TECHNICAL REVIEWERS' RATING SUMMARY

R028-A

Solar Soaring Power Manager (Phase III)

Packet Digital, LLC

Principal Investigator: Andrew Paulson

Request for $375,000; Total Project Costs $1,000,000

Rating Category	Weighting Factor	Technical Reviewer 1A	2A	3A	Average Weighted Score
		Rating			
1. Objectives	9	5	3	3	33.00
2. Achievability	9	3	2	2	21.00
3. Methodology	7	4	1	5	23.33
4. Contribution	7	5	2	4	25.67
5. Awareness	5	2	2	4	13.33
6. Background	5	5	4	5	23.33
7. Project Management	2	3	3	4	6.67
8. Equipment Purchase	2	5	5	5	10.00
9. Facilities	2	5	5	5	10.00
10. Budget	2	5	5	5	10.00
Average Weighted Score		206	132	191	**176.33**
Maximum Weighted Score					**250.00**

OVERALL RECOMMENDATION

FUND	x		x
FUNDING MAY BE CONSIDERED		x	
DO NOT FUND			

R028-A
Solar Soaring Power Manager
Submitted by Packet Digital, LLC
Principal Investigator: Andrew Paulsen
Request for $375,000; Total Project Costs $1,000,000

1. The objectives or goals of the proposed project with respect to clarity and consistency with North Dakota Industrial Commission/Renewable Energy Council goals are: 1 – very unclear; 2 – unclear; 3 – clear; 4 – very clear; or 5 – exceptionally clear.

Reviewer 1A (Rating: 5)
The goals are exceptionally clear. Highly efficient solar energy applied to an airborne device that can have very long endurance and carry payloads that support the agricultural and natural resource wealth of North Dakota are exceptionally beneficial to the North Dakota economy. If the intellectual capital to make those devices resides in North Dakota, it will bring jobs and economic expansion.

Reviewer 2A (Rating: 3)
- The goal of the Phase III project is to complete the system test and integration of the solar power system UAS, enabling long flight duration. Also included in the Phase III is the development of a manufacturing plan for the extended endurance solar UAS. Both are important steps in realizing potential translation to manufacturing that then create a pathway to economic impact.
- There are various applications relevant to ND (particularly in agriculture) that the UAS would have an impact on, potentially resulting in an increased use of renewable solar powered propulsion.
- While 20 to 25 individuals are to be employed during the project, there is no indication or estimate of long-term value to jobs beyond the project duration.
- The team notes that the 40% efficient cell being targeted would have widespread value to many application, though this is revealed to be misleading given that the team notes they are not cost competitive for many applications.

Reviewer 3A (Rating: 3)
Clear objectives. What's a bit less clear is how this is a fit with the REC goals. Beyond the 20 FTEs to be hired as part of this project it is unclear how this creates a large, sustainable renewables-based industry. This is a smart idea and a worthy effort, to be clear. However, the logical outcome even if this project is successful would be a UAV manufacturing effort outside of ND and a market that is mostly outside of ND. That said, it's a worthy effort and does have application for ND, so I didn't want to penalize it unduly here.

2. With the approach suggested and time and budget available, the objectives are: 1 – not achievable; 2 – possibly achievable; 3 – likely achievable; 4 – most likely achievable; or 5 – certainly achievable.

Reviewer 1A (Rating: 3)
The proposal suggests that the next increment of $1M will develop a manufacturing plan for a commercially viable extended endurance UAS. Within some degree that is possible, however the plan lacks clarity in what they mean by "commercially viable". A manufacturing plan for an immature design is of marginal utility, and this design is still undergoing changes—an example is what sort of solar cells to use (they alternately propose a high efficiency solar cell, and then a more 'commercially viable' cell with less efficiency). There isn't an explicit mention of which sort of payload would be carried in the 'commerically viable" design. The payload will take size, weight, and power. The proposal suggests the air vehicle system will have integrated and optimized power management, but with no payload choice (and the same integration and optimization would need to be done on the payload for a balanced design) it is difficult for me to say a description of commercially viable is forthcoming.

