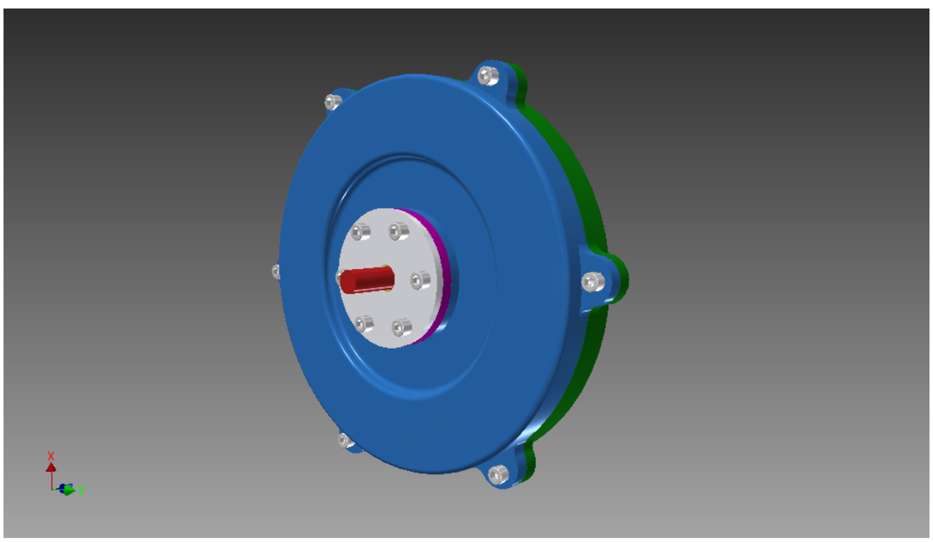
Education Development and Stimulus Fund

2015 Grant Submission



A. Describe and document the applicant's organizational structure

i3Detroit is organized as a 501(c)(3) nonprofit organization with EIN 27-0553505. The Board of Directors are elected by members and Officers are appointed by the Board of Directors. Both agents serve without compensation. We are an entirely community run organization with no paid employees. The makerspace itself is partitioned into zones that specialize in specific capabilities such as welding, bicycle repair, and CNC to mention a few, with 16 zones in all. i3Detroit has a talented group of zone wardens that oversee these zones and coordinate with members to host classes, maintain the zone, and make zone improvements.

B. Describe the proposed project

We propose to design and build the first of three phases in a larger project to make a flywheel bicycle. A flywheel bicycle has a rotating mass called a flywheel to store and release energy. Energy can be stored when the cyclist wants to slow down; instead of wasting the cyclist's kinetic energy as heat with the brakes, the cyclist would transfer kinetic energy from the bicycle to a flywheel energy storage unit (FESU). The advantage of a flywheel battery is that it doesn't use any type of electrochemical battery or gasoline, making it is less expensive, more reliable, and better for the environment. A flywheel bicycle will increase a cyclists range and encourage motorists to ride their bike to work, to visit friends, or go shopping. The overall project will be completed in three phases.

