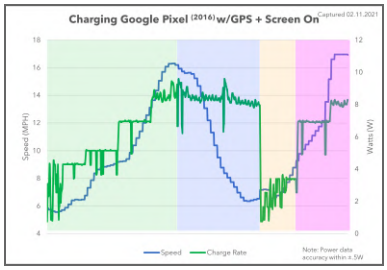
Google Pixel (2016)

~10W Peak Power, GPS + Screen on





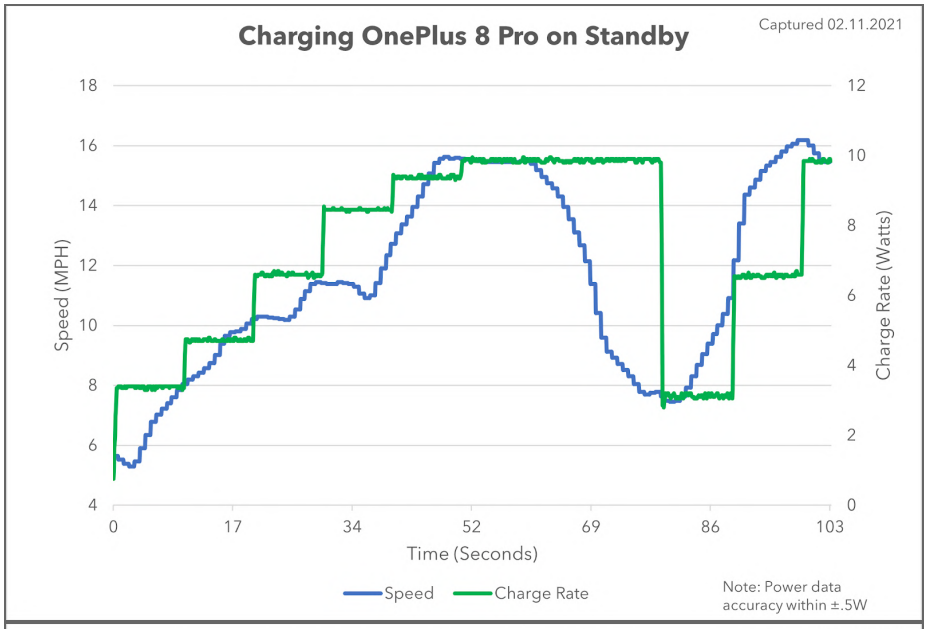


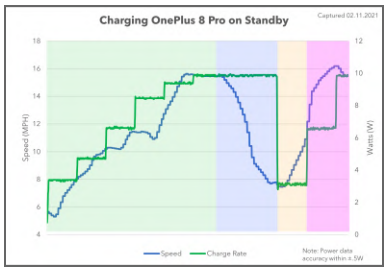


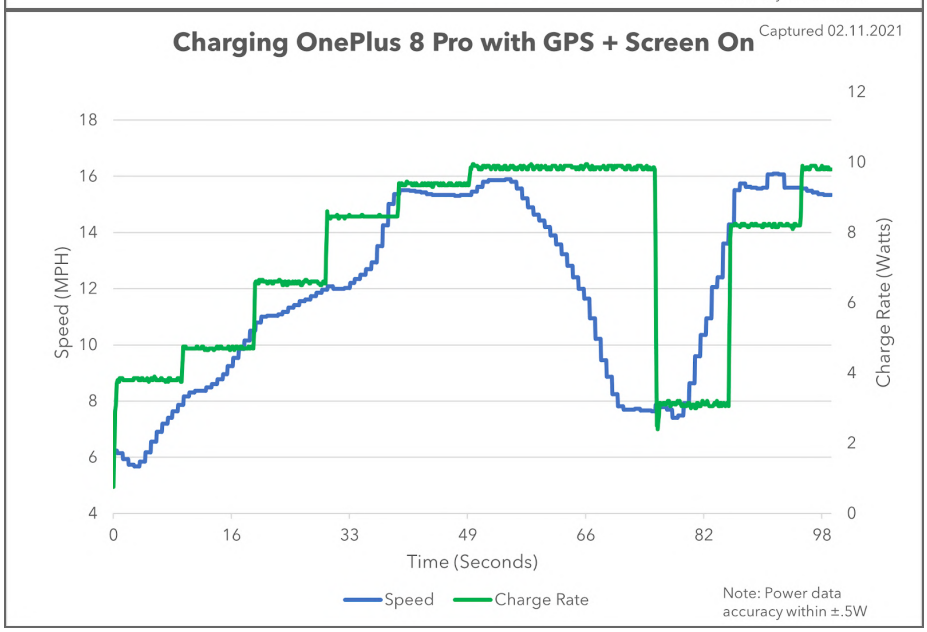
1) **Increase Speed, Increase Power:** Dynamically negotiated to the fastest charging profile of 6W on standby and 10W with GPS + screen on.
2) **Decrease Speed, Maintain Power:** Maintained peak profiles as speed decreased via supercapacitor load sharing. Lower energy consumption output led to longer load sharing in the "Standby" trial.
3) **Renegotiate at Low Power Level:** Charged Pixel at 3.5W profile as supercapacitors charged.
4) **Reinitiate Increase speed, Increase Power:** Dynamically negotiated back to peak 6W + 10W charge profiles once supercapacitors were charged and speed rose.

