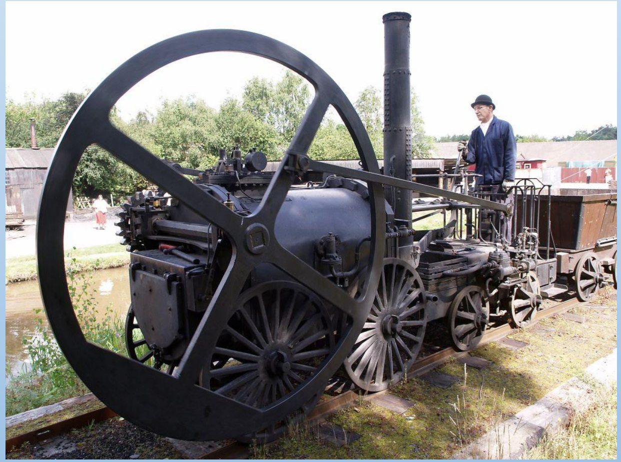
Flywheel Energy Storage (FES): Exploring Alternative Use Cases

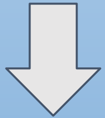
Caroline Ayanian, Jessica Matthys, Randy Frank, Daniel Herron, Cameron Simpson, Nate Sizemore, Jack Carey, Dante Cordaro

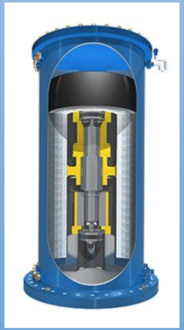
4/24/17

Executive Summary

1. Problem Background
2. Market Forces
3. Peak Shifting, Peak Shaving
4. Flywheel Theory
5. Prototype Design
6. Our Results
7. Environmental Analysis
8. Business Model
9. Final Thoughts







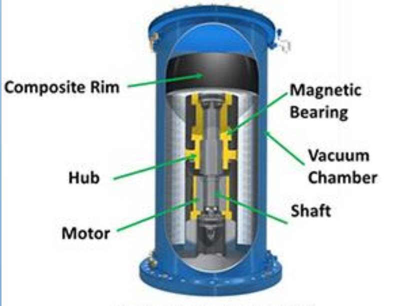
Duke UNIVERSITY | BASS CONNECTIONS

Problem Background

Technological Characteristics

Category	**Lead-Acid**	**Li-Ion**	**Flywheel**
Discharge Efficiency	83-85%	83-85%	85-93 %
Typical Storage Time	Minutes/Short Term/Days	Minutes/Short Term/Days	Minutes/Short Term
Max Cycle #	500-1000	1,000-10,000	20,000+
Estimated Lifespan	5-15 years	5-15 years	20+ years
Ecological Source Materials	Toxic	Toxic, Rare Earth Minerals	Standard, recyclable

Energy!