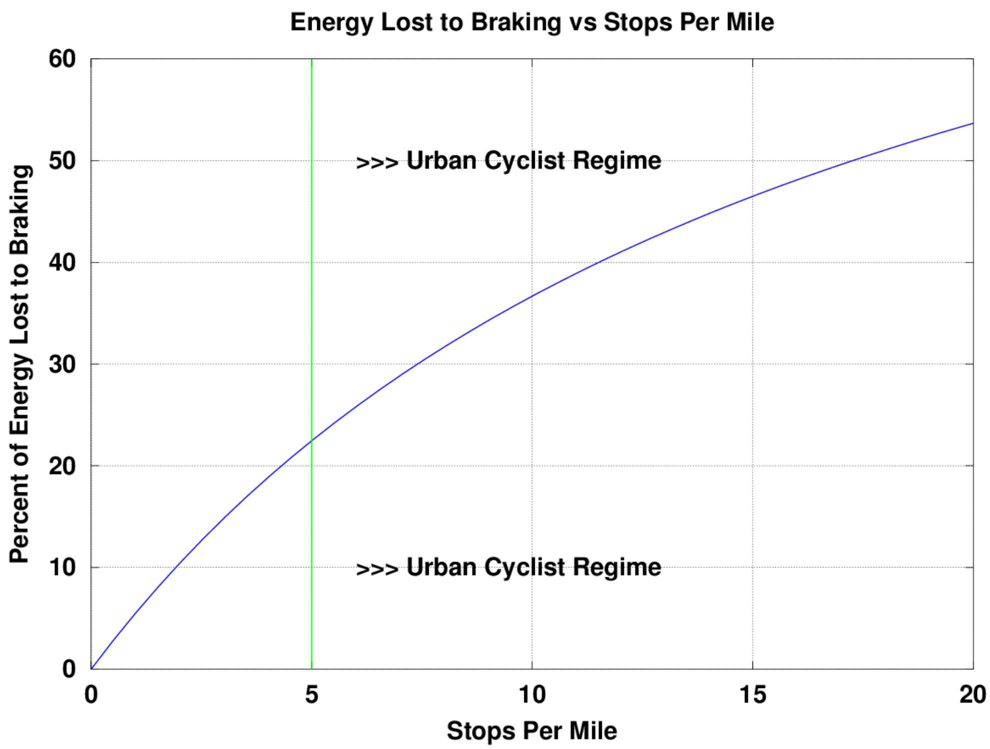
Phase 1: Flywheel Energy Storage Unit Development

Phase 2: Flywheel Energy Storage Transmission Development

Phase 3: Integration of the Flywheel Energy Storage Unit and Transmission into a Bicycle Drive

To stay with in the timing requirements for the grant project, we will only be focusing on developing the Flywheel Energy Storage Unit (FESU) in *Phase 1*, which concludes with the testing of the FESU in a test fixture. Through theoretical calculations and testing, we will determine an optimized flywheel design, including material, mass, diameter, and RPM required for efficiently recovering and storing energy for our Flywheel Bicycle application. A preliminary feasibility study using calculations, researching materials, and developing CAD models helped us formulate a working concept for the FESU design.

The preliminary study started with the question, "How much energy can a cyclist save with a flywheel energy storage unit?" We found that cyclists could recover up to 50% of their energy output that's normally wasted as heat by the brakes by storing it in the FESU. When braking on a conventional bicycle, kinetic energy from the motion of the bicycle is entirely wasted as heat energy, but with a FESU, kinetic energy of the cyclist can be transformed into rotational energy, slowing down the bicycle while also storing energy for later use. A cyclist is constantly losing energy to braking, aerodynamic drag, and rolling resistance of the tires, but the FESU can recover the part of that energy that would be wasted on brakes. It turns out that with as few as 5 stops per mile, or one stop every 1000 ft, energy lost to the brakes accounts for 22% of the energy exerted to drive the bicycle (see Figure (1)). Moreover, if the bicycle makes 17 stops per mile, or stopping every 310 ft (i.e. city and neighborhood blocks), the energy lost to brakes accounts for 50% of the total energy the cyclist needs to exert! From these results, it's clear that cyclists in urban cycling situations, that require frequent stops, can benefit greatly from the FESU.



Figure(1). Percentage of energy lost to braking

After establishing that the FESU could make a real difference in the way people bicycle, we continued to look at feasibility for flywheel rotor materials. The rotor material needs to be easy to work with, lightweight, affordable, and safe. After considering these factors, we decided that the material for the major components in the project will be high strength 7000 series aluminum. Table (1) shows some of the materials that we considered in our preliminary study. Lightweight, low density, materials like aluminum are known to produce the most effective flywheels. While aluminum is denser than composites like carbon-epoxy, it is much easier to design and fabricate aluminum parts. The more affordable cost of the raw aluminum would make the product accessible to a broad market. Additionally, our calculations show that the material strength has a sufficiently high safety factor to ensure safe operation based on the rotations per minute (RPM) that the rotor would experience at full energy storage capacity. We estimated that to convert the kinetic energy of a cyclist at 20 MPH entirely into rotational energy, the rotor would spin at approximately 4000 RPM. A 7075 Aluminum rotor would be nearly 23 times stronger than the centripetal forces it would experience, ensuring safe operation.

