UNIVERSITY of GUELPH

CHANGING LIVES IMPROVING LIFE

Experimental investigation of the factors affecting Archimedes screw generator power output

HYDRO 2017
Session 26, 11 October 2017
Seville, Spain

Scott Simmons, MASc. Candidate
School of Engineering, University of Guelph

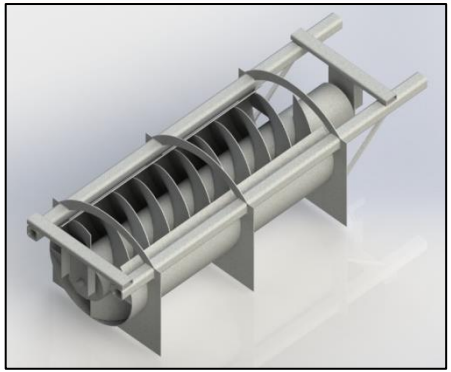
Overview

- Archimedes screw generators (ASG)
- Screw geometry
- ASG laboratory and experiments
- Results
- Conclusion
- Acknowledgments

Archimedes Screw Generators

What is it?

- Implemented as a pump in antiquity
- Pico- or micro-hydro turbine
- Helical array of blades around a central tube
- Suitable generator for moderate flow rates and low head



Three-flighted lab-scale Archimedes Screw

From: http://rachel122333.files.wordpress.com/2012/02/archimedes-screw.jpg

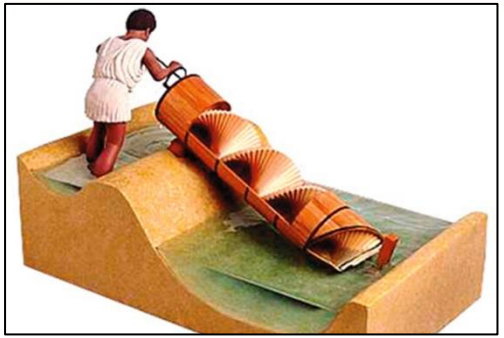
History of the Archimedes Screw

Naming of the Screw

- Evidence that the device was invented for King Sennacherib of the Assyrian Empire (7th Century BCE) to water what is thought to be the Hanging Gardens of Babylon
- Popularized by Archimedes of Syracuse (circa 287-212 BCE)

Uses of the Screw in Antiquity

- Pumps for the Roman Empire's mines in modern Spain
- Pumps for irrigation systems
- Bilge pump for ships

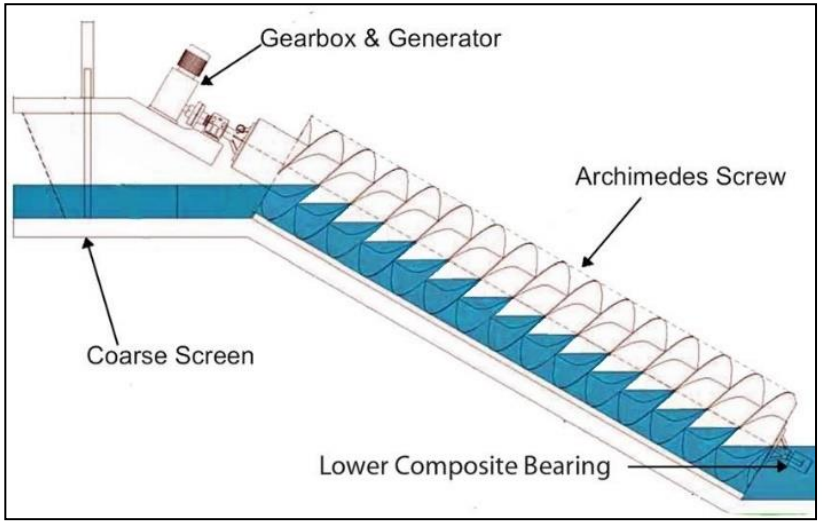


Archimedes Screw used for Irrigation with cut-away to show screw flights inside the outer diameter casing (Randy Lewis, 2013)

A fresco recovered from the House of the Ephebe in Pompeii showing a man driving an Archimedes screw (then termed *cochlea*) as a treadmill. *The New York Times*, November 6, 1927; page E3

Archimedes Screw Generators

- Flowing water travelling down the screw induces a torque about the central shaft causing it to rotate, turning a generator
- Screw is rather large in many installations
  - A 7.2 kW installation has a diameter of about 1.5 metres