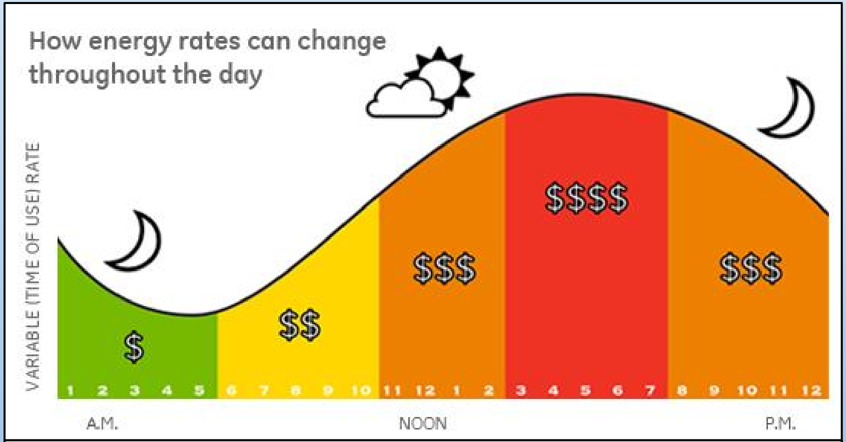
Source: Beacon Power, LLC

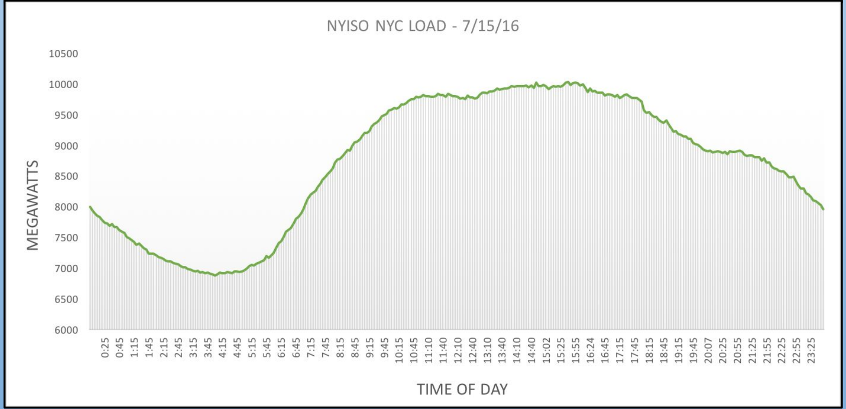
Duke UNIVERSITY | BASS CONNECTIONS

Problem Background

Market Forces at play:

- Electricity prices shift due to: fuel costs, weather, wire congestion, grid failures
- NY PSC estimates “the **top 100 hours of demand cost New York’s ratepayers as much as $1.2-1.7 billion** annually.”
- When consumption is high and lines are congested, utilities charge a **demand charge (kW)**





Duke UNIVERSITY | BASS CONNECTIONS

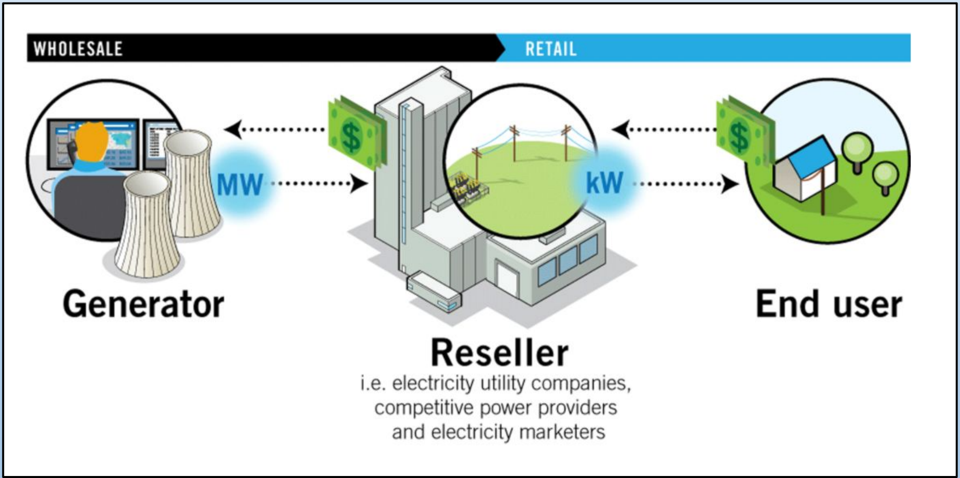
Problem Background

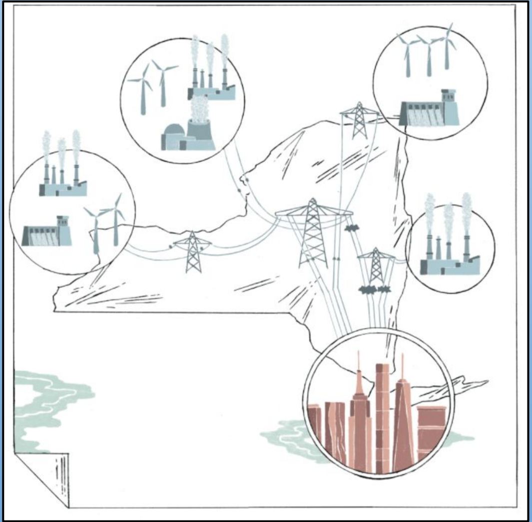
Flat Rate (FRP):

Regardless of major electricity price fluctuations, customers pay a predetermined rate for KWh's consumed

Voluntary Time of Use (VTUP):

