

Human Generated Electricity for Transport, Communication and Sustainability.

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Abstract

Physical activity is healthy and can – and needs to be – part of transport. On bikes and electric bikes (E-bikes), it provides kinetic energy for motion. But physical activity can also generate electricity for uses combining transport with communication and other activities.

Examples of these mergers include pedal power summoning emergency air transport via the Royal Flying Doctor Service, pedal powered phone chargers at train stations and airports, and on-bike generation for lights and smartphones. However, new mergers of power generation and transport are in development, and this article discusses Shebs, or Series Hybrid Electric Bikes, alternatives to E-bikes using electricity generated on cycles for motive power.

Electricity generation on cycles allows effort to be used for a range of tasks. In transport this can be where direct human power is insufficient or can't be applied easily to drive a vehicle. Examples are where long or exposed transmissions are a problem or the vehicle is self-driving. The technology is being applied to vehicles such as velomobiles which can have stability, aerodynamic, and weather protection advantages over more conventional cycles.

As electric machines involving energy, E-bikes can be part of low emission networks such as DC (direct current) microgrids. These grids are fulfilling household electricity needs for lighting, charging computers and driving fans. However most E-bikes can only **take** power from microgrids. Series Hybrid Electric Bikes can **supply** them as well. This article discusses existing machines and their potential for generating energy for microgrids, and proposes a new machine designed with this purpose in mind.

This paper highlights machines generating electricity through human power and contributing to transport, communication and sustainability. The technologies involved include low current DC power and new human powered vehicle designs, both becoming more important as decarbonisation of transport and economies continue.

1.Introduction

“How to apply this muscle power to useful ends other than personal transport? How can we develop ways.....of helping people to help themselves in rich and poor countries, by their own efforts, without dependence on expensive oil?” From James McCullagh (1977, p. 38).

“Pedal power is a priceless asset to our fragile planet, and across the world there is a new imaginativeness amongst many makers of cycles and accessories.” From Alan Davidson, editor of Encyclopedia (1994, p. 2).

“Would Leonardo Da Vinci conceive that a single individual would drive a chariot equipped with the power of over 200 horses....for the most capricious of purposes, for journeys of down to 100 yards?” From David Gordon Wilson (McCullagh 1977, p. 106)

“London, Lagos and Tokyo can experience traffic jams of similar proportions” From James McCullagh, author of *Human Power* (1977, p. ix).

This paper deals with human powered machines and Series Hybrid E-bikes for transport and power generation. Its purpose is to highlight these low power, active technologies and their potential to create low pollution, congestion-immune transport and sustainable modernization. While the context and some mechanical aspects of Series Hybrid E-bikes are covered, specifics of circuitry, voltage and current requirements are out of scope¹.

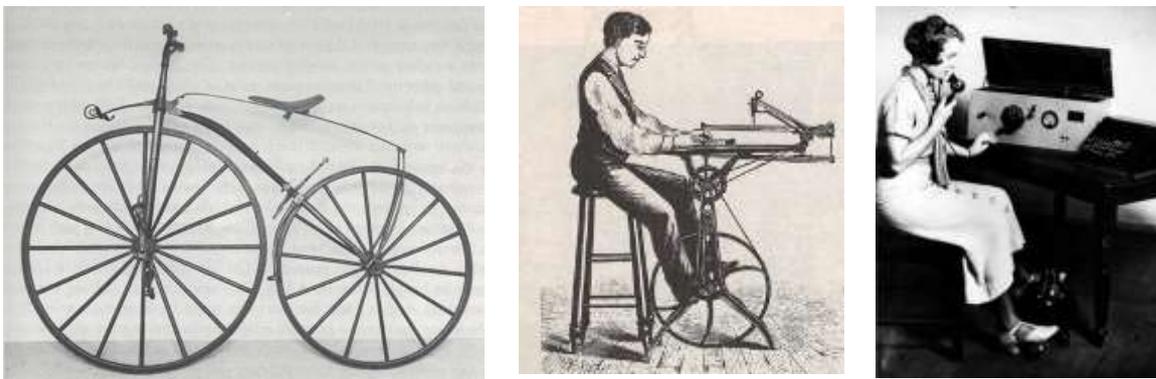
The paper starts with background on human power in transport and non-transport tasks and discusses systems using this power including DC microgrids. It then introduces Series Hybrid Electric Bikes and other technologies through examples. Finally, it proposes a new transport cycle type capable of generating and using power in microgrids.

