Electrically assisted solar powered cargo bicycle in Prague

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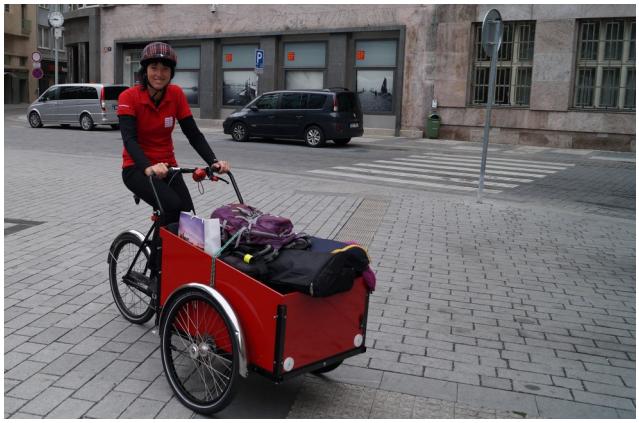
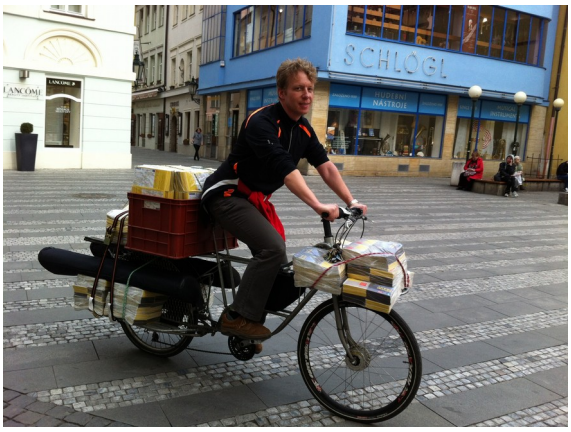
Due to its location in valleys and on hillsides, Prague had historically limited bicycle culture, at least compared to other smaller Czech towns and cities located in flat lowlands. During second half of 20th century, bicycle usage in Prague was considered to be mainly recreational or sports activity. But major change of perception of transport role of bicycles is going on right now.

Cargo bicycle usage in Prague is still relatively limited. The only company which uses cargo bicycles extensively for last mile delivery is Messenger. This is because Prague city center is currently easily accessible by cars and cargo delivery is not facing major obstacles.

Prague, in cooperation with Ministry of Environment, plans to declare Low-Emission zone, which would restrict entry for cars manufactured before 2001/Euro 3 standards. This was originally planned for 2016, but now it is not likely to happen. Such restriction is expected to spark interest in alternative means of transport, including cargo bicycles. Another vision of some inhabitants of Prague and politicians (but unfortunately not of those, who matter) is toll for entering city center by car, or optionally total restriction of all car traffic from city center, like in many other European cities. This would make providing alternatives to car transport really urgent.





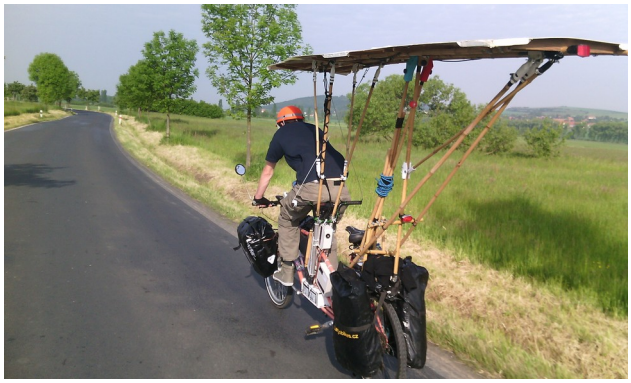
Prague tries to use cargo bicycles for transporting material to selected PR events. Unfortunately, this is not standard procedure and city hall itself does not own any cargo bicycle.

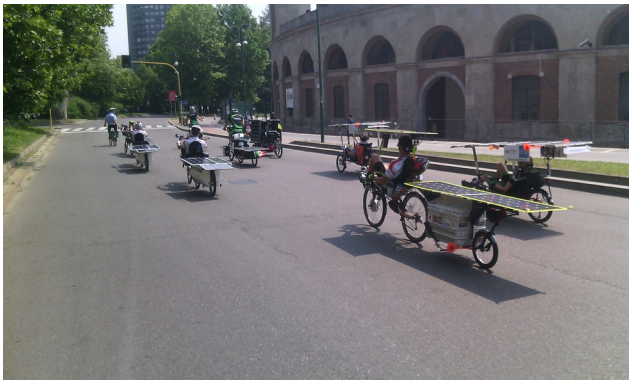
The problem may be lack of supply of cargo bicycles. There are actually no cargo bicycle retailers in Prague and no representation of foreign manufacturers and distributors. Another obstacle is inadequate bicycle infrastructure, but this is improving gradually.