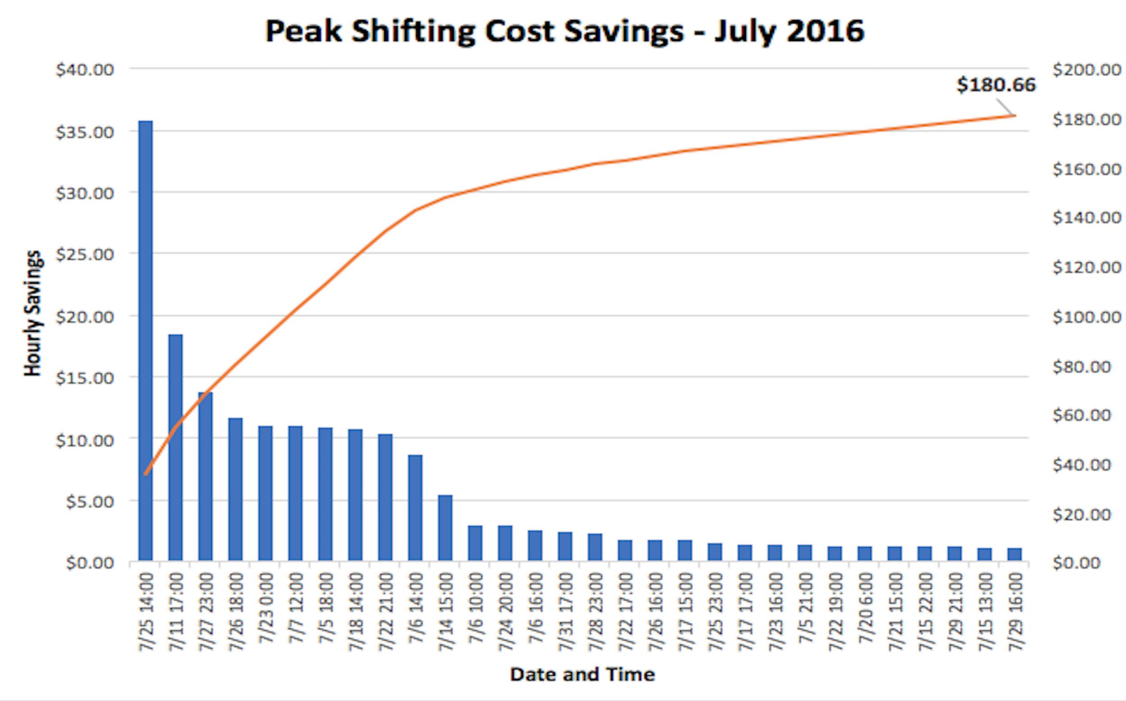
Customers are charged the market spot price for electricity, which varies greatly over the course of the day to push better consumer behaviors (Running the washing machine at night).





Duke UNIVERSITY | BASS CONNECTIONS

Economic Modeling: Peak Shifting



DOE Building Load Data

NYISO Real Time Pricing Data

ConEd Demand Charge Pricing

100 kW system

1 Hour Charge/Discharge Cycle

85% round trip efficiency

30 cycles

Consumption cap: 1,640 kWh

Duke UNIVERSITY | BASS CONNECTIONS

Economic Modeling: Peak Demand Shaving

Shifting: $180.66 (24.34%)

Shaving: $561.45 (75.66%)

Total: $742.11

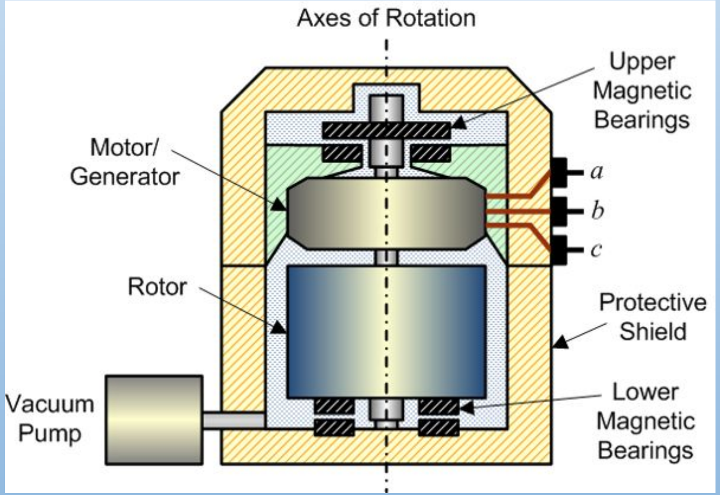
Shifting: $180.66 (39.33%)

