Use of Human Power in the Developing World

Rev. Dr. Jason K. Moore

Department of Mechanical and Aerospace Engineering
University of California, Davis

January 21, 2016

Historical Uses of Human Power

Transportation:

- walking and running
- hand carts
- rowing boats
- bicycle

Tools:

- plow
- water pump
- food processors
- lathes, saws, sewing
- spinning

Historical Uses of Human Power

Transportation:

- walking and running
- hand carts
- rowing boats
- bicycle

Tools:

- plow
- water pump
- food processors
- lathes, saws, sewing
- spinning

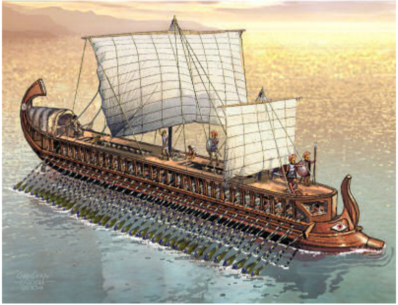
Historical Uses of Human Power

Transportation:

- walking and running
- hand carts
- rowing boats
- bicycle

Tools:

- plow
- water pump
- food processors
- lathes, saws, sewing
- spinning



Historical Uses of Human Power

Transportation:

- walking and running
- hand carts
- rowing boats
- bicycle

Tools:

- plow
- water pump
- food processors
- lathes, saws, sewing
- spinning

Historical Uses of Human Power

Transportation:

- walking and running
- hand carts
- rowing boats
- bicycle

Tools:

- plow
- water pump
- food processors
- lathes, saws, sewing
- spinning

Historical Uses of Human Power

Transportation:

- walking and running
- hand carts
- rowing boats
- bicycle

Tools:

- plow
- water pump
- food processors
- lathes, saws, sewing
- spinning

Historical Uses of Human Power

Transportation:

- walking and running
- hand carts
- rowing boats
- bicycle

Tools:

- plow
- water pump
- food processors
- lathes, saws, sewing
- spinning

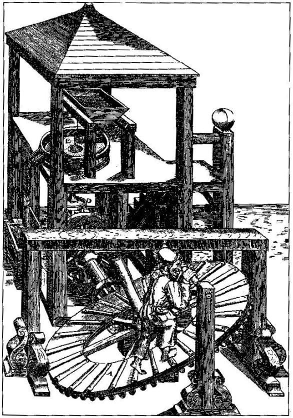


Figure 1.3
Inclined treadmill powering a mill. (From Gnudi and Ferguson 1987.)

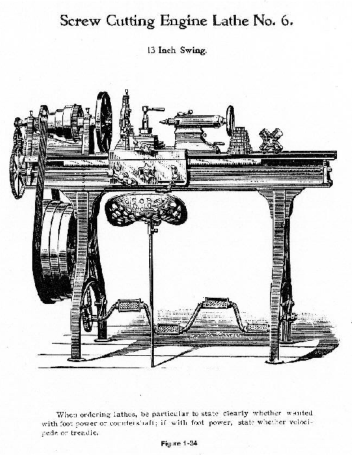
Historical Uses of Human Power

Transportation:

- walking and running
- hand carts
- rowing boats
- bicycle

Tools:

- plow
- water pump
- food processors
- lathes, saws, sewing
- spinning



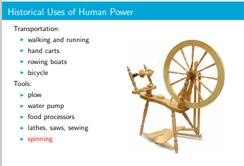
Historical Uses of Human Power

Transportation:

- walking and running
- hand carts
- rowing boats
- bicycle

Tools:

- plow
- water pump
- food processors
- lathes, saws, sewing
- spinning



From the dawn of humankind we have relied on human power to get things done. Our bodies are amazing machines and for most of our history, the best machines we had available to perform manual tasks. Our bodies have always been used for transportation, they essentially evolved to move us about in a very efficient manner. As, tools and machines began to arrive on the scene began the search for the optimal use of our muscle power.

The Human Machine

- We are energy transformers!

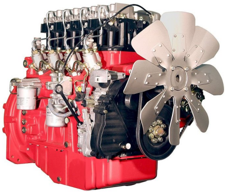
The Human Machine

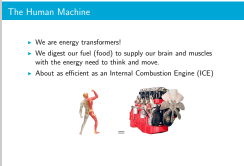
- We are energy transformers!
- We digest our fuel (food) to supply our brain and muscles with the energy need to think and move.