Cargobikes.cz have been active in cargo bicycle scene for almost five years. Company does sales, service, rental, custom logistic services and development of vehicles of its own design. Recently, some city halls became paying clients of Cargobikes.cz, which may be example for other cities to follow.

There is no motor car registered to the company and all raw materials and spare parts for bicycle production are delivered either by self-owned or 3-rd party bicycles. Company design philosophy put emphasis on usefulness and endurance, rather than optimization of weight and appearance.

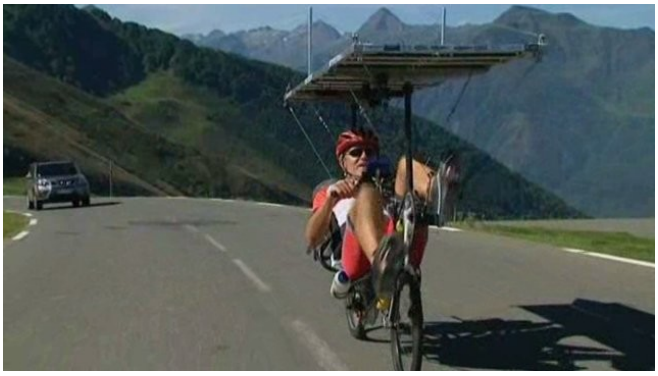
Contact-less brakes for increasing endurance, interval between service calls and energy regeneration are currently being developed. Testing of solar panels mounted on electric motor assisted cargo bicycles is also underway. The goal is to offer autonomous vehicles, which would find uses in areas where it is not common yet.





Usage of solar energy for recharging and powering heavily loaded expedition bicycle was tested during The Sun Trip 2015 rally of solar bicycles, from Milan through two checkpoints located in Turkey - Antalya and Mt Ercinyes - and back. Entire trip was around 7000 km long, with participants free to choose their own route. The fastest participant, Bernard Cauquil, made 6600 km trip in just 25 days. The Cargobikes.cz/Arachne Aerospace solar powered prototype was not so powerful, but our Earth Exploration Rover (tandem with solar bamboo roof and single crew) still managed to cover total distance of 7900 km (first 1000 km where from Prague to Milan) in about 73 days. Maximum daily range was around 150 km, which would be impossible for untrained cyclist without solar electric assistance.

The prototype was partly based on CycloTruck components - eg. heavy duty rear wheel. Bamboo roof made use of several types of 3D printed parts, some of which survived entire journey. I used Solar energy not only for bike, but also to power immersion heater (to make tea, coffee and porridge) and I even carried tiny USB fridge (but it didn't survived long...).

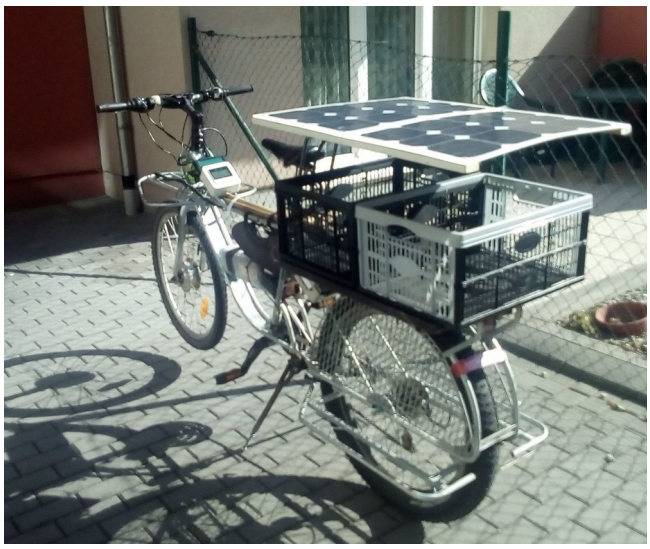


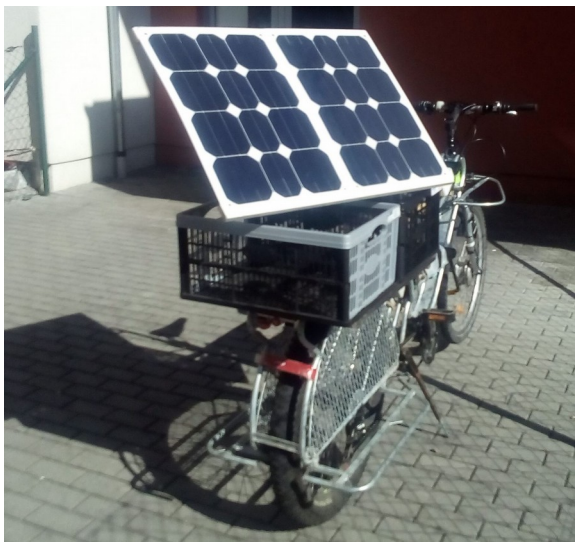
The Sun Trip is currently attended mostly by participants from French speaking regions of Europe, but this is already changing and if fact, we hope to use this opportunity to spread the word about this alternative cycling event and attract more new participants in 2017.