Three-flighted Archimedes Screw as a Generator

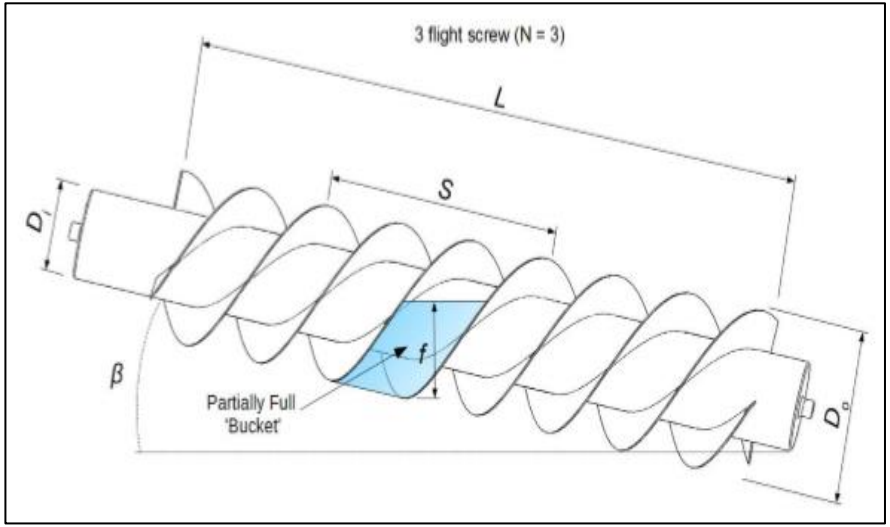
Advantages of Screw Generators

1. *Ecological Impact*
   - Coarse screen at inlet allows for sediments, debris, nutrients, and even fish and other marine life to pass through the turbine itself without any harm
2. *Costs*
   - Low cost of installation and maintenance due to simple, robust design
3. *Operational Range*
   - Well suited for Run-of-river installations, and can operate with relatively high efficiency under seasonal flow conditions

Coarse intake grate allows passage of fish and small debris. (*Greenbug Energy Inc., 2012*)

ASG Geometry

- Water that fills the volume between adjacent flights is called a “bucket”
- Geometric Parameters of ASGs:
  - Length of Screw Flights (*L*)
  - Number of Flights (*N*)
  - Diameter Ratio (D_i/D_o)
    - Inner Diameter (D_i)
    - Outer Diameter (D_o)
  - Pitch (*S*)
- Other key Design Factors:
  - Angle of Inclination (β)
  - Rotational Speed (ω)



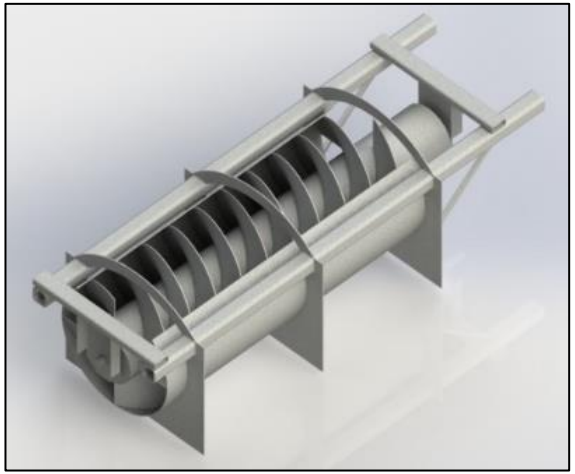
Three-flighted Archimedes Screw (K. Songin, 2016

Archimedes Screw Laboratory

- 16 unique lab-scale screws tested for varying flow rates, rotational speeds, and outlet fill heights

Dimensions of University of Guelph laboratory-scale Archimedes screws.