The Human Machine

- We are energy transformers!
- We digest our fuel (food) to supply our brain and muscles with the energy need to think and move.
- About as efficient as an Internal Combustion Engine (ICE)

=





In a way, we are simply another type of energy covnerter. We convert energy from food to primarily mechanical energy. Some believe that the evolution of us as a complex machine was simply to optimize our motion and movement capabilities. But just as any energy conversion process, energy is lost along the way. Human's are not especially fundamentally energy efficient, so we have to think carafully aobut how we maximize the efficiency of the work we do?

Energy and Power

- Work is a measure of energy

Work: a measure of energy

$$Work = force \cdot distance \; (Joules = Newtons \cdot Meters)$$

Energy and Power

- Work is a measure of energy

Work: a measure of energy

$$Work = force \cdot distance \ (Joules = Newtons \cdot Meters)$$

- Power is the measure of how fast we can do work

Energy and Power

- Work is a measure of energy

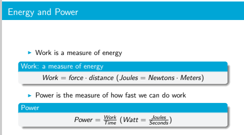
Work: a measure of energy

$$Work = force \cdot distance \; (Joules = Newtons \cdot Meters)$$

- Power is the measure of how fast we can do work

Power

$$Power = \frac{Work}{Time} \; (Watt = \frac{Joules}{Seconds})$$



Human bodies are built to transform energy. We covert food stuff to both electrical and mechanical (maybe spiritual too) energy so that we can think and compute and so that we can use our muscles to do work. There are two important concepts that I want to reenforce from Physics 101 that aren't always understood (I blame it partially on the energy companies confusing use of kilowatt-hours). Work is a measure of energy and can simply be described as the force times the distance it acts over. If I apply a force to this table and it moves a certain distance, the product of those numbers is a measure of how much energy is used to move the table. Power is how fast we do work, or work per unit of time. If I take all day to push this desk across the room versus taking 30 secs, then the former takes much less power.

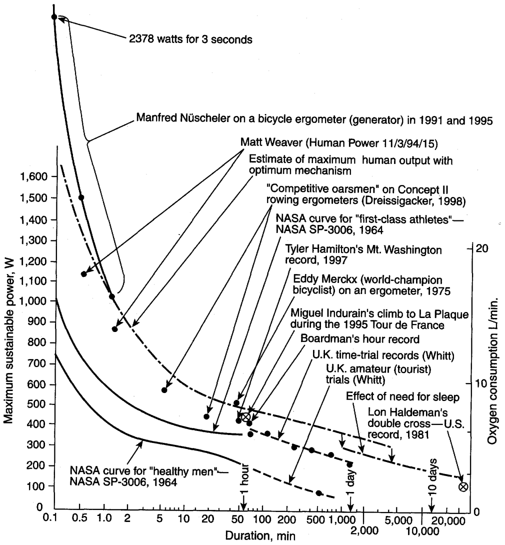


Figure 2.4
Human power output, principally by pedaling. Curves connect the terminations through exhaustion of *constant-power* tests. (Data collected by Dave Wil-

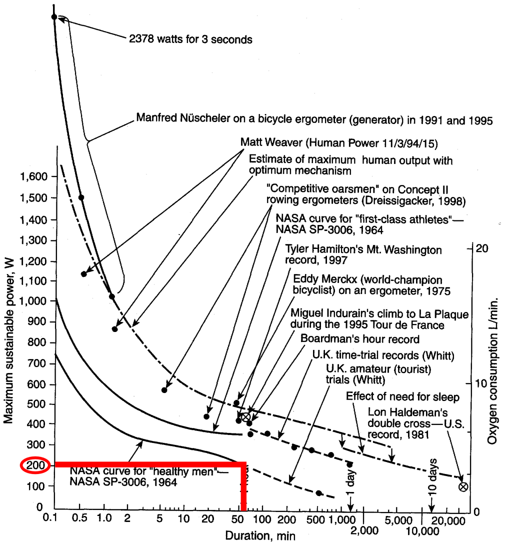


Figure 2.4
Human power output, principally by pedaling. Curves connect the terminations through exhaustion of *constant-power* tests. (Data collected by Dave Wil-