Material	Yield Strength (MPa)	Density (kg / m^3)	Strength Per Weight (MPa m^3 / kg)	Rotor Mass (kg)	Material Safety Factor at 4000 RPM	Approx. Price per Pound	Raw Material Cost Per Rotor
CrMo 4130	480	7850	0.061	8.184	21.8	$0.45	$8.10
6061 Aluminum	241	2700	0.089	2.815	10.9	$1.36	$8.42
7075 Aluminum	503	2810	0.179	2.929	22.8	$1.50	$9.67
Carbon-Epoxy	1600	1600	1.000	1.668	72.5	$28.20	$103.48
E-Glass-Epoxy	1500	2570	0.584	2.679	68	$1.33	$7.82
Titanium	830	4430	0.187	4.618	37.6	$8.60	$87.37

Table (1). Flywheel rotor materials considered in the preliminary study

Wrapping up the preliminary study, we looked into development of CAD models. Figure (2) shows the CAD model with the FESU parts completely assembled. On the exterior of the FESU, you can see the blue and green parts that make up the rotor housing. The rotor housing surrounds the flywheel rotor and ensures that the cyclist is protected from the high speed rotation of the rotor. To transfer power to and from the flywheel, the CAD view has a red drive shaft at the center of the model. The drive shaft will be constructed out of stainless steel due to its strength, resistance to corrosion, and its galvanic compatibility with aluminum alloys. Around the drive shaft is a gray cap plate that holds and protects some of the internal components including seals and hybrid-ceramic bearings.

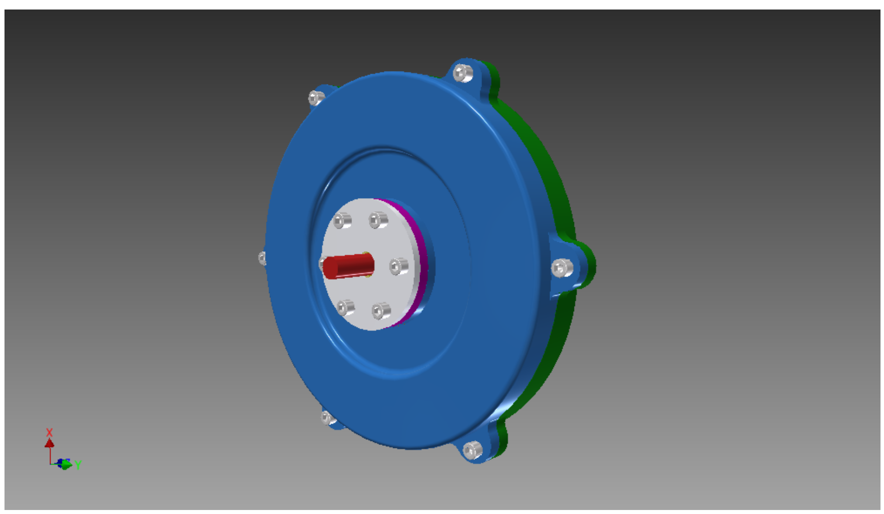


Figure (2). The FESU CAD concept in a fully assembled view

Taking a look inside the housing with the “exploded view” in Figure (3) we can see all of the components. Behind the gray cap plate, there is a set of seals (yellow and gray) and bearings (gold) which fit around the drive shaft. The hybrid-ceramic bearings reduce friction on the rotation of the flywheel and also help prevent vibration by keeping the rotor on its axis. Seals around the bearings help keep dirt and rain from getting into the precision machined parts of the FESU. There is also a purple collar around the bearing that rigidly constrains the bearing. Lastly, the gold flywheel rotor is the heart of the FESU. The rotor is what actually stores the energy by using its RPM and something called rotational inertia. More rotational inertia means the flywheel can store more energy per RPM. To maximize that inertia while keeping the rotor lightweight, the majority of the mass of the rotor is near its perimeter as shown by the thick ring on the outer edge of the rotor.