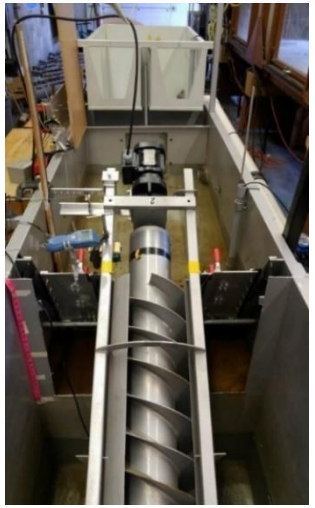
Screw	OD (cm)	ID (cm)	S (cm)	L (cm)	N	ID/OD	S/L	L/S
#1	31.58	16.83	44.45	121.92	3	0.53	0.36	2.74
#2	31.62	16.83	31.75	121.92	3	0.53	0.26	3.84
#3	31.67	16.83	25.4	121.92	3	0.53	0.21	4.8
#4	31.69	12.7	31.75	121.92	5	0.4	0.26	3.84
#5	31.66	12.7	31.75	121.92	4	0.4	0.26	3.84
#6	31.62	12.7	31.75	121.92	3	0.4	0.26	3.84
#7	31.62	12.7	31.75	63.5	3	0.4	0.5	2
#8	31.57	12.7	31.75	40.64	3	0.4	0.78	1.28
#9	31.64	10.16	31.75	121.92	3	0.32	0.26	3.84
#10	31.61	10.16	44.77	52.07	4	0.32	0.86	1.16
#11	37.8	16.99	30.2	46.89	4	0.44	0.64	1.55
#12	37.69	16.89	30.4	61.39	4	0.44	0.5	2.02
#13	37.69	16.79	30.51	94.69	4	0.44	0.32	3.1
#14	38.2	16.99	38.3	46.61	4	0.44	0.82	1.22
#15	38.1	16.79	38.2	61.7	4	0.44	0.62	1.62
#16	38.61	16.89	38.3	94.89	4	0.44	0.4	2.48



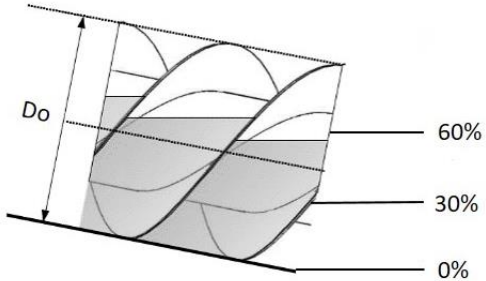
Three-flighted lab-scale Archimedes Screw

Experimental Procedure

- Experiment run with varying flow rates, rotational speeds, and outlet fill heights (OHF)
  - Flow Rates: 6, 8, 10, 12, and 14 L/s
  - Speeds: 20, 30, 40, 50, 60, and 80 RPM
  - OFH: 0%, 30%, and 60%
- Populated a database to characterise the performance of ASGs based on parameters
- Sensors measure basin depths, flow rate, rotational speed, and torque