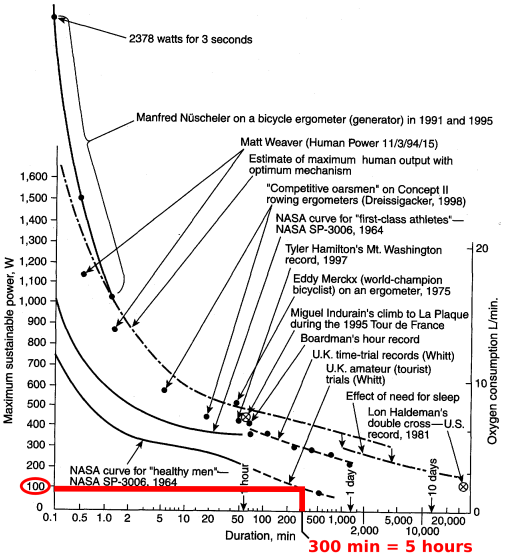


Figure 2.4

Human power output, principally by pedaling. Curves connect the terminations through exhaustion of *constant-power* tests. (Data collected by Dave Wil-

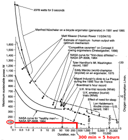


Figure 2.4
Human power output, principally by pedaling. Curves connect the terminations through exhaustion of *constant-power* tests. (Data collected by Dave Wilson added to an original NASA chart.)

So now that we are refreshed about work and power, I'd like to show you one of my favorite graphs about human power output. This graph is generated from series of experiments in which the person generates a fixed amount of power until they are completely exhausted. On the X axis is time to exhaustion on a non-linear scale. The Y axis is the power generated during the test. The lowest curve is for a nominal healthy man and the curves and data points above that are for various elite atheletes. I'm not sure were an average person from a malnurished place may fall, but certainly below the healthy man line. Notice the slope of the curves for durations under and hour and how steep they are. To drive this graph home some let's see how long a heatly man can generate 200 watts of power (e.g. to power two 100 watt lightbulbs). He can last about 1 hour, until he is completely exhausted. But check out if we lower the power output to 100 watts, the duration increases to about 5 hours. 100 watts is about how much we expend when bicycling at an average commuting

Efficiency

- Energy is lost when converting from one type to another.

Efficiency

- Energy is lost when converting from one type to another.
- Efficiency is a measure of this loss.

Efficiency

- Energy is lost when converting from one type to another.
- Efficiency is a measure of this loss.

Efficiency

$$efficiency = \frac{output}{input}$$

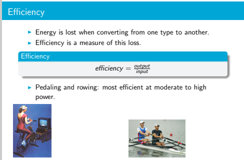
Efficiency

- Energy is lost when converting from one type to another.
- Efficiency is a measure of this loss.

Efficiency

$$efficiency = \frac{output}{input}$$

- Pedaling and rowing: most efficient at moderate to high power.



We all know that in the real world, there is always energy lost in processes and we are on a constant mission to reduce these energy losses. This is especially important when designing power extracting machines for humans, due to the limited power they can generate. The efficiency of a process is the output divided by the input. We almost always need the efficiency to be as high as possible. It turns out that for human power generation, rowing and pedaling are the most efficient methods of generating moderate to maximum power. They both make use of our largest muscles, the legs and cyclic motions.

How efficient are we?

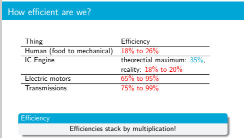
Thing	Efficiency
Human (food to mechanical)	18% to 26%
IC Engine	theorectial maximum: 35%, reality: 18% to 20%
Electric motors	65% to 95%
Transmissions	75% to 99%

How efficient are we?

Thing	Efficiency
Human (food to mechanical)	18% to 26%
IC Engine	theorectial maximum: 35%, reality: 18% to 20%
Electric motors	65% to 95%
Transmissions	75% to 99%

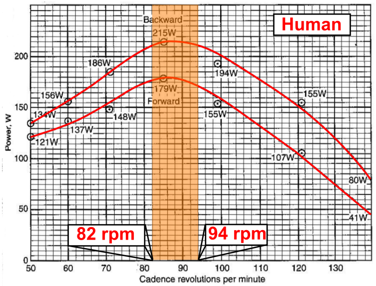
Efficiency

Efficiencies stack by multiplication!