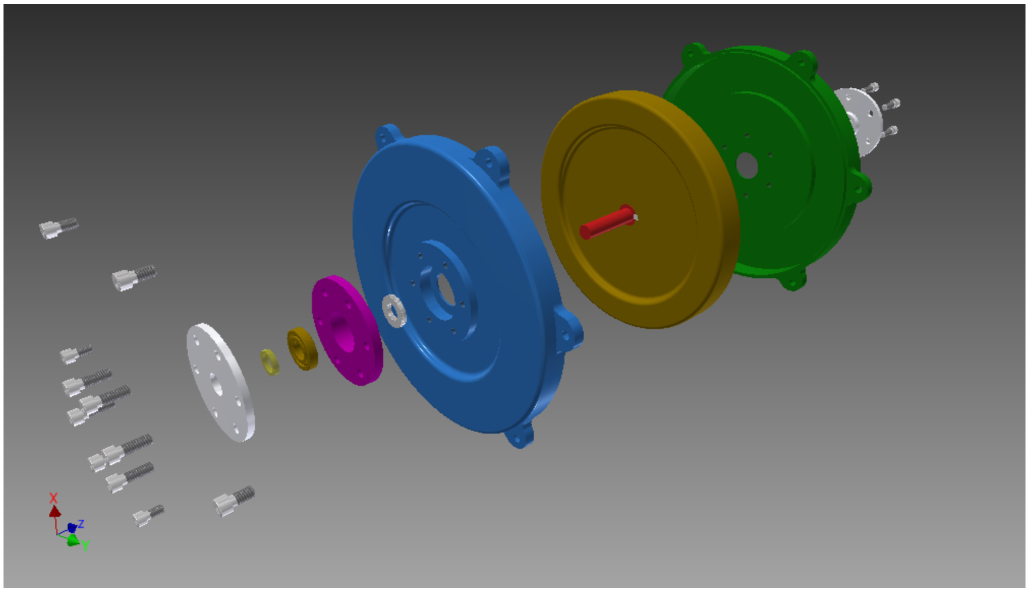


Figure (3). The FESU CAD concept in an "exploded" view

The CAD model, combined with the material analysis and energy analysis gives a good picture of the design and manufacturing challenges ahead of us. We learned that the flywheel rotor needs to spin up to 4000 RPM and that we can achieve that safely and affordably with 7075 Aluminum. Most of all, we showed that the FESU has potential to change they way urban cyclists get around by storing up to 50% of the energy they would normally lose to brakes!

C. Describe how the applicant's team is organized and how the Team will proceed with work on the proposed project

The team is a group of i3Detroit members who are excited by the opportunity to build a flywheel bicycle using the Tormach CNC mill. Once the grant is secured, the team would designate a leader to help manage key activities, ensure goal achievement and maintain contact with EDSFUND representatives. The team will be organized into the following focus areas: fundraising, scientific research, design, and machining. Members will share workload based on skillsets while leveraging the know-how of the i3 membership (counting more than 100 strong) to help overcome challenges.

<u>List of Key Team Members</u>

Konrad Brown - Cyclist, Engineer, Machinist
Ken Siegner - Engineer, Fabricator, Machinist
Derek Kuschel - Engineer, Fabricator, Machinist
Joe Zakar - Engineer, Designer, Machinist

Nate Warnick - Engineer, Maker, Designer
Jim Kemp - CNC Mentor, CNC Programmer, i3Detroit CNC Zone Warden
Tom Kim - Engineer, Machinist

D. Define the role of Tormach equipment in achieving the project goal

The Tormach CNC mill and supporting tooling will play a major role in processing raw material into the custom designed components required for the project. Many of the components will be designed uniquely for the FESU and can not be purchased at the local hardware store or from an online distributor. The Tormach CNC mill will be the workhorse that will get the project done. With the addition of a 8” rotary indexing table to the CNC mill, we can bring our designs to reality through 4-axis CNC milling, a capability not currently available at i3Detroit. The precision of use of the Tormach mill will allow us to build a reliable and efficiently designed FESU. Furthermore, the robust and easy-to-learn nature of Tormach CNC will amplify the team’s capability to manufacture the FESU as some of the team members learn how to use a CNC machine for the first time.

Capability for 4-axis milling will make it possible to machine details necessary for the rotating parts of the FESU, such as keyways on drive shafts, bearing mounts, and gear teeth. Additionally, cutting a precision balanced flywheel rotor, for high RPMs can be done more accurately and more easily using the rotary indexing table, compared to 3-axis milling.

