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Simple, low-cost solar pumping is now a reality

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A breakthrough has been achieved in making small solar pumps affordable and easy to set up and use by small farmers in Africa. Numerous off-the-shelf pumps running on direct current were tested when connected directly to a single solar panel, without any battery or additional electronics. Of the many pump models tested, two were found to meet our criteria for low-cost solar pumping for small-scale irrigation. These pumps have been successfully operating in Cameroon, Chad, Burkina Faso, Senegal and Canada since 2014. We present information on the components, cost and performance of these pumps for small-scale irrigation.

The need and the opportunity

In most developing countries, the production of high-value horticultural crops on a small scale is often an attractive option for small farmers to increase and diversify their income. The production of high-value crops usually requires irrigation, at least for some months of the year. Crop prices are generally much higher during dry periods when irrigation is needed. Many small farmers practicing irrigation are severely constrained by the small quantity of water they can deliver to their crops using only human energy, including carrying watering containers, or with the use of hand pumps or foot pumps. Some farmers do successfully scaleup using small internal-combustion pumps for irrigation, but the cost and availability of fuel in rural areas is usually a significant obstacle to profitability. Grid-powered electric pumps are a viable option only in the limited areas where grid power is available.

Solar pumps have been a technically feasible option for small-scale pumping for some decades. However, until recently, the cost of available solar pumping systems has been too high to make them economically feasible for small farmers. For example, Lorentz, a leading German manufacturer of solar pumps, offers as one its smallest models the 300-Watt PS2-150 C-SJ5-8 solar submersible pump. This pump is technically suitable for small-scale irrigation, delivering 4m3/hour at 5m head. In 2018, this model was offered at a retail cost of US$1795 (equivalent) on a competitive European website, without solar panels. This corresponds to US$6 per electrical watt for the pump and controller alone. Some Chinese manufacturers including Jintai and Sunmoy do offer similar submersible pumps in the 300W range at around US$1 per Watt for the pump only, which is a step closer to affordability.

A company called Futurepump has attempted to address the need for a low-cost solar pump with its SF-1 piston pump, using an 80-watt solar panel. But at a retail price of US$650 (according to 2017 press reports), the system cost of over $8 per watt is even higher than a small Lorentz pump.

The good news is that in recent years, the cost of solar panels has decreased dramatically, and panels have become widely available in developing countries. In many African countries, solar panels are easily available at a cost of less than US$1 per Watt. Consequently, small-scale solar technology is being spontaneously adopted in many rural areas in Africa, most often for lighting, phone charging and other small appliances. However, this new, economical source of energy has so far not helped most farmers who are looking for an alternative to human energy for lifting water.

Our approach to low-cost solar pumping

In 2013, we set out to develop a simple, low-cost solar pumping system, targeting especially small farmers looking for alternatives to both manual water lifting and small engine pumps. The approach was to build a system with off-the-shelf components, and with a minimum number of components. This reduces the need for capital and time required to design, test and then go into production with new technology. We hoped to find pumps on the market that are economically priced, by virtue of being already mass-produced for other markets, even if not specifically designed for solar. Additionally, we decided to avoid the use of batteries, which would result in additional cost, complexity, weight, and maintenance issues. With these criteria in mind, we investigated a wide range of existing electric pumps powered by direct current, in the range of 12-24V. To date, more than 30 different pump models have been tested, and testing is ongoing.

Initial success: marine bilge pumps powered directly by solar panels

One category of DC pumps that are produced for a mass market is bilge pumps for small to medium-sized boats. We found that the smaller models of 100W or less were very inefficient, and only capable of pumping to a height of a few meters. However, some models in the 200W range were found to be reasonably efficient, as well as economical.

One of the better-known brands is Rule, manufactured by US-based Xylem. These pumps come in 12V and 24V (nominal) versions, as they are designed to operate on batteries with those voltages. However, a manufacturer's representative advised that the pumps would not tolerate widely fluctuating input voltages, as would be the case if operating from panels with no battery. Practical tests showed that the bilge pumps could in fact operate directly from solar panels, speeding up and slowing down as the sunlight intensity varies. After some weeks of testing in this mode, we set up the first fully functional small irrigation system in the field.

Our 2013 Youtube video (https://www.youtube.com/watch?v=bPvPJuvLw9Q) shows this first system being tested in Kedougou Region, Senegal. The system used a Rule model 4000 12V pump, consuming a little over 200W of electrical power. The pump was powered directly by five solar panels of 80W each, connected in parallel, for a total of 400W. This permitted the system to operate at full power even with less than full sun. For portability and to allow manual tracking of the sun, the panels were mounted on a 2-wheel cart fabricated at a local welding shop. The other components included some electric cable, simple electrical connectors, a flexible hose and a rubber bucket to protect the pump inside the water source. The operating voltage of the array was about 18V, and the voltage drop in the cable was about 1V, resulting in an input voltage to the pump of about 17V. The pump was found to tolerate this voltage for extended periods without any problem. In fact, the initial system operated exactly as shown in the video for two full irrigation seasons to supply water to a village garden beside the Gambia River. The system is still operational in 2018, although the original pump unit failed during its third irrigation season and had to be replaced.