Reviewer 2A (Rating: 2)
- All aspects of the project, outside of the solar cell/wing development, are budgeted properly and have shown a trajectory through Phases I and II that indicate they will meet their objectives in the proposed Phase III.
- The solar cell/wing development is not likely to meet the objectives of the project within the timeline. As discussed in more detail in (3) below, the team has revealed the the MJ solar cells it has been developing are too costly for the application. It has decided to turn to commercially available crystalline silicon (c-Si) solar cells, but these are rigid have typical manufacturing efficiencies of only half the targeted 40% efficiency goal of this project. Thus, it is unlikely, at best, that the team will realize the project goals using commercial c-Si solar cells over the Phase III effort.
- The proposed budget is sufficient and appropriate for the project.

Reviewer 3A (Rating: 2)
This is a complex project – I would have liked to have given multiple grades here for the various aspects. The power management and UAV design aspects seem feasible given analogous already-developed technologies that are available and the background of the responsible parties in this project. The solar cell development effort is the one that gives me significant pause. New high-efficiency solar cell technology is simply not easy to develop, much less make the kinds of efficiency gains projected here, in the one-year timeframe projected.

The caliber of the researcher involved is high, so this is not impossible. However, what I believe is much more likely is that the development of the necessary high-efficiency PV solutions will take longer than the other aspects of the project. Fortunately, from what's provided in this proposal it seems like even a shorter-duration UAV would still be a valuable step forward.

3. The quality of the methodology displayed in the proposal is: 1 – well below average; 2 – below average; 3 – average; 4 – above average; or 5 – well above average.

Reviewer 1A (Rating: 4)
While the idea, engineering framework, and clever technology are clearly above average, the systems engineering approach has not apportioned design attributes for a meaningful payload or payloads. A long endurance air vehicle that does not perform a function is not useful. It

doesn't produce and outcome just by existing in the air. It must perform a task which would require some sort of payload. Another weakness in the proposal (but an improvement from phase II) is the small mention of extended flight in national airspace. The FAA will govern flight options of the vehicle they describe, and no size, weight, power or other design attributes are apportioned. (what I mean is, if I were designing this device I would have size, weight, and power of the air vehicle apportioned for the necessary airspace functions). This keeps the proposal from the highest rating.

Reviewer 2A (Rating: 1)
- While the NRL team has made progress in its MJ cells, now reaching 33% efficiency, solar-wing level efficiencies are only at 27%. This is far short of the 40% target of the program.
- The team indicates that the MJ cells it has been developing in the first two phases of the project are not cost viable, and will "only be viable in markets that can tolerate the high price." This is very disappointing since a back of the envelope cost should have been undertaken in Phase I, quickly coming to this conclusion. A good portion of the time and cost/cost-share of the project to date has been focused on the MJ solar cell development and implementation onto a solar-wing. To discover that the approach is not cost viable so late in the project is rather concerning since those resources should have been applied towards more cost effective alternatives.
- Task 2 of the Phase III project aims to look towards commercially available crystalline silicon (c-Si) solar cells. Though these currently enjoy over 90% market share of PV, such cells are ~150 micron thick rigid cells that are not conformal. An extremely limited number of companies have worked on thin c-Si cells that are partially flexible, but these do not enjoy the same efficiency, cost, and availability as their conventional commercial counterparts. Thus, the team's decision to look towards c-Si cells as a replacement is not an appropriate route in the stated timeline, and will certainly struggle to reach more than half of the targeted 40% efficiencies for the UAS wing array.
- Methodologies associated with the other elements of the project (storage, algorithms, etc.) are more logical and appropriate.

Reviewer 3A (Rating: 5)
This is a rigorous effort being undertaken by a collection of researchers and vendors with the background to accomplish most of the methodology laid out here.