The Tormach CNC with rotary table is capable of cutting the flywheel rotor to the kind of tight tolerances needed for high RPM. The formula for centripetal force is $F = mr\omega^2$ where *m* is the rotor mass, *r* the distance from the rotor’s center of gravity to the rotor’s axis of rotation, and ω is the rotational speed in radians per second (420 rad./sec. ≅ 4000 RPM). Because the centripetal force increases with ω^2, the force can be quite large at 4000 RPM, causing undesirable and inefficient vibrations. We can minimize vibrations by taking advantage of the Tormach CNC’s capability to make high precision cuts and minimize *r*, keeping the rotor’s center of gravity to within 0.001” of the axis of rotation.

Our team’s research into Tormach equipment has showed us that the Tormach CNC mills are robust and easy to learn compared to other CNC options. We gathered information through online forum discussions, conversations with i3 members that have used Tormach CNCs, and phone calls with Tormach instructors at TechShop Detroit. All of these sources tended to tell us that a Tormach CNC would be an excellent tool to grow the community of i3 members with knowledge of CNC machine setup and operation.

The Tormach equipment proposed for the grant project will expand i3Detroit’s capability allowing us to make parts that we could not otherwise machine at i3. The Tormach CNC’s ability to hold high precision tolerances is crucial to meeting the RPM needs of the flywheel of the FESU. Finally, in the process of making the FESU, team members will learn and gain experience with CNC machining, enriching the i3Detroit community

E. Provide a project timeline

A graphical timeline is attached to the last page of this grant proposal.

Tormach Grant Project	**354.38 d**	**Wed 4/15/15**	**Fri 4/15/16**
Submit Grant Application	0 days	Tue 3/31/15	Tue 3/31/15
Notification of Grant Award	0 days	Wed 4/15/15	Wed 4/15/15
Fundraising	115 days	Wed 4/15/15	Wed 8/12/15
Performance Analysis of Key Parameters	45 days	Wed 4/15/15	Sat 5/30/15
Design for Manufacture and CAD Design	90 days	Mon 6/1/15	Tue 9/1/15
Purchased Component Sourcing	20 days	Mon 6/1/15	Sat 6/20/15
Purchase Tormach CNC and tools	0 days	Wed 8/12/15	Wed 8/12/15
Order Materials and Components	10 days	Wed 8/12/15	Sat 8/22/15
Tormach Shipping	10 days	Wed 8/12/15	Sat 8/22/15
Tormach Installation	5 days	Sat 8/22/15	Thu 8/27/15
Raw Materials Received	0 days	Fri 8/21/15	Fri 8/21/15
Design Freeze	0 days	Fri 8/21/15	Fri 8/21/15
First Chips, Trial Machining, Troubleshooting	65 days	Fri 8/21/15	Tue 10/27/15
Trial Assembly	10 days	Tue 10/27/15	Fri 11/6/15
Optimization of Manufacturing and Engineering Changes	40 days	Fri 11/6/15	Fri 12/18/15
Final Machining	30 days	Fri 12/18/15	Mon 1/18/16
Design Testing Fixture to Test Prototype Flywheel Performance	45 days	Mon 1/18/16	Fri 3/4/16
Build Testing Fixture	30 days	Fri 3/4/16	Tue 4/5/16
Special Processing (precision balancing, defect analysis)	35 days	Mon 1/18/16	Tue 2/23/16
Final Assembly	15 days	Wed 2/24/16	Thu 3/10/16
First Prototype Flywheel Completed	0 days	Thu 3/10/16	Thu 3/10/16
Install Flywheel on Test Fixture	1 day	Thu 3/10/16	Fri 3/11/16
Test Flywheel Performance	30 days	Fri 3/11/16	Mon 4/11/16
Write Final EDSFUND report	34 days	Fri 3/11/16	Fri 4/15/16