This type of bilge pump is based on brush-type motor, which has a limited lifetime. Specifically, the brushes and the rotating seal on the shaft are the parts likely to fail. It is possible in principle to replace the brushes, although we have not yet attempted to do so. If the rotating seal fails and allows water inside the motor, then the motor would most likely have to be replaced.

Based on field experiences so far, we expect pumps of this type to last for at least two irrigation seasons of four months before requiring repair or replacement. Since the panels should last for decades if not physically damaged, we consider it acceptable and cost-effective to replace the pump unit every two years, using profits from the irrigated crops.

A step forward: pumps using a single solar panel

After testing more pump-panel combinations, we found that it was possible to improve substantially on the initial prototype by using a 24V bilge pump of about 200W connected directly to a single solar panel of 60 cells and at least 250W. Since 60-cell panels are widely available with power ratings in the range of 250W to 300W, it is easy to find a panel that is matched to this type of pump. These panels have an operating voltage close to 30V, which has been found to be well tolerated by the pumps tested. The use of a single panel simplifies and reduces the cost of the system, and increases its portability. Depending on the situation, a panel of this size may be carried short distances by hand, or mounted on a wheelbarrow, for ease of transportation as well as manual tracking of the sun.

Table 1 presents our performance test results for a Rule 4000 24V pump connected to a 250W, 60-cell panel under clear skies.

Table 1. Performance of Rule 4000 pump with 250W panel						
Head (m)	**Flow rate (m^3/h)**	**Electric power used (W)**		**Head (m)**	**Flow rate (m^3/h)**	**Electric power used (W)**
0	13.3	220		5	5.7	216
1	12.0	217		6	4.7	213
2	9.7	219		7	3.0	192
3	9..0	221		8	1.8	177
4	7.4	220		9.5	0	147

This pump was found to be reasonably efficient up to 7m head. As a practical example, at 4m head the pump can deliver 7.4m^3/h, or about 44m^3/day in a 6-hour pumping day. Depending on the irrigation method and agronomic factors, this may be sufficient to irrigate between 0.3ha and 1ha. The area irrigated will obviously be less as the head increases.

The retail cost of the Rule 4000 24V pump on US websites is under US$200, or less than US$1/Watt. Unfortunately, these pumps are currently not widely available in developing countries. However, we believe it should be feasible to import the pumps in quantity and offer them at an affordable price.

Several Rule 3700 and Rule 4000, 24V pumps are currently being used by small farmers for irrigation in Cameroon and Senegal. At least two farmers have used the profits from their first system to purchase a second system of this type.

Bilge pumps with similar characteristics to Rule pumps have been developed by manufacturers in other countries, including China. We tested several other brands of bilge pump in the 200-Watt range, with mixed results. One particular Chinese brand, Seaflo, has survived in the market for several years, which may be an indicator of acceptable reliability. Initial test results with a Seaflo 3700 pump (see Photographs 1 and 3) suggest that it may be a little less efficient than the similar Rule model. We do not yet have enough information to estimate the lifetime of the Seaflo pumps. However, with a retail cost as low as $50, these pumps are dramatically cheaper than the Rule pumps, so they may prove to be more economical overall, even if the pump unit has to be replaced more often.

Another family of pumps: brushless DC pumps

Brushless DC pumps are another category of pumps that are already mass-produced for non-solar applications, including circulating fluids in industrial machinery, and automotive cooling.

The potential reliability of brushless DC pumps has been demonstrated by several companies in western countries whose products are in wide use. However, the pumps offered by these western companies are still very expensive, in the range of several hundred dollars to over a thousand dollars for pumps in the power range of 50 to 200 Watts. In recent years, several Chinese companies have entered the market for brushless DC pumps, including some with novel design features.

After testing several types of brushless DC pumps, we found that certain models from ZKSJ Pumps (https://zksjpump.com) are effective, economical and sufficiently reliable for small-scale solar irrigation. While many models are available from this company, including some new models not yet tested by us, we have found the model ZKSJ DC50B-24130S to be adaptable to a range of situations for small-scale irrigation. These pumps are small, light, and contain only one moving part, which is the rotor-impeller assembly (see photographs 1, 2 and 4). The rotor uses permanent magnets rather than coils, so there are no brushes. The rotor runs immersed in water and lubricated by water, so there are no rotating seals, and the expected lifetime is in the tens of thousands of hours. The pump comes with an attached, waterproof electronic control unit, which actually contains a 3-phase inverter as well as circuitry to protect the pump from overvoltage.

This particular model consumes between 50 and 120 Watts, depending on the input voltage and head. With a wholesale cost of only $30 in China, this model has enabled us to achieve a breakthrough of creating a complete solar irrigation system at a retail cost in Africa of less than $200.