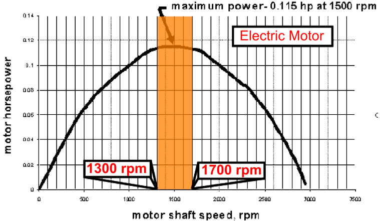


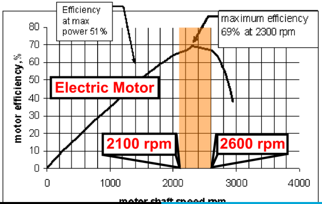
This table gives some idea of how efficient we are compared to other systems. Human's are only 18 to 26 percent efficient in converting their food to mechanical energy. An adult's nominal metabolic rate of energy consumption is 100-150 watts. We're producing 3kW right here in the room, doing nothing. The IC Engine is very similar in efficiency to a human and electrical motors are pretty efficient. Keep in mind that efficiencies mutliply when you stack devices. A human pedaling a generator through a transmission has an efficiency from food to electricity of something like 15%.

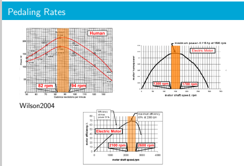
Pedaling Rates



Wilson2004



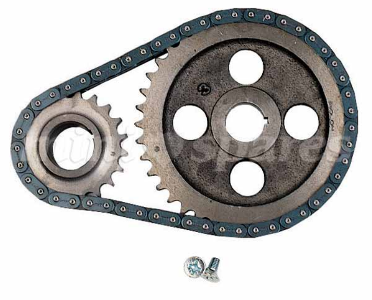




So how does this efficiency and power generation play out in the design of human power harvesting machines? Take a look at these curves. The first is a typical power versus pedaling rate for a cyclist. Notice that the maximum power is produced somewhere around 85 rpm. Imagine that you want to have the person generate electricity with a DC generator. The plot on the right shows the power curve for a typical motor. The maximum power output here is around 1500 rpm. And on top of that the most efficient rpm for the motor is around 2300 rpm. A machine that couples the rider to the generator will have to be designed to take all of this and more into account. First graph taken from Wilson2004 and motor graphs from:
http://www.recumbents.com/mars/pages/proj/sadler/assist/projsadassist.html

Pedaling to Rotational

- Chain drives: 90%+
- Shaft drives: 80-90%
- Flat belt drives: 90%+
- Friction drives: <80%



Pedaling to Rotational

- Chain drives: 90%+
- Shaft drives: 80-90%
- Flat belt drives: 90%+
- Friction drives: <80%

Pedaling to Rotational

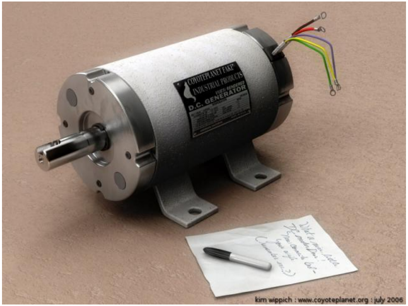
- Chain drives: 90%+
- Shaft drives: 80-90%
- Flat belt drives: 90%+
- Friction drives: <80%

Pedaling to Rotational

- Chain drives: 90%+
- Shaft drives: 80-90%
- Flat belt drives: 90%+
- Friction drives: <80%

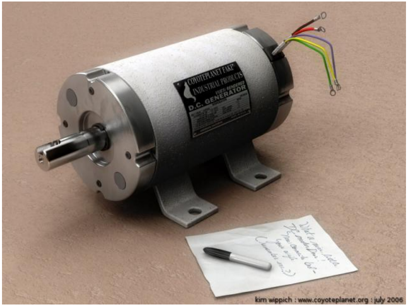
Rotational to Electrical

- Rotational generators are most common: 65-95%



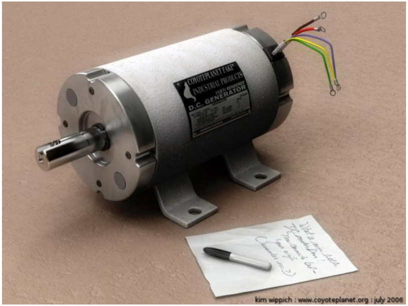
Rotational to Electrical

- Rotational generators are most common: 65-95%
- Difficult to find low speed generators