2. Background

The bicycle with pedals was invented in 1865 (Figure 1a), and soon after, pedalled machines were employed for useful work in homes. By 1892, Americans had a range of pedalled and treadled machines (Figure 1b) available for sawing, turning metal, sewing and grinding (Bijker, 1995, 27, McCullagh 1977, 28-35). However in the 1920’s in developed countries, grid electricity made electric appliances common, and pedalled machines for domestic use became less popular (Pearsall, 1973, 172).

In the different context of more remote areas, however, pedalled machines remained important. Alfred Traeger invented the pedal wireless in Adelaide in 1927. It became vital in outback Australia, where summoning air ambulances or consulting expert medical help saved lives in the bush. The radios also helped educate children via the School of the Air and help alleviate isolation (Figure 1c). As smartphones have progressed today to simplify and enable different modes of communication, the pedal wireless progressed from sending morse code messages, to sending typed messages to voice communication (SA State Library 2006).

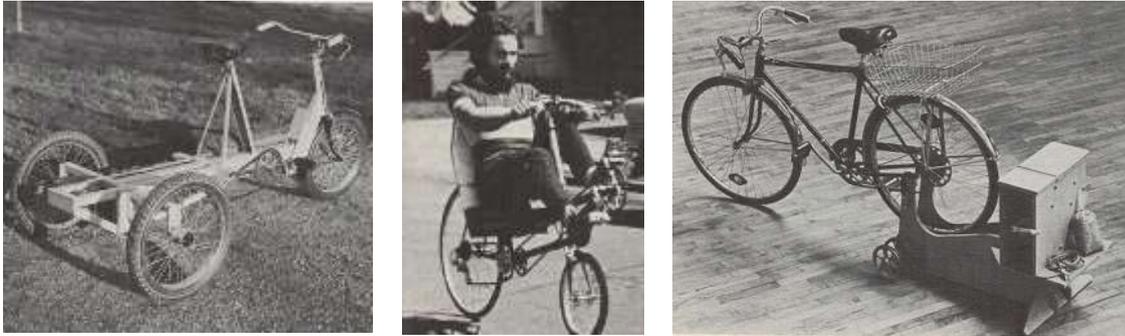
Figure 1: a) 1865 Michaux velocipede (Bijker, 1995), b)1890’s pedal driven saw (McCullagh, 1977), c) 1937 pedal powered radio (SA state Library).



¹ Some electronics hardware design notes for E-bikes are provided in Raghunath (2014), and Lovatt and coauthors (2011) provide design procedures for electric vehicle drivetrains.

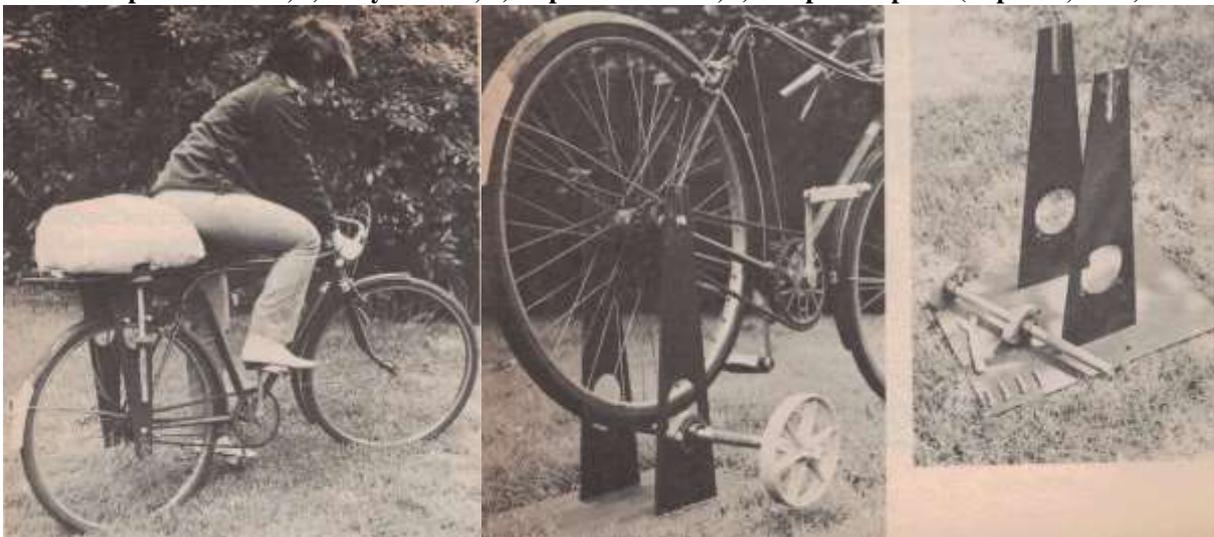
By the 1970's, there was a growing awareness that human power could play important roles in transport and domestic life, and help relieve emerging ecological crises. Inventions related to human power proliferated, with James McCullagh (1977) promoting appropriate use of human power for transport, homes and farms (Figure 2).