F. Provide a specific list of the Tormach equipment to be purchased with the EDSFUND award

i3Detroit Tormach Grant Shopping List		
Tormach CNC Mill and Tools		**Notes**
PCNC 1100 Series 3 w/ Auto Oiler	$ 8,706.00	
PCNC 1100 Deluxe Machine Stand w/ Coolant Pump	$ 1,645.00	
PCNC 1100 Power Draw Bar	$ 1,193.50	
8" Rotary 4-axis	$ 1,447.11	
3 Jaw Chuck for 8" Table	$ 310.20	
Commercial w/out Dock, w/ Liftgate	$ 383.00	
Tormach Shopping Cart Total	$ 13,684.81	
EDSFUND.ORG Grant Funds	$ 5,473.92	
i3Detroit Tormach Matching Funds	**$ 8,210.89**	
Moving and Installation Costs		
Fork Truck Rental	$ -	Borrow from our neighbor B-Nektar
Wire / Liquid Tight / Bulkheads	$ 100.00	
Disconnect / J-box / Fuses	$ 100.00	
Labor	$ -	i3 licensed volunteers
Additional Costs		
Mach3 License	$ 175.00	
Computer	$ -	Donated by Members
Kurt Vise	$ -	Donated by Jim K.
Collets, Table Clamps	$ -	Already have them
Cutters	$ -	Donated by local cutter suppliers
i3Detroit Total Funds Needed	**$ 8,585.89**	

G. Describe how the Project Team will interact with EDSFUND throughout the project, and how the Project Team will make a final report

The project progress will be documented through blog posts, video logs, and pages on the i3Detroit wiki (www.i3detroit.org/wiki), followed by a final written report delivered to EDSFUND. The final report will be provided as a compilation of key video logs throughout the project, as well as a written report that includes milestones achieved, challenges faced, and testing results from the completed FESU in a test fixture. The team leader will be in charge of correspondence with EDSFUND.

H. Matching Funds And Letter of Support

The matching funds for the Tormach equipment will be covered by contributions from the i3Detroit Budget, member out-of-pocket pledges, and donations sought from individuals and corporations. While i3Detroit is financially capable of matching funds for the Tormach equipment entirely from the i3Detroit budget, the organization has historically funded new tools with pledges from the members who are very interested in having the the new tool at the makerspace. In addition, corporate donations have been used to fund new tools.

Past examples of tool funding includes i3Detroit's Millermatic 212 MIG welder, and G. Weike LC1280 Laser Cutter. The Millermatic 212 was funded by $1000 of member pledges, and $1600 covered by the i3Detroit budget. The LD1280 Laser Cutter was funded by $6080 of member pledges, $300 of i3Detroit budget, and $1000 donated by Eaton Corporation.

Our team will leverage member pledges, online crowdsource funding, past donors, and fundraising at public events to cover the bulk of the matching funds required for the Tormach equipment. This is a proven approach to funding makerspace improvements that has worked well for i3Detroit.

Please also see the next page for a letter of support from i3Detroit's board of directors and the CNC Zone warden.

Imagine, Innovate & Inspire

1481A Wordsworth St.
Ferndale, MI 48220

March 22nd, 2015

Dear EDSFUND Reviewers,

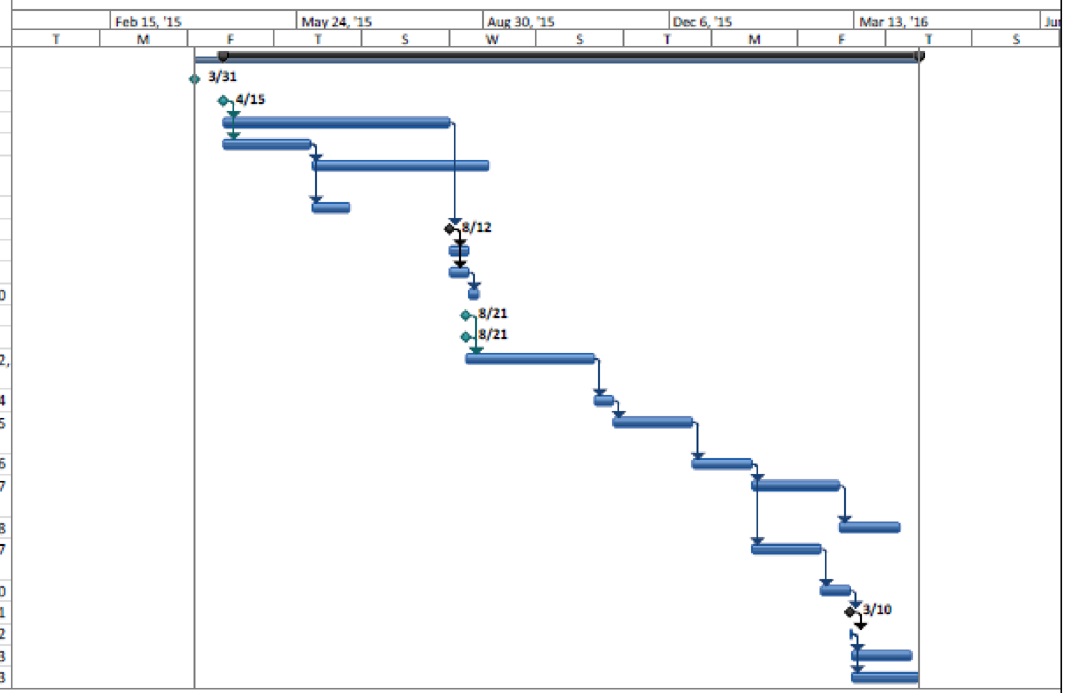
The i3Detroit Board of Directors and i3Detroit CNC Zone Warden wholeheartedly support this EDSFUND grant proposal submission by Ken Siegner and Konrad Brown. The Tormach equipment planned in the proposal will be a welcome addition to the CNC Zone at i3Detroit, and Ken and Konrad have approval to fundraise donations for the remainder of the equipment costs as representatives of i3Detroit. We have high esteem in their imaginative and technical capabilities, and in their ability to complete the obligations of the grant with excellence.