ASG Laboratory Setup



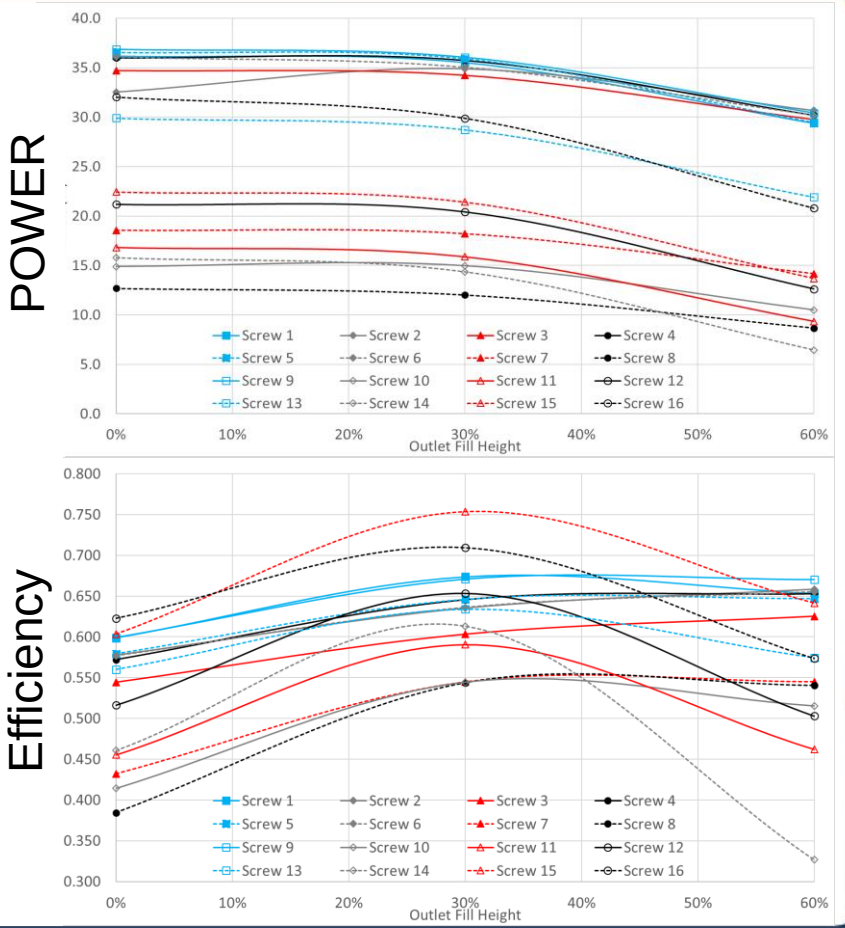
Outlet Fill Height (OHF) Definition

Results

- Outlet fill height
- Length
- Number of flights
- Diameter ratio
- Pitch

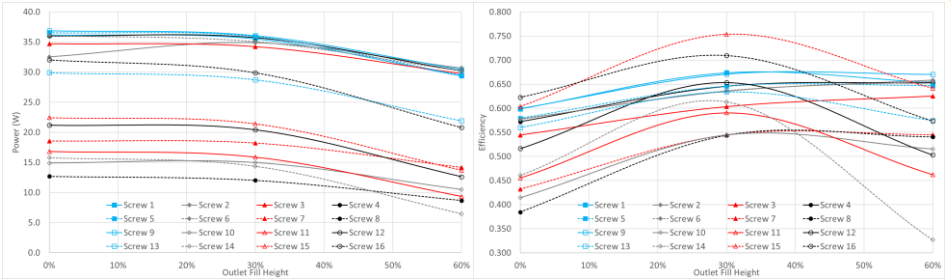
Results – Outlet Fill Height (OFH)

- As the OFH increases:
  - Power Decreases
  - Efficiency Increases
- Produces less power because there is less head (and less available water power)
- More efficient since the lower buckets have more fill height
  - With 0% OFH the lower buckets tend to empty
  - 60% OFH will be used for the remainder of the analysis

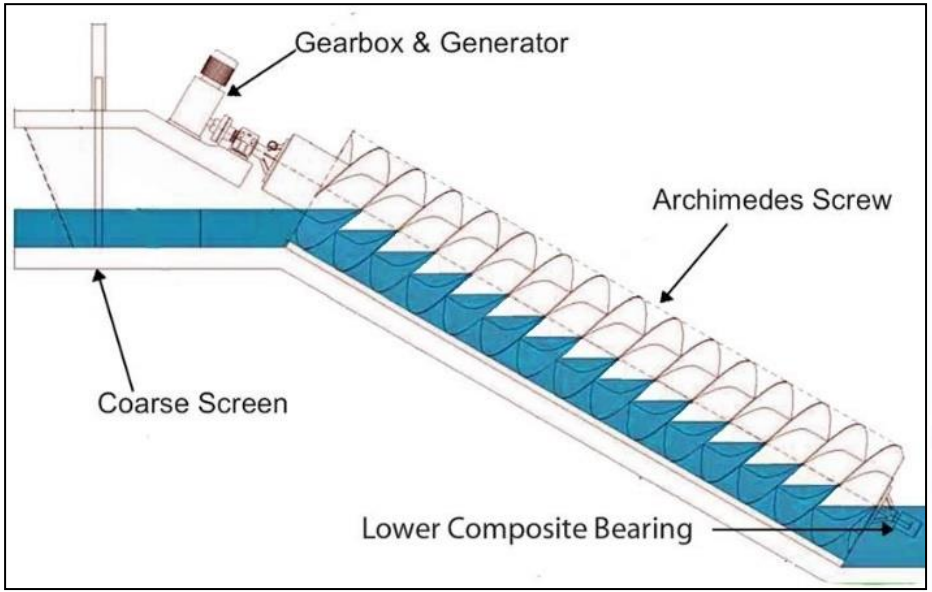


Results – Outlet Fill Height (OFH)