Figure 2: Human powered machines as shown in McCullagh: a) Oxtrike freight trike, b) aerodynamic recumbent bicycle, c) Bik-o-generator to generate electricity or power a grain mill directly



Other 1970's developments included Victor Papanek's (1972, p. 168, 224) hand cranked fridge and cycle designs, including a bike with a sturdy rear rack doubling as a stand and power takeoff (Figure 3). In 1975 International Human Powered Vehicle Association started promoted racing of streamlined recumbents (Kyle 2005).

Figure 3: Cycle rack by Michael Crotty & Jim Rothrock which rotates about the wheel axle to double as a stand and power takeoff, a) as cycle rack, b) as power take-off, c) component parts (Papanek, 1972)



The 1990s saw commercialisation of these ideas with manufacturers across E-bike, load bike, recumbent bike, and recumbent trike styles featured in the Encyclopedia Book series (Davidson 1994, 1996). Two technologies proposed during the 1990's and coming into use today are the Series Hybrid Electric Bike and the front hub gearbox cycle.

Andreas Fuchs and Jurg Blatter championed the series hybrid E-bike, a form of chainless bicycle, and in 1998 introduced the technology as a way of simplifying transmissions. Their electric assist all weather velomobile had four chains and 2 planetary gearboxes and was heavy at 127kg. As a reaction to that vehicle, they saw having compact, separate, weatherproof generator, drivemotor and battery, and generating electricity on cycles as a

practical solution for motive power on light vehicles (Fuchs and Blatter, 1998). Figure 4 shows their prototype series hybrid alongside a modern production version.

Figure 4: Series Hybrid Electric Bikes, a) by Fuchs and Blatter (Fuchs and Blatter 1998) and by Bike2 in 2018 (Bike2.dk)



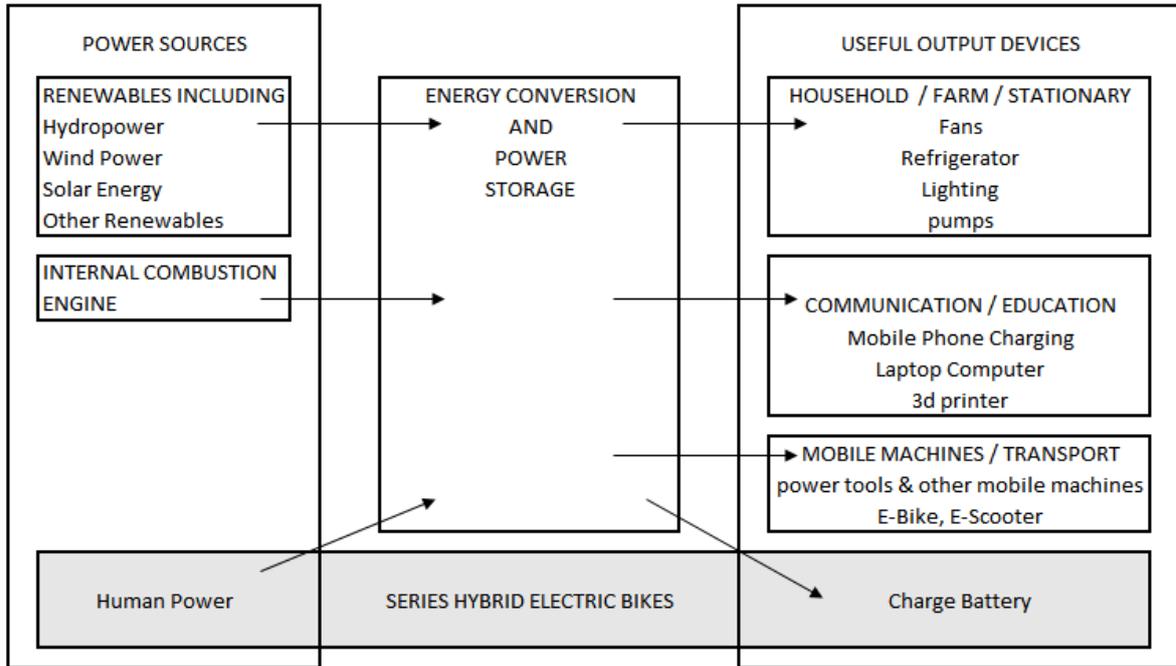
Almost concurrently, Thomas Kretschmer (Figure 5a) proposed a modern return to the front wheel drive chainless bicycles which dominated cycle traffic as boneshakers (Figure 1a) or penny farthings from 1865 to 1884 (Bijker, 1995, 71). His proposal included a front-wheel-housed-gearbox providing pedalling-to-wheel-speed-ratios from 1:1 to 1:4.5. This gearbox replaced the derailleur gearing used on today's bicycles to help cyclists pedal efficiently in different conditions (refer Appendix 1). This configuration allows for ergonomic pedalling, and the geared front wheel can be part of a modular range of vehicles. This cycle layout is now coming into production as the Kervelo (Figure 5b) and is reimagined as part of a DC microgrid at the end of this paper (Kretschmer 1999, 1999a, Kervelo 2018).