Shaving: $278.80 (60.67%)

Total: $459.46

Duke UNIVERSITY | BASS CONNECTIONS

FES: Theory



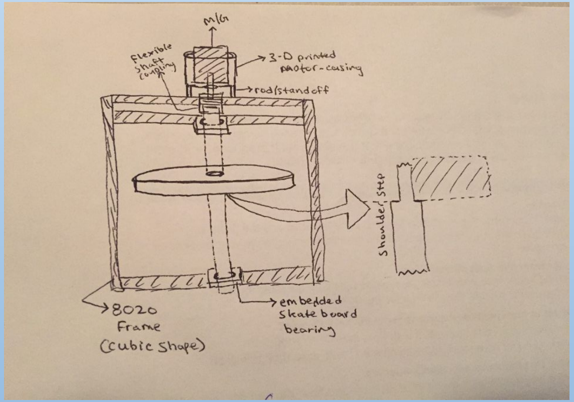
$$E = \frac{1}{4}\rho h r^4 \omega^2 - (\mu m g * r\omega + \frac{1}{2}\rho A c * (r\omega)^3) * \mathit{time}$$

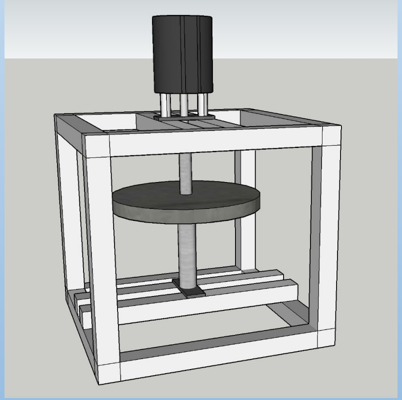
FES: Theory

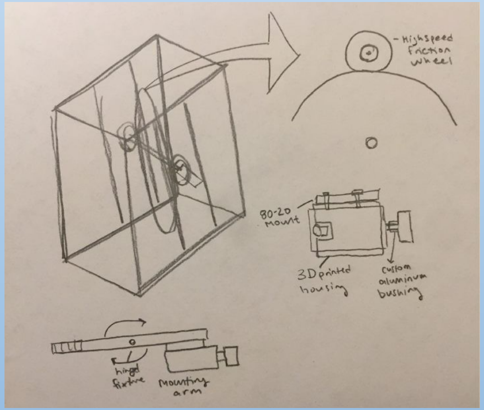
Inputs		Intermediate Values		Outputs	
Diameter (m)	0.3048	Mass (kg)	14.91889286		
Motor Wattage	210	Radius (m)	0.1524		
Motor RPM	600	Moment of Inertia (kg*m^2)	0.1732513125	Energy Storage (kJ)	0.205178527
Efficiency (fudge factor)	0.6	Density (kg/m^3)	8,050	Energy Storage (Wh)	0.05699403526
Thickness (m)	0.0254	Angular speed (rad/s)	62.83		
Material	Steel	Volume (m^3)	0.001853278616		
Geometry	Cylinder	Torque(kg*m^2/s^2)	11.15220063		

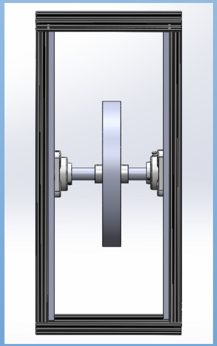
$$E = \frac{1}{2} I\omega^2 - \left(\mu m g r \omega + \frac{1}{2}\rho A c (r\omega)^3\right) * \textit{time}$$