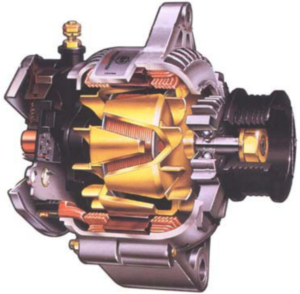
Rotational to Electrical

- Rotational generators are most common: 65-95%
- Difficult to find low speed generators
- DC generators: voltage is proportional to the speed



Rotational to Electrical

- Rotational generators are most common: 65-95%
- Difficult to find low speed generators
- DC generators: voltage is proportional to the speed
- Alternators: minimum excitation needed, but easy to find



Energy Storage Types

- Springs store potential energy $E = \frac{1}{2}kx^2$

Energy Storage Types

- Springs store potential energy $E = \frac{1}{2}kx^2$
- Flywheels store kinetic energy $E = \frac{1}{2}I\omega^2$

Energy Storage Types

- Springs store potential energy $E = \frac{1}{2}kx^2$
- Flywheels store kinetic energy $E = \frac{1}{2}I\omega^2$
- Capacitors store energy like a spring $E = \frac{1}{2}CV^2$

Energy Storage Types

- Springs store potential energy $E = \frac{1}{2}kx^2$
- Flywheels store kinetic energy $E = \frac{1}{2}I\omega^2$
- Capacitors store energy like a spring $E = \frac{1}{2}CV^2$
- Batteries create energy from a chemical reaction and store energy

Energy Storage Types

- Springs store potential energy $E = \frac{1}{2}kx^2$
- Flywheels store kinetic energy $E = \frac{1}{2}I\omega^2$
- Capacitors store energy like a spring $E = \frac{1}{2}CV^2$
- Batteries create energy from a chemical reaction and store energy
- They all act as an energy buffer

The Bicycle

The Bicycle

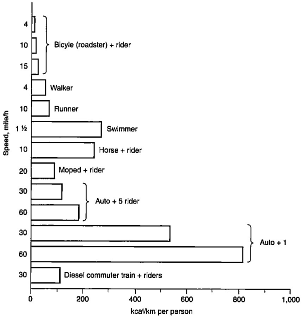


Figure 4.16
Energy cost of human movement and of the propulsion of various vehicles.

The Bicycle

www.alaindelorme.com

The Bicycle

If there is one human powered machine that just can't be matched, it is the bicycle. The bicycle is the most energy efficient means of transportation. It is even more efficient than walking! Bicycles are the most abundant transportation machine on the planet and they are utilitize in a multiude of ways to move people and goods. The bicycle is a very valuable item in most of the developing world. Many people think that an inexpensive and durable bicycle can be a life saver for people in developing nations, allowing for better commerce, kids getting to school, etc. There are an array of projects that are trying to better lives with bicycles. But the bicycle is still a distant commodity for many people as the price is not within reach. If anyone can create a less than $50 durable bicycle for the developing world, they will get the Nobel prize.

Water Pumps

Hand operated water pumps (hand pump) are some of the most widely used, reliable and appropriate human powered machines. The classic water pump's design is practically indestructable and parts are available in the most remote locations allowing well drawn water to be brought to communities around the world. Your designs should aspire to be as simple. http://en.wikipedia.org/wiki/Hand_pump

Kickstart Water Pumps

www.kickstart.org

Kickstart Water Pumps

www.kickstart.org

KickStarts Original MoneyMaker pump was introduced in September 1996. This small treadle operated pump could pull water from as deep as 23 feet (7m) and be used to furrow irrigate up to two acres of land. It was superseeded buy the Super-Money Maker in 1999 to provide hose and sprinkely based watering that could be pumped uphill. Primarily used in East Africa.

The Full Belly Project

www.thefullbellyproject.org

The Full Belly Project

www.thefullbellyproject.org

The Full belly project introduced the universal nut sheller in 2005, orginally designed to shell peanuts. It can shell 50 kg of peanuts per hour compared to 1.5 kg by hand in an hour. It has a simple design using only concrete and some metal parts and should last 20 years with little maintenance. The simplicity of this design is the major reason it has been so succesful.

One Laptop Per Child

The OLPC project launched around 2006 with the goal of introducing an inexpensive computer to children in the developing world. They've worked on leveraging the rapid decrease in power consumption in electronics to develop an extremely low power laptop (on the order of 2 watts or less). They've developed a hand crank to charge/run it and are working on integrated solar. Side note: research is being done where they leave computers in rural places and find that there is rapid self learning.