A significant feature of this model is that it can operate over a wide range of input voltages, from less than 12V to about 30V. When the current exceeds about 4A, the controller automatically shuts off the pump, and turns it on again when the voltage comes back into the accepted range. The flow rate and head of the pump are dependent on the input voltage. This means that systems with different levels of power and performance can be created simply by using different solar panel models.

Many of the commonly available solar panels in developing countries use 36 cells and have an operating voltage of about 18V, which is appropriate for charging 12V lead-acid batteries through a charge controller, for example for small home lighting systems. When connected to a 36-cell panel, this pump model consumes 55 Watts or less. Thus, it can be used as the basis for a low-cost, entry-level irrigation system with a panel of as little as 60 Watts.

The same pump model can operate with a panel of 54 cells (which exist but are not common), or 60 cells (which are commonly available in the power range of 200W to 300W). This means that this pump model can be matched with different panels, depending on the water needs and the budget of the user. Two or more pumps can also be operated with a single panel, providing either higher flow or higher head, depending on the situation.

Table 2 presents our test data for the ZKSJ DC50B-24130S pump with two commonly available panel types.

Table 2. Performance of ZKSJ DC50B-24130S pump with different panel types

Head (m)	Basic system: 36-cell panel of at least 60 watts	Higher-performance system: 60-cell panel of at least 120 Watts
	Flow rate (m^3/h)	Flow rate (m^3/h)
2	1.3	
3	1.2	1.6
4	1.0	1.5
5	0.89	1.4
6	0.76	1.2
7	0.63	1.1
8	0.46	1.0
9	0.26	0.95
10	0	0.87
11		0.77
12		0.68
13		0.56
14		0.45
15		0.30
16		0

The boxes highlighted in green in Table 2 indicate where the flow rate of the pump is over $0.5m^3$/hour, which we consider to be of interest for small-scale irrigation for income generation. If we consider a typical pumping rate of $1m^3$/h, in a 6-hour pumping day, the pump would deliver $6m^3$/day. Depending on agronomic factors, this may be sufficient to irrigate 500 to $1500m^2$ of intensive crops.

System components and cost

A key parameter for potential purchasers of these simple pumping systems is the total system cost. In Table 3, we present the list of components and estimated cost for several system configurations, based on 2018 retail costs in Bamenda, Cameroon. These are complete and ready-to-use small irrigation systems, including a flexible hose to deliver the water directly to the garden beds. The panel sizes are the minimum recommended; a larger panel will generally provide a more steady flow of water when the intensity of sunlight is variable. The quantities mentioned for cables and hoses are typical, but may vary by situation.

We have not included any amount for system assembly and installation. This is because a farmer with basic electrical and plumbing skills can assemble the components and set up these systems herself, once she has seen a system in operation. Otherwise, in many African countries, a local technician may be called upon to assemble a system for about $10.

Table 3. Typical system components and cost (US$)

System component	System 1: Entry-level – 1 ZKSJ pump	System 2: 2 ZKSJ pumps in parallel for higher flow	System 3: 2 ZKSJ pumps for higher flow and higher head	System 4: Bilge pump for high flow at low head
Pump(s)	ZKSJ DC50B-24130S $57	ZKSJ DC50B-24130S Qty 2 - $114	ZKSJ DC50B-24130S Qty 2 - $114	Seaflo 3700 24V $85
Panel (minimum recommended power)	60 Watt, 36 cell $60	120 Watt, 36 cell $120	250 Watt, 60 cell $250	250 Watt, 60 cell $250
Electric cable (recommended 2 x 16mm2 aluminium outdoor service cable)	15m cable $9	20m cable $11	20m cable $11	20m cable $11
Flexible hose	1” x 25m $29	1” x 30m $34	40mm x 30m $67	50mm x 30m $103
Electrical and plumbing connectors	$5	$10	$10	$10
Wheelbarrow, with modifications (optional, not included in total)			[$55]	[$55]
Total system cost	$160	$289	$452	$459
Typical system performance	6m^3/day @ 4m head	12m^3/day @ 4m head	12m^3/day @ 8m head	40m^3/day @4m head

Conclusion

While there is plenty of scope to develop more efficient, long-lasting and economical small solar pumps, we have demonstrated cost-effective systems which can already make this technology affordable to millions of small farmers in developing countries. These systems are easy to assemble and set up, using off-the-shelf components. All that is required is for interested enterprises to import and distribute the solar pump units, as the other system components are already available in most countries. Our experience so far suggests that once farmers have seen these systems in operation, they will be interested to purchase and start using them, in many cases without financial support or credit facilities.

The pumps presented here are most suitable for irrigation from an open water source, such as a natural water body, reservoir, canal or open well. These cases represent the vast majority of sites where small-scale irrigation is potentially viable. In addition, the smaller ZKSJ pumps have been successfully adapted to operate in hand-drilled boreholes.

Photograph 1. ZKSJ model DC50B-24130S and Seaflo 3700 pumps

Photograph 2. Complete, entry-level irrigation system using one ZKSJ pump

Photograph 3. Complete irrigation system using one Seaflo 3700 pump

Photograph 4. Working system drawing water from a well

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