Internal rules of The Sun Trip specify, that electrically assisted bicycles participating in the rally are allowed to be charged solely by solar energy and regenerative braking. The bicycles are heavy because the must support huge solar panels and they are also heavily loaded by camping equipment and luggage. This is what makes them great testbed for construction and propulsion technologies useful also for urban cargo bicycles - in fact, some of participating designs were based directly on converted cargo bikes. But large solar surface area makes them ill suited for urban zones, making it hard to maneuver, find parking places, drive in heavy traffic in congested streets, on unevenly paved streets, etc. Prototype bikes developed for long range solar cruise would not be very useful as urban cargo delivery bicycles. It would be probably possible to directly convert them for long range suburban cargo delivery, on countryside roads with lots of sunlight and limited car traffic, but large solar panel area and lithium battery capacity makes them both too heavy (reducing payload capacity) and too expensive (economically uncompetitive).

Lot of useful data collected during The Sun Trip rally is directly relevant for any solar powered vehicle. After the rally started in June, solar panels with nominal output 260W were producing up to 1 kWh of energy every sunny day, declining to something like one quarter of this value on cloudy, rainy days. Later in the rally, solar panels became damaged and also days where shortening and temperature increased, especially during extreme heat wave in August. Temperatures over 30° Celsius negatively impaired solar panel efficiency, so near the end of rally, energy production of damaged panels declined to something like 300 Whs per day. But even such limited amount of energy proved very useful when climbing uphill, which is what inspired current solar assisted version of CycloTruck: 300 Whs were still enough to provide one hour of full power for 250W motor, which was incredibly useful during uphill climbs.

The fact, that there are so many steeply climbing streets in Prague was strong motivation for contemplating some propulsion capability for Prague cargo bicycles. In our city, this may turn out be critical factor.





Let's assume, that cargo bicycle (including solar electric equipment) weights 35 kg, the driver 75 kg and cargo 50 kg. On flat road, it doesn't take major effort for average cyclist to move this total weight of 160 kg around. Average human power output, sustainable for typical daily 8 hour shift, is 75 W (according to Wikipedia). While sportsmen can provide 300 W for limited periods of time, this is not the power output we can expect from average

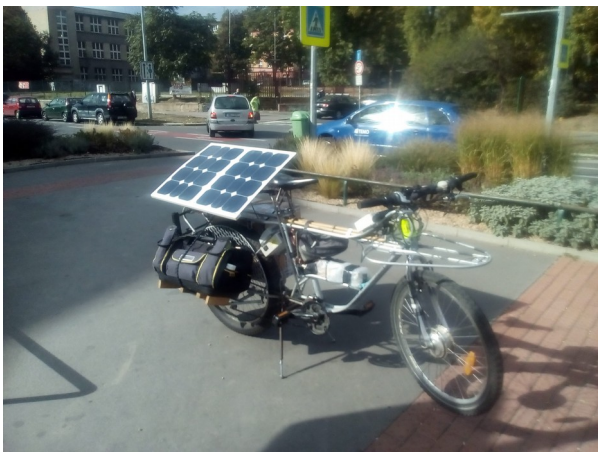
cargo bicycle driver to provide most of the time. So we have to add the missing energy by other means.

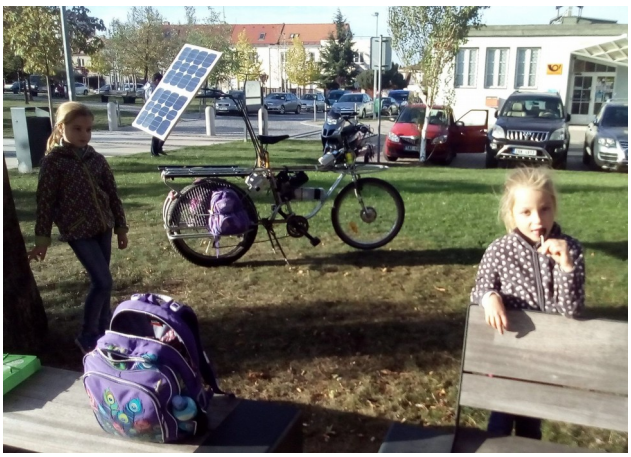
Typical elevation of Prague city quarters located on hills surrounding downtown can be 150 meters above river level. 150 m x 160 kg x 9.81 (gravitational acceleration on Earth) is equal to cca 65 Wh (Watt hours). This is (coincidentally) almost exactly what the solar panel of nominal power 60 W (which we have mounted on the solar version of Cargobikes.cz CycloTruck CT3 bicycle) would produce during one hour (under ideal circumstances, eg. on equator if temperature there was just 20 °C, which almost never happens in real life, of course). In real world, it would take our small solar panel more like 2 hours to produce this amount of energy (and maybe more during winter season). But if we compare it to average sustainable human energy output, it is clear, that the additional solar energy collected by our relatively small solar panel is far from being negligible. Numbers actually obtained during our test rides confirmed the calculations.