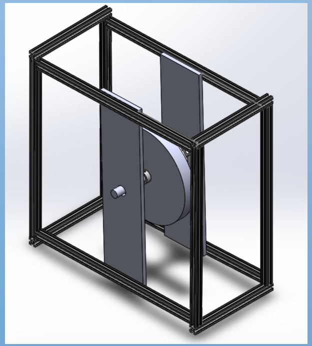
Prototype Design

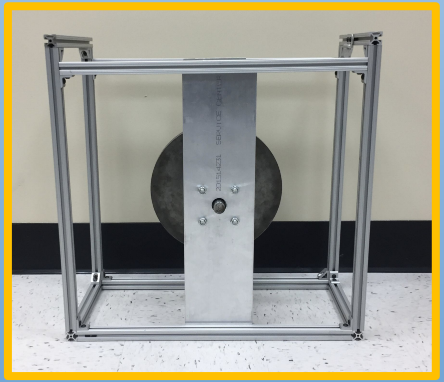




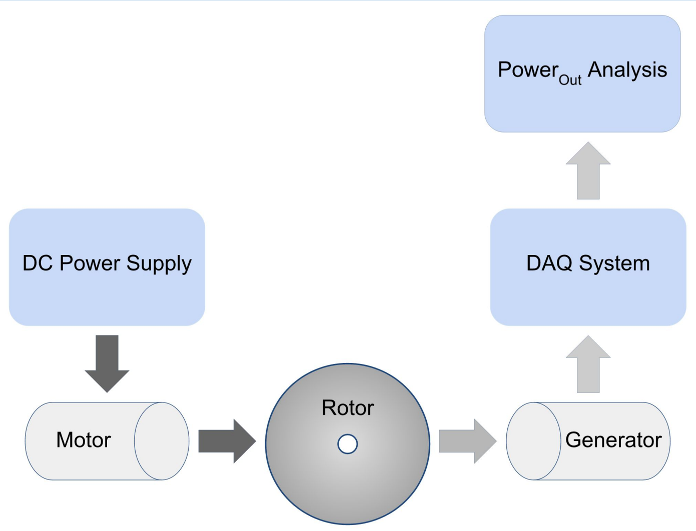


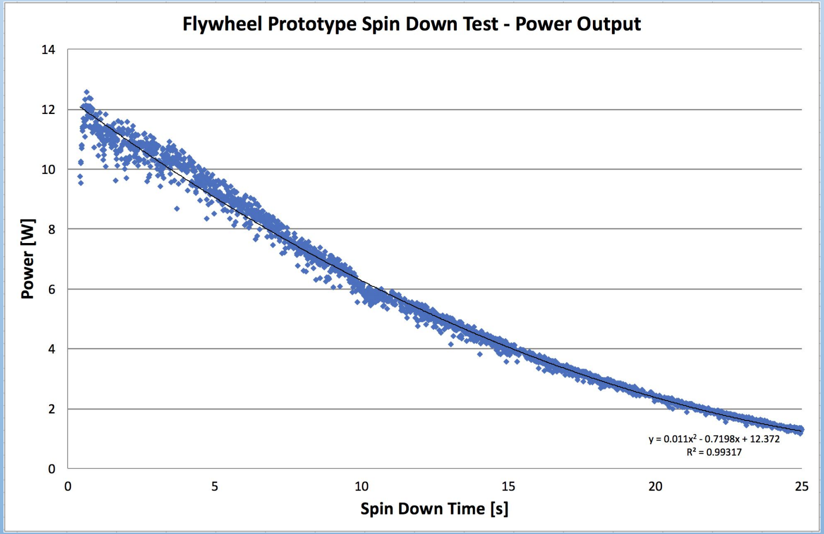






Prototype Results



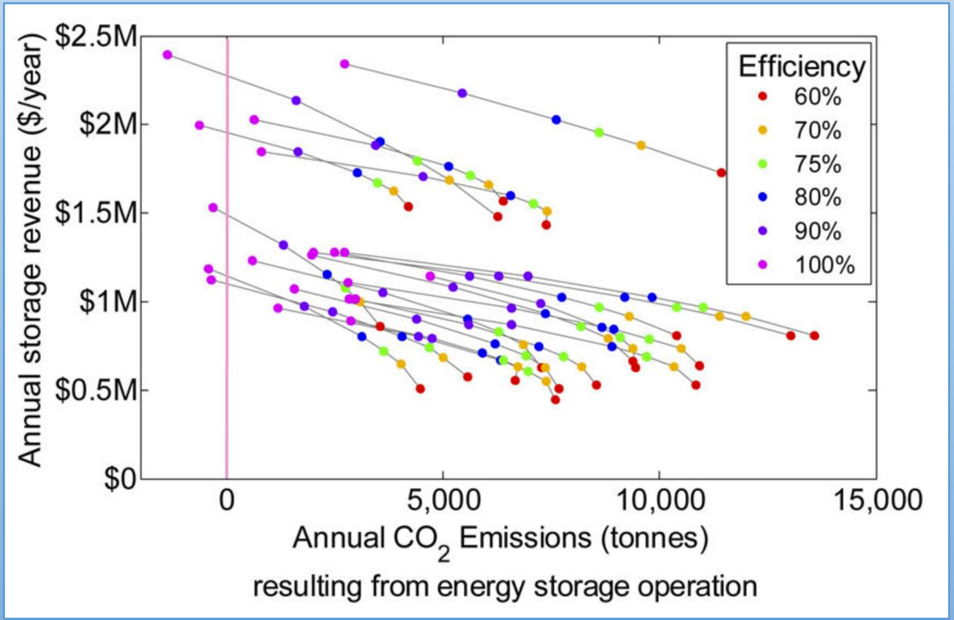


Final Efficiency: 16.9%

Duke UNIVERSITY | BASS CONNECTIONS

Environmental Impact

- Net energy consumer
- Increase GHG emissions
- Eliminates market for peaking natural gas plants



Hittinger and Azevedo, 2015

Environmental Impact

- Renewable Integration
  - output variability
  - generation-demand mismatch
  - forecast uncertainty
  - power quality
- Resources Used
  - Standard, recyclable
  - Extended lifetime

https://www.amazon.com/p/feature/e9gomtbrh5qk4yp

Basic Business Model

Unsubsidized Case

Assumptions		
System Size (kWh)		25
System Size (kW)		100
Flywheel Cost ($/kWh)	$	2,500
Estimated July Savings	$	731.34
Estimated Monthly Savings	$	548.51
Cost of 100 kW System	$	62,500
ConEd Subsidy	$	-
Discount Rate		3%

Year	0	1	2	3	4	5	6	7	8	9	10
Costs	$ 62,500	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Savings Estimate	$ -	$ 6,582.06	$ 6,582.06	$ 6,582.06	$ 6,582.06	$ 6,582.06	$ 6,582.06	$ 6,582.06	$ 6,582.06	$ 6,582.06	$ 6,582.06
Net Savings	-$ 62,500	-$ 55,918	-$ 49,336	-$ 42,754	-$ 36,172	-$ 29,590	-$ 23,008	-$ 16,426	-$ 9,844	-$ 3,261	$ 3,321
Discounted Savings	-$ 62,500	-$ 54,289	-$ 46,504	-$ 39,126	-$ 32,138	-$ 25,524	-$ 19,269	-$ 13,355	-$ 7,771	-$ 2,500	$ 2,471