Low power electronics

Low power electronics

There are a number of super low power devices that can be power by the user. The shaker type flashlight is very popular, along with an assortment of radios and other lights. Arjen Jansen has recently published his dissertation on the subject of these devices. And his country is the home of the Watt dance floor where the dancers produce the club's lighting.

Rock The Bike

Rock The Bike

Rock the Bike is a bay area baed group that started up developing ways to power sound systems with human power. They have music concerts that are pedal powered by the audience and have even sent touring bands out only be bicycle and setup to power all there own sound equipment. They also have a sweet bicycle blender and now even an ice cream maker.

Green Gyms

R2B2 by Christoph Thetard

www.christoph-thetard.de

R2B2 by Christoph Thetard

www.christoph-thetard.de

This universal kitchen appliance is a pretty elegant design. Many people have worked on various forms of human powered machines with interchangeable devices.

iRock Rocking Chair

http://www.treehugger.com/gadgets/irock-rocking-chair-charges-your-apple-device.html iRock Rocking Chair

http://www.treehugger.com/gadgets/irock-rocking-chair-charges-your-apple-device.html

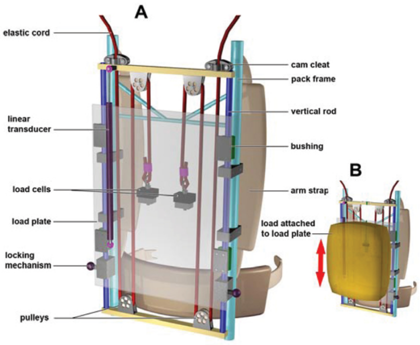
Clever way to extract energy from rocking.

Piezoelectric Dance Floor

Piezoelectric Dance Floor

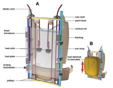
Piezoelectric floor tiles generate enough energy from dancing to power LEDs in the floor.

Electricity generating backpack



http://www.lightningpacks.com

Electricity generating backpack



http://www.lightningpacks.com

Recovers electricity from normal walking.

ZAmbulance and wheelchairs in Zambia, Africa

- Short distance transport for patients

ZAmbulance and wheelchairs in Zambia, Africa

- Short distance transport for patients
- Materials are imported and very expensive

ZAmbulance and wheelchairs in Zambia, Africa

- Short distance transport for patients
- Materials are imported and very expensive
- Only NGO's can purchase and distribute

Human powered machines in Guatemala

- Corn grinding for masa

Human powered machines in Guatemala

- Corn grinding for masa
- Rope water pump

Human powered machines in Guatemala

- Corn grinding for masa
- Rope water pump
- Macadamia nut husker

Human powered machines in Guatemala

- Corn grinding for masa
- Rope water pump
- Macadamia nut husker
- Clothes washing machine

Human powered machines in Guatemala

- Corn grinding for masa
- Rope water pump
- Macadamia nut husker
- Clothes washing machine
- Peanut sheller

UC Davis Human Powered Utility Vehicle

Mobile Ministry Unit

Pedal Desk

- Power a laptop with pedal power
- Educate students on power usage
- http://mae.ucdavis.edu/~biosport/jkm/ped_desk.htm

Pedal Desk

- Power a laptop with pedal power
- Educate students on power usage
- http://mae.ucdavis.edu/~biosport/jkm/ped_desk.htm

We built this desk to demonstrate how much power it actually takes to run a laptop. Turns out that it would take 250,000 people to power UCD's electric needs.

How many people does it take to power a home?

http://www.youtube.com/watch?v=C93cL_zDVIM

Whipped Cream

VERSUS

www.moorepants.info

Resources:

- James C. McCullagh, David Gordon Wilson, Stuart S. Wilson, John McGeorge, Mark Blossom, and Diana Branch.
  Pedal Power: In Work, Leisure, and Transportation.
  Rodale Press, Emmaus, PA, 1977.
- David Gordon Wilson.
  Understanding pedal power.
  Technical report, Volunteers in Technical Assistance, 1986.
- D. G. Wilson and Jim Papadopoulos.
  Bicycling Science.
  MIT Press, 3rd edition, 2004.
- Tamara Dean.
  The Human-Powered Home: Choosing Muscles Over Motors.
  New Society Publishers, 2008.
- Arjen Jansen.
  Human Power: Empirically Explored.
  PhD thesis, Delft University of Technology, 2011.