Sincerely,

Mike Fink
Director
I3Detroit

James Kemp
CNC Zone Warden
i3Detroit

ID	Task Mode	Task Name	Duration	Start	Finish	Pre
1		**Tormach Grant Project**	**354.38 d**	**Wed 4/15/15**	**Fri 4/15/16**	
2		Submit Grant Application	0 days	Tue 3/31/15	Tue 3/31/15	
3		Notification of Grant Award	0 days	Wed 4/15/15	Wed 4/15/15	
4		Fundraising	115 days	Wed 4/15/15	Wed 8/12/15	3
5		Performance Analysis of Key Parameters	45 days	Wed 4/15/15	Sat 5/30/15	3
6		Design for Manufacture and CAD Design	90 days	Mon 6/1/15	Tue 9/1/15	5
7		Purchased Component Sourcing	20 days	Mon 6/1/15	Sat 6/20/15	5
8		Purchase Tormach CNC and tools	0 days	Wed 8/12/15	Wed 8/12/15	4
9		Order Materials and Components	10 days	Wed 8/12/15	Sat 8/22/15	8
10		Tormach Shipping	10 days	Wed 8/12/15	Sat 8/22/15	8
11		Tormach Installation	5 days	Sat 8/22/15	Thu 8/27/15	10
12		Raw Materials Received	0 days	Fri 8/21/15	Fri 8/21/15	
13		Design Freeze	0 days	Fri 8/21/15	Fri 8/21/15	
14		First Chips, Trial Machining, Troubleshooting	65 days	Fri 8/21/15	Tue 10/27/15	12,
15		Trial Assembly	10 days	Tue 10/27/15	Fri 11/6/15	14
16		Optimization of Manufacturing and Engineering Changes	40 days	Fri 11/6/15	Fri 12/18/15	15
17		Final Machining	30 days	Fri 12/18/15	Mon 1/18/16	16
18		Design Testing Fixture to Test Prototype Flywheel Performance	45 days	Mon 1/18/16	Fri 3/4/16	17
19		Build Testing Fixture	30 days	Fri 3/4/16	Tue 4/5/16	18
20		Special Processing (precision balancing, defect analysis)	35 days	Mon 1/18/16	Tue 2/23/16	17
21		Final Assembly	15 days	Wed 2/24/16	Thu 3/10/16	20
22		First Prototype Flywheel Completed	0 days	Thu 3/10/16	Thu 3/10/16	21
23		Install Flywheel on Test Fixture	1 day	Thu 3/10/16	Fri 3/11/16	22
24		Test Flywheel Performance	30 days	Fri 3/11/16	Mon 4/11/16	23
25		Write Final EDSFUND report	34 days	Fri 3/11/16	Fri 4/15/16	23



Project: TormachProject_v2
Date: Tue 3/31/15

Task		Project Summary		Inactive Milestone		Manual Summary Rollup		Deadline	
Split		External Tasks		Inactive Summary		Manual Summary		Progress	
Milestone		External Milestone		Manual Task		Start-only			
Summary		Inactive Task		Duration-only		Finish-only			