Figure 5: Front wheel drive gearbox cycles: a) 1999 Kretschmer prototype, b) 2017 Kervelo e-assist delta trike with electric motor on visible rear wheel. (Kretschmer 1999a, kervelo.com)



Along with these transport and human power developments we have had advances in electronics, communication, appliances, and generation of electricity for domestic use. Technologies as diverse as led lighting, laptop computers, solar power, smartphones, 3d printers, fans and fridges (Taufik 2010) can now all make use of or contribute to DC power in self-sufficient networks microgrids (Figure 6).

Figure 6, DC microgrid with pedalling as power source (from Taufik 2010, Fuchs 2008)



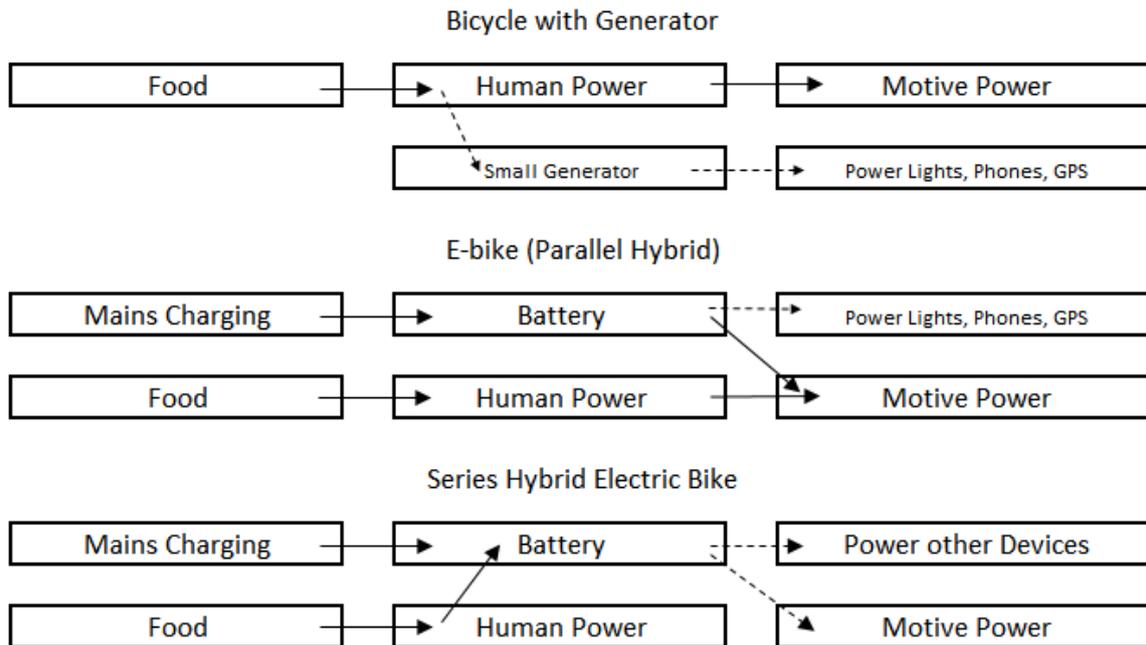
These DC microgrids encompass many technologies, often permanently located and spread throughout a home or village, however smaller relocatable grids for power generation and use are becoming common. For example, Wewatt from Belgium make pedalled mobile phone chargers (Figure 7a) that can be located at stations or airports to bring practical, healthy, static, off bike exercise to the time spent waiting for transport. As well, on-bike dynamo systems for powering lights (Figure 7b) are now used to power devices including smartphones. These small DC grids made by power generation are examples of self-sufficiency in electrical supply, and contribute to sustainability (ABC 2017, St. Kilda Cycles 2018).

Figure 7, Self-sufficiency: a) Brisbane Airport phone chargers from We-Watt, b) Dynamo equipped touring bicycles (ABC 2017, author's photo)



Conventional bike generators make power for ancillary purposes, but the generation of power in series hybrid E-bikes and similar machines can also be for on-bike-motive, and on-and-off-bike-ancillary purposes as shown in Figure 8 (Fuchs 2008).