The energy budget will further improve with addition of regenerative braking unit, currently being developed, which promises efficiency of up to 90%: the total energy we intend to collect when descending to downtown Prague is comparable to cca 45 minutes of average sustainable human power output. On non-electric bicycle, this energy would be wasted to heat breaks or to ride dangerously fast (which is especially problem when carrying heavy cargo).

The real life situation is not as simple, as this basic math suggests, because the small motor we are evaluating rapidly looses efficiency when speed drops under cca 15 km/h. Such speed is hard to maintain on short stretches of steep uphill climbs (up to 10%), which are quite typical for Prague urban environment. This would usually result in those 65 Wh being consumed before reaching elevation of 150 m, with possibly as much as 50% of an energy being wasted as heat. More sophisticated motor control units, emulating sine curve waveform more precisely and more powerful motor are possible workarounds.

Design decision to equip already-heavy cargo bicycle with heavy and relatively expensive electric equipment is not easy. The price tag of electric bicycle is comparable to moped (scooter), but the range may be more limited, especially when carrying heavy load. Battery and motor can easily become additional dead weight when discharged prematurely. Charging bicycle battery takes some time and requires driver to take additional care of the vehicle. Regenerative braking capability built in generic motor control units is quite inefficient, just around 10% (if it is implemented at all). Conventional electric bikes are far from being autonomous vehicles, and also the fact, that most of the electricity in the grid still comes from coal burning power plants doesn't really help to remove overall carbon footprint (which may be also important criterion for someone).





Partly aware of these issues and partly because the added cost of solar panels, electric equipment of CycloTruck CT3 was stripped-down from original Sun Trip configuration and it is currently as lightweight and cheap as possible: battery capacity is just 288 Wh, because it is no intended for cruise on flat road, but to be used mainly for uphill climbs and faster acceleration on crossroads (where slowly accelerating, heavily loaded cargo bike can force other vehicles to wait). System voltage is just 24V, which is not typical for electric bicycles, but it allows off-the-shelf solar charge (MPPT) unit and relatively simple solar panel setup to be used. Maximum speed assisted by 24 V motor is just around 20 km per hour, at which point energy consumption drops to something 50 W. Total weight of such small battery, solar charge controller and small solar panels is less than 10 kg (not including front wheel mounted hub motor). We currently use safe, non-flammable LiFePO4 battery, but moving on to Li-ion would further reduce the weight. Propulsion components we are evaluating, including motor and solar panels, cost just around 700 euro (in retail prices), which means that our configuration could easily become "autonomous electric vehicle for the masses" - it is not exclusive hi-tech prototype. But the price tag is expected to raise slightly after regenerative breaking is implemented.

Among advanced features being considered is automated sun-tracking of solar panel, so driver doesn't have to take care of it manually. This is not hard or expensive to implement and it would make sense for solar cargo bicycles, which spend several hours every day just parked at the fixed location, while sun moves in the sky. For winter use, it may be also necessary to add the 220 V grid charging capability, which is now not implemented at all (as a legacy of The Sun Trip rules).

One important and quite straightforward advantage is inclusion of USB charger on-board, which allows recharging of smartphones. GPS navigation application in smartphones are quite energy hungry, so smartphone recharging capability can be mission critical for on-time cargo delivery. This feature was originally intended for outdoor "off-the-grid" energy autonomy and camping in wilderness, but it turned out to be as much useful in the middle of "urban jungle" as well.

Most of the optimisation done to maximize daily range outside cities work actually very well for urban cargo delivery and vice versa: so just like we are now using equipment originally developed for The Sun Trip 2015 rally for urban cargo delivery, we also expect the future components developed for cargo bicycles to allow for much more successful participation in The Sun Trip 2017 (if there will be any) or other solar vehicle contests worldwide (which we know nothing about yet).

We have also contacted other teams all over Europe, developing solar assisted cargo delivery solutions (eg. Italy, Macedonia) and we intend to open our data and share our technical solutions in the spirit of open source software/hardware development