- As the OFH increases:
  - Power Decreases
  - Efficiency Increases

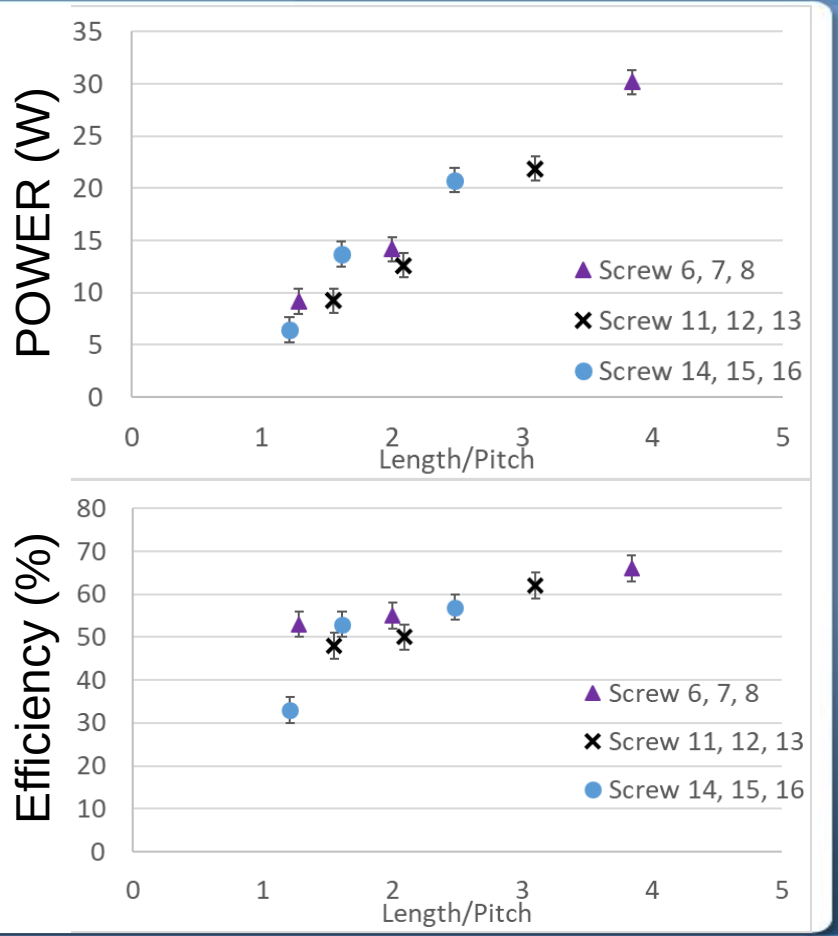


- Produces less power because there is less head (and less available water power)
- More efficient since the lower buckets have more fill height
  - With 0% OFH the lower buckets tend to empty
  - 60% OFH will be used for the remainder of the analysis



Results – Length

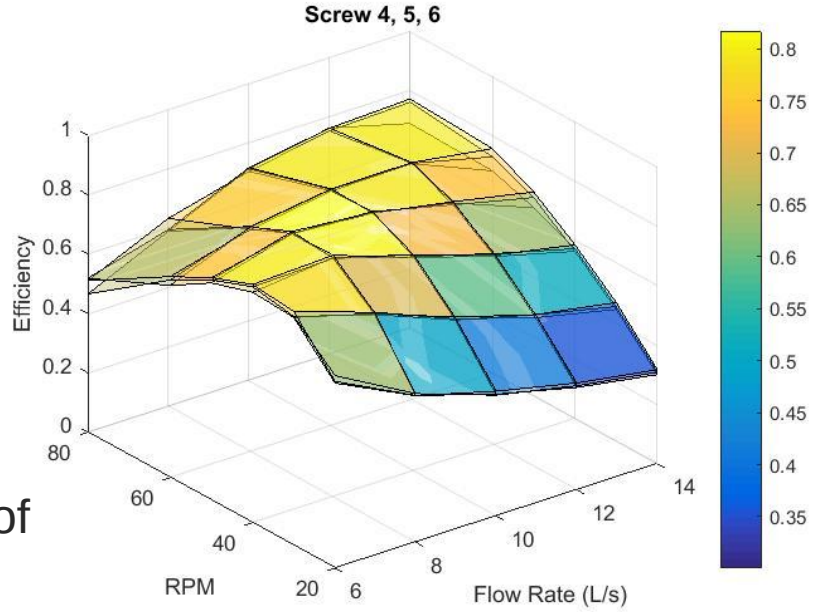
- As the Length increases:
  - Power Increases
  - Efficiency Increases
- Produces more power, more efficiently because there are more surfaces for water to engage with
- There should be a point (not seen in these experiments) where the frictional losses due to the screw length have more effect and efficiency drops