Figure 8: Energy flows in bicycle, Parallel Hybrid E-bike and Series Hybrid E-bike (from Fuchs 2008, Fuchs 2014)



3. Application and Efficiency

Tanjimul Patowary and coauthors researched the use of human power in microgrids (2016) and made practical devices for delivering DC power from cycle technology. They concluded that villagers who use bicycles in this way could benefit the most. Phadke (2017) considers 25W of solar energy sufficient to supply electricity to modernize a house, and Greenmicrogym advertise delivering 30W of energy with their adaptable cycle generating system (greenmicrogym 2018). Wilson (2004, p. 44) indicates that healthy males can sustain cycling outputs of 100W for more than 3 hours, and McCullagh (1977, p. 38) considers 75W a reasonable sustained output. These figures indicate that even with low-cost components achieving 65% efficiency (of human power converted to electricity²) cycling technology can contribute at least 50W³ to DC microgrids (Wilson 2004, p. 338).

Creating electricity by pedalling can be inefficient in terms of energy transformation from food to useable power (ebikereview.com 2016, Lemire-Elmore 2004), however sometimes inefficiency doesn't matter and effectiveness does. When human effort gives necessary, voluntary and healthy exercise, the energy supply is free, and can be made effective by enabling modern necessities and conveniences (Braungart 2002 p.72). Both Taufik (2010) and Patowary (2016) mention intermittency of solar and other renewable energy sources as reasons for including human powered inputs to DC microgrids.

The technology might not be best applicable in modern cities, however in the context of more remote areas relying on microgrids, series hybrid cycles could provide sustainable solutions for energy, transport and modernisation.

² Note that when generating power for microgrids, the efficiencies of series hybrids do not include motor efficiencies. From Wilson 2004, generating efficiency with low cost components is 0.7 x 0.98 x 0.95 x 100%.

³ Approx. 65% of 75W

4. Series hybrids – low power cycles

In 1998 Andreas Fuchs and Jurg Blatter promoted series hybrid electronic bicycles, or *shebs*, or nonpositive drive bicycle (Figure 9a), with energy transferred from pedals to driven wheels via electricity and electronics. As shown in Figure 8, this contrasts with standard “parallel hybrid” E-bikes where human power and motors drive wheels directly and concurrently (Fuchs 1998, Fuchs 2014, Wilson 2004, p. 337).

Series hybrid energy transfer eliminates mechanical connections and stresses between pedals and wheels which can be awkward in boats, multirider or enclosed vehicles, or with electrical inputs such as solar charging (Nurse 2018, Liegfiets 2017). It is estimated that with modern components, overall efficiencies could reach 80 percent, ie 80% of the power generated at the pedals could reach the wheels as mechanical energy. This overall efficiency consists of controller, generator and motor efficiencies (Wilson 2004, p. 338).

Fuchs made three wheel shebs (Figure 9b) and promoted four wheel cycles from gilgen.com (Figure 9c). These multi-track vehicles have static stability, allowing the cycles to be pedalled to charge batteries even when stopped. In general, shebs allow riders to pedal at optimum pedal revolutions of 60 - 80 rpm without interruptions for gearchanges (Fuchs 2008, McCullagh 1977, p. 37, Wilson 2004, p. 339).

Figure 9: Series Hybrid Cycles: a) Fuchs bicycle prototype, b) Fuchs tadpole trike, c) gilgen quadracycle (Fuchs 1998, 2008)



Several companies now manufacture series hybrid cycle technology including Mando from Korea and Bike2 from Denmark. Mando are a large automotive parts firm and make the 0.25kw Footloose folding bike and non-folding Footloose IM (Figure 10a). The design of the Footloose bikes make them a closed or completed design, leaving little room for user customisation or modification. One reviewer needed to suggest a workaround as a way of installing a rear rack and was disappointed with the finicky pedal mounted stand (electricbikereview.com 2015 , Jencks & Silver 1972, p. 42).

Bike2 take a different approach, and make series hybrid bicycle components. Their website shows cycles incorporating a 0.75 kw motor, and frame mounted generators (Figure 10b, c).

Figure 10: Mando IM cycle, Bike2 equipped cycle, Bike2 generator in Sunrider velomobile (Mando website, Bike2 website)



One of these cycles is the Sunrider 4 velomobile from Alligt (Figure 11a) which replaces the long, standard velomobile transmission chain with electrical wires, possibly simplifying maintenance (Bike2 website 2018, Liegfiets 2017). Another series hybrid velomobile under development is the Podbike from Norway (Figure 11b). Podbike promise to make future versions of the Podbike autonomous and have developed the Podbike Garage, a lockable solar-powered charging, parking and storage facility (Podbike 2018).