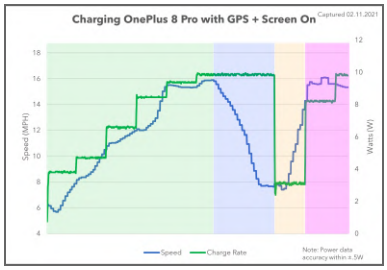
OnePlus 8 Pro

~10W Peak Power, Standby and GPS + Screen on





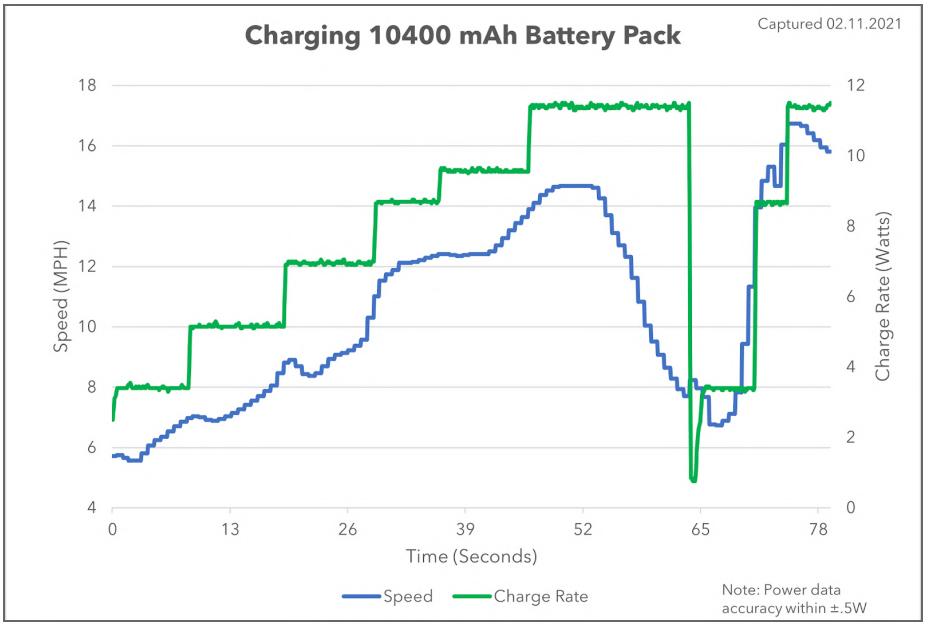


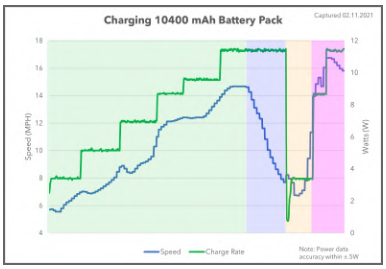


1) **Increase Speed, Increase Power:** Dynamically negotiated to the fastest charge profile of 10W.
2) **Decrease Speed, Maintain Power:** Maintained peak 10W profile as speed decreased via supercapacitor load sharing.
3) **Renegotiate at Low Power Level:** Charged OnePlus at 3W profile as supercapacitors charged.
4) **Reinitiate Increase speed, Increase Power:** Dynamically negotiated back to peak 10W charge profile once supercapacitors were charged and speed rose.

Tronsmart 10400mAh Battery

~12W Peak Power





1. **Increase Speed, Increase Power:** Dynamically negotiated to the fastest charge profile of 12W.
2. **Decrease Speed, Maintain Power:** Maintained 12W profile as speed decreased via supercapacitor load sharing.
3. **Renegotiate at Low Power Level:** Charged battery at 3.5W profile as supercapacitors charged.
4. **Reinitiate Increase speed, Increase Power:** Dynamically negotiated back to peak 12W charge profile once supercapacitors were charged and speed rose.

Conclusion

PedalCell's experimental charging data showcases how its CadenceX Technology dynamically negotiates with a broad range of USB devices to provide fast, safe and stable charging. The product was able to activate faster charging profiles as speed rose. Once speed decreased, PedalCell used its supercapacitor and generator power to maintain the fastest charge profile for a select period of time. Once the supercapacitors were drained, PedalCell automatically activated a slower charging profile and diverted power to charging its supercapacitors. Once the supercapacitors were charged, and speed rose, PedalCell again activated faster charge profiles.

PedalCell successfully negotiated multiple charge profiles and charged at a peak rate of 12W for the iPhone. 12W is the maximum charge rate of PedalCell’s high-power port. The Pixel showcases how PedalCell can accommodate different usage behaviors, providing nearly 70% more power when the phone has its screen on and GPS activated. The OnePlus device and 10400 mAh Battery Pack also showcase PedalCell's wide range of charging profiles, reaching respective peak rates of 10W and 12W.

PedalCell is designed from the ground-up with a proprietary generator and electronics design. PedalCell's Generator provides fast charging and the ability to charge more than one device at a time. PedalCell's Smart Power Hub contains its patented CadenceX Technology, using supercapacitors to provide stable power output with drastically greater efficiency and lifespan than lithium-ion batteries. CadenceX Technology's firmware ensures that devices are kept at a fast charge rate, even with changes in ride speed. The product’s performance is packaged in a design that can mount on nearly any bike in minutes with 11 moisture-resistant seals. PedalCell's feature-set and performance allow cyclists to stay safe and connected with a top-tier bicycle charging experience.