Subsidized Case

Assumptions		
System Size (kWh)		25
System Size (kW)		100
Flywheel Cost ($/kWh)	$	2,500
Estimated July Savings	$	731.34
Estimated Monthly Savings	$	548.51
Cost of 100 kW System	$	62,500
ConEd Subsidy	$	20,000
Discount Rate		3%

Year	0	1	2	3	4	5	6	7	8	9	10
Costs	$ 42,500	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Savings Estimate	$ -	$ 6,582.06	$ 6,582.06	$ 6,582.06	$ 6,582.06	$ 6,582.06	$ 6,582.06	$ 6,582.06	$ 6,582.06	$ 6,582.06	$ 6,582.06
Net Savings	-$ 42,500	-$ 35,918	-$ 29,336	-$ 22,754	-$ 16,172	-$ 9,590	-$ 3,008	$ 3,574	$ 10,156	$ 16,739	$ 23,321
Discounted Savings	-$ 42,500	-$ 34,872	-$ 27,652	-$ 20,823	-$ 14,368	-$ 8,272	-$ 2,519	$ 2,906	$ 8,018	$ 12,829	$ 17,353

Duke UNIVERSITY | BASS CONNECTIONS

What Will Success Look Like?

Working scaled prototype

Written Report

Final Presentation

Business Model for Implementation

Choose Technology → Design Prototype → Take data, Iterate → Measure environmental impacts → Business Model → Final Presentation

Final Thoughts

Further idea for a student group: software to automate spin up, spin down

Our prototype works as a proof of concept

Industry will work towards improved efficiency and minimizing no-load losses

Our novel flywheel application would successfully save money

We could limit friction with magnetic bearings and a vaccum chamber

Limitations?

Duke UNIVERSITY | BASS CONNECTIONS

Movie Time

Duke UNIVERSITY | BASS CONNECTIONS

Questions?