Results – Number of Flights (NoF)

- As the Number of Flights increase:
  - Power tends not to change
  - Efficiency tends not to change

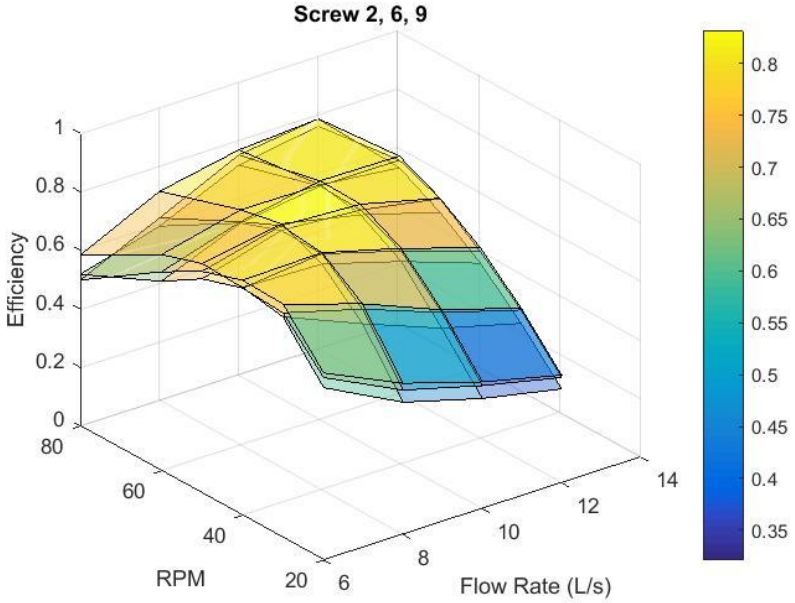
- It is believed that any increase in power production and efficiency caused by a change in the number of flights was offset by frictional losses (which will have a much more significant impact in these small laboratory-scale experiments)



Efficiency as a function of flow and rotation speed for screws 4, 5, and 6

Results – Diameter Ratio

- As the Diameter Ratio increases:
  - Power increases slightly
  - Efficiency increases slightly
- Smaller inner diameters allow for larger buckets, and reduces contact between the water in the screw and the central rotating shaft of the screw
- Within experimental uncertainty, the effect of the diameter ratio on ASG performance was found to be very minimal



Efficiency as a function of flow and rotation speed for Screws 2, 6, and 9.

Results – Pitch

- As the Pitch increases:
  - Power increases to a maximum
  - Efficiency increases to a maximum

- The experimental results reflected current ASG design practices
- Usual designs are set with pitch equal to the outer diameter, and this was experimentally shown to have the highest efficiency and most power production

Average power and efficiency for Screws 1, 2 and 3.

Screw	OD	ID	ID/OD	L	N	S	S/OD	Power	Efficiency (%)
#1	31.58	16.83	0.53	121.92	3	**44.45**	**1.41**	26.43 ± 1.36	66± 3.1
#2	31.62	16.83	0.53	121.92	3	**31.75**	**1.00**	27.98 ± 1.39	67 ± 3.1
#3	31.67	16.83	0.53	121.92	3	**25.4**	**0.80**	27.37 ± 1.34	63 ± 2.9

Conclusion

- This study was carried out to develop a database of 1440 points of ASG performance under varying flow rate, head, outlet fill heights, and geometry conditions at laboratory-scale
- It was found that the most impactful parameters of screw design, in descending order, are flighted length, outlet fill height, pitch, diameter ratio, and the number of screw flights
- The results of this experimentation may be used to further optimise Archimedes Screw Generator Design

Fletcher's Horse World – ASG installation.
(Greenbug Energy Inc., 2012)

Acknowledgements

Scott Simmons
MASc. Candidate
University of Guelph
ssimmons@uoguelph.ca

Kathleen Songin
Graduate Researcher
University of Guelph
ksongin@uoguelph.ca

William David Lubitz
Associate Professor
University of Guelph
wlubitz@uoguelph.ca

- Natural Sciences and Engineering Research Council of Canada (NSERC)
  - Undergraduate Student Research Awards (USRA)
  - Collaborative Research and Development (CRD)
- Greenbug Energy Inc. (Delhi, Ontario, Canada).