Figure 11: a) Sunrider 4 and b) Podbike velomobiles with series hybrid drives (Bike2 , Liegfiets).



It is important to note that the motor in series hybrids provides the entire motive force for the vehicle and is not assisted by human power. Therefore the motor can feel underpowered if it has the standard Australian E-bike power limit of 250W (Ebikereview 2015). Fuchs (2014) recommends that a series hybrid E-bike motor have twice the power of an equivalent standard E-bike motor.

5. Serial hybrids – other transport uses

As well as low powered vehicles, series hybrid technology is under development for high speed trikes and human powered paragliders. Kronfeld motors are developing the Raht Racer series hybrid trike which is aerodynamic, gets 1/5 of its energy from human power and is capable of 144 kph (Figure 12). The human energy input is useful for extending its battery range from 120k without pedalling to 160k with pedalling (kronfeldmotors.com 2018).

Figure 12: Kronfeld Raht Racer (Kronfeldmotors.com)



Thomas Senkel has made and publicised a sheb trike, and has successfully tested a fully-electric combined scooter and paraglider (Figure 13). His series-hybrid pedal assisted cycle and paraglider is still under development and has separate motors powering the rear wheel and propeller. This vehicle's drivetrain shows series hybrid technology's ability to supply multiple motors mounted at awkward angles.

Figure 13: a) Thomas Senkel with series hybrid trike, b) prototype pedal assisted recumbent bike / paraglider, c) electric scooter / paraglider (Senkel 2014, 2017, 2016).



Senkel uses youtube videos to show his research and has had 4 million views of his Sky rider, scooter and paraglider video. Vi Vuong is another transport innovator using youtube to good effect, showing and sharing inventions, and possibly earning money in the process (Senkel 2014, 2016, 2017, Nurse 2016, Vuong 2018).

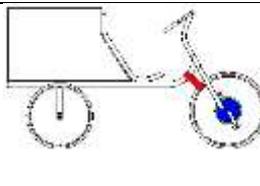
6. Cycles for DC Power Generation

Standalone units for DC Power are sold commercially for use on yachts and charging phones in emergency situations (k-tor.com 2018) . However E-bikes configured to produce power exist, and others with regenerative braking (such as Bionx equipped E-bikes) can be set up to produce power.

Series hybrid cycles can charge their own battery through pedalling, and could also be configured to supply DC to microgrids, with advantages of efficient pedalling position and power conversion.

Table 1 shows real and hypothetical cycles for microgrid power generation, and describes the required setups, which should be inbuilt or innate if possible. Line 6 proposes a recumbent, load carrying, series hybrid trike with uses including DC power generation. It is described further in Appendix 2.

Table 1 : Human powered machines for electricity generation

Generator Type			Conditions for Generation				
Description	Photo / Sketch	Links	Generator can rotate.	No rolling forward.	Balance	Steering Lock	Comments
1. Established Ebike, rear wheel regen motor for grid & battery charging		Greenmicrogym 2018	Stand lifts rear Wheel	Rear Wheel Stand	Rear Wheel Stand	Not Applicable	Upright for desk and computer work. Existing setup
2. Proposed Makita Ebike, rear wheel drive, batteries also used in lights, radios etc.		Trayon.com 2018	Stand required to lift back wheel	Rear Wheel Stand	Rear Wheel Stand	Not Applicable	Example ecosystem for non-transport energy use.
3. Proposed Mando IM series hybrid as generator cycle.		Mandofooloose.com 2018	Innate	Use stand or brake front or rear wheel	Stand for front or rear wheel	Not Applicable	Example series hybrid as generator cycle.
4. Proposed tadpole trike, chain driven rear wheel drive with Bionx regen motor, 4 software controlled regen levels		Electricbikereview.com 2017 , .electricbike.com 2013	Stand required to lift back wheel	Rear Wheel Stand or front brakes on	Innate	Not Applicable	Example, relaxed supported position.
5. Bike2 Generator module in appropriate static or rolling machine		Ebiketips2016	Innate	Innate	Innate	Not Applicable	Integrate into microgrids with appropriate controller
6. Proposed delta trike series hybrid, pedal input to front wheel generator, output from concentric regen. motor.		Appendix 2	Innate	Strap front wheel or use rear brakes.	Innate	Strap front wheel.	Relaxed, supported seating, no stands needed to generate power, optimized power generation

8: Conclusion

Today, the pro-human power sentiments from the introductory quotes are becoming more like imperatives. Some countries are striving to modernize while keeping traffic delays, pollution and carbon dioxide emissions in check. Meanwhile the populations of other countries struggle to keep fit and usefully active in the face of increased mechanization.

This paper has introduced Series Hybrid Electronic Bikes. As well as being useful in transport, they can be useful in DC microgrids, offering mobile, ergonomic human powered charging to complement solar and wind power. Their technology has potential in a range of hybrid human / electric powered vehicles including applications where mechanical drivetrains are awkward, load haulers, bikes, trikes, high speed velomobiles and boats. Consideration should be given to supplying series hybrid technology in the form of kits, and not only as completed cycles, allowing design diversity to flourish. In high powered series hybrids, human power can be useful in extending distances between charges.

This paper has discussed low- and human-powered- technologies which are compatible with sustainable, low stress transport and modern communication systems. The existence and effectiveness of these technologies isn't enough, they need publicity and sufficient adoption to progress. This introduction of the technologies is to help their cause by increasing public awareness.

9. Acknowledgements

I would like to thank Mehran Ektesabi and Saman Gorji from Swinburne University for their help writing this paper. In particular, Saman provided information on E-bike electronics.

Appendix 1.

Table 2: Gear ratios and pedalling speeds for bicycle with 650mm diameter / approx. 2m circumference rear wheel. Low gear ratios are used to overcome high resistive forces, ie pedalling uphill or into headwinds. Complete equations quantifying forces on cycles are provided in Van De Walle (2004)

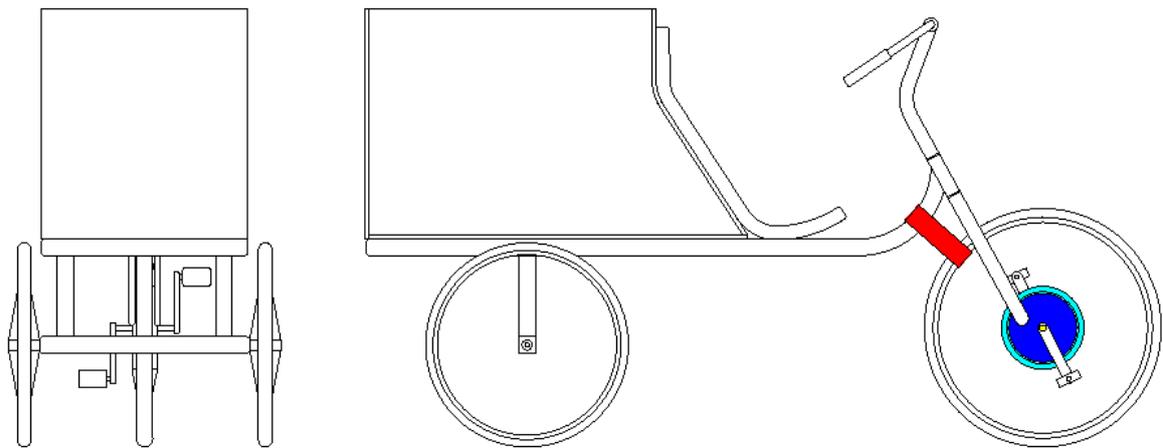
Pedalling speed		Gearing			Speed	
rpm	rps	Chainring teeth	Sprocket teeth	Ratio	m/s	kph
60	1	48	48	1	2.0	7.4
80	1.33	48	48	1	2.7	9.8
60	1	48	24	2	4.1	14.7
80	1.33	48	24	2	5.4	19.6
60	1	48	16	3	6.1	22.1
80	1.33	48	16	3	8.1	29.3
60	1	48	12	4	8.2	29.4
80	1.33	48	12	4	10.9	39.1

Appendix 2. A Cycle for DC Power generation

A cycle for DC power generation should be able to generate power with high efficiency, a good pedalling position, little setup time, and little or no auxiliary equipment. To generate power the cycle must be stable and the mechanisms used to generate power (ie rear wheel motor, line 1, table 1) must be free to move.

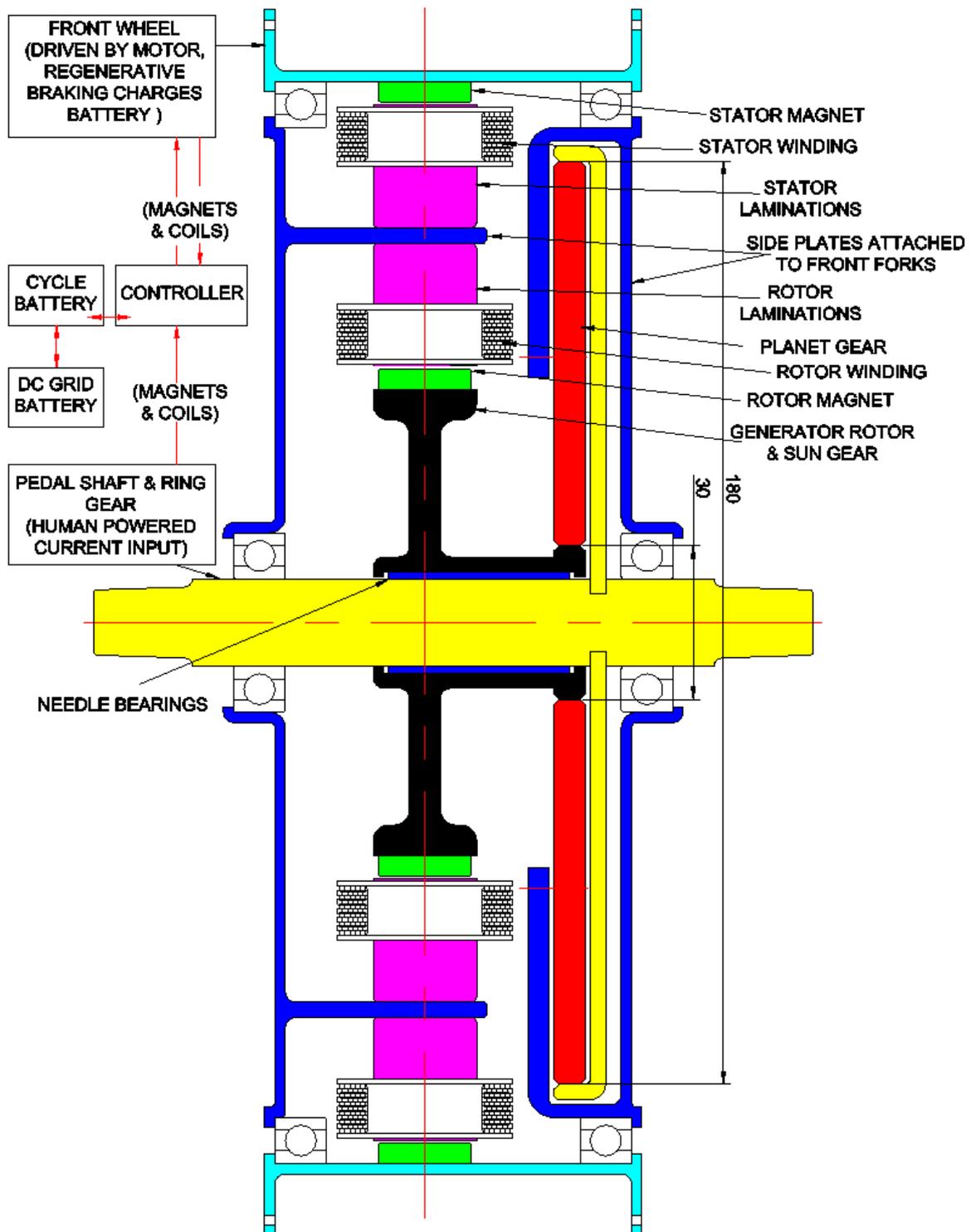
Figure 14 shows a proposed cycle to meet these criteria. It includes a pedal shaft surrounded by a generator and motor, all mounted in the front wheel hub. A velcro strap could suffice to keep the front wheel stationary when pedalling the cycle as a generator. This design has similarities to the purely mechanical cycle design proposed by Thomas Kretschmer 20 years ago and now coming into production through Kervelo cycles as shown in Figure 5. The complex front hub could be complemented by simple, modular rear sections to make trikes, bikes and cargo hauling vehicles (Kretschmer 1999). Solar panels and DC powered tools and equipment could also be included.

Figure 14: Proposed series hybrid delta trike for power generation. Red component represents a removable strap to stop rolling and for steering lock, see Figure 15 for hub detail.



A proposal for the front hub of this cycle is shown in Figure 15. It contains the motor and generator of a series hybrid cycle, with batteries and controllers housed elsewhere. The hub includes a flat planetary gearset to step up the rotation of the generator by a factor of $(180\text{mm} / 30\text{mm} =) 6$ compared to the pedals.

Figure 15: Proposed pedaled generator / motor hub.



This hub could be designed for multiple configurations, such as without motor components in a machine solely for DC power generation, or as the rear hub of a bicycle with a chain driven input. This flexibility is respectful of diversity, (Braungart 2002, p. 118) and allows the hub to be mounted in a number of ways, for instance letting the pedaller sit at a desk and work while generating power as shown in Table 1 line 1.

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