4. The scientific and/or technical contribution of the proposed work to specifically address North Dakota Industrial Commission/Renewable Energy Council goals will likely be: 1 – extremely small; 2 – small; 3 – significant; 4 – very significant; or 5 – extremely significant.

Reviewer 1A (Rating: 5)
The integration of technologies is often overlooked as a contribution to science. Many scientific discoveries take years to benefit a population, ease burdens, or become profitable. The clever fusion of the several significant scientific breakthroughs (active power management, 40% efficient solar cells, software algorithms for soaring, etc…) is extremely significant.

Reviewer 2A (Rating: 2)
- If not for the current FAA limitation of 400ft for UAS craft, the soaring algorithm development would likely be valuable in enhancing the flight times for commercial applications. The new indication that the NRL MJ cells are not economically viable for such applications has significantly reduced the original potential value of the project since there currently does not seem to be a viable pathway towards mitigation within the time frame of the Phase III effort. It appears likely that the proposed Phase III will not result in a manufacturing ready design for a solar UAS that can be then translated into manufacturing. Thus, limited economic impacts are expected from the proposed work.

Reviewer 3A (Rating: 4)
The pursuit of the PV and flight objectives, even if ultimately it takes longer than projected here, will still provide valuable scientific/technical progress.

5. The principal investigator's awareness of current research activity and published literature as evidenced by literature referenced and its interpretation and by the reference to unpublished research related to the proposal is: 1 – very limited; 2 – limited; 3 – adequate; 4 – better than average; or 5 – exceptional.

Reviewer 1A (Rating: 2)
There is very little reference made to a survey of current research activity. Collaborator goals are clear, but not contrasted with competing ideas from industry, academia, and government laboratories.

Reviewer 2A (Rating: 2)
- There were no references to external works in the narrative.
- References were made to NRL MJ cell results, but there were no listed publications to provide verification of such results, nor any technical data/figures/images showing the listed accomplishments.
- Limited to no unpublished research data was provided.

Reviewer 3A (Rating: 4)
I only marked down because there wasn't very much discussion about the very deep external efforts underway in multiple other places to also produce high efficiency solar technologies. This is actually good news as the objectives here around UAV flight duration could probably benefit from external innovations as well. So the mark-down is only to reinforce the "awareness" aspect of this question.

6. **The background of the investigator(s) as related to the proposed work is: 1 – very limited; 2 – limited; 3 – adequate; 4 – better than average; or 5 – exceptional.**

Reviewer 1A (Rating: 5)
An easy google search corroborates their previous contributions. The science they are pursuing is not beyond what they've already contributed—it is just a new application.

Reviewer 2A (Rating: 4)
- Based on the Phase I and Phase II progress, the team is very capable and current in its respective fields. The solar soaring algorithms and power management system developments from the team indicate that it capable of successfully realizing the project tasks.
- NRL has a history of MJ cell development and has demonstrated its expertise in this area.

Reviewer 3A (Rating: 5)
Deep roster of collaborators, all of whom seem to be deeply experienced in their specific aspects of the project. Impressive group.

7. The project management plan, including a well-defined milestone chart, schedule, financial plan, and plan for communications among the investigators and subcontractors, if any, is: 1 – very inadequate; 2 – inadequate; 3 – adequate; 4 – very good; or 5 – exceptionally good.

Reviewer 1A (Rating 3)
The timetable on page 14 of 15 is a little confusing. The tasks are clear in singular, but why full system integration finishes before a subcomponent (lower cost solar wing integration) is probably an error. The number of hours called out for each task is reasonable.

Reviewer 2A (Rating: 3)
- A general Gantt chart for Phase III tasks was provided, showing the timeline for each of the project tasks.
- Specific milestones were not included, making it difficult to assess when some tasks are to be considered complete. For example, NRL flight testing is to be carried out, but it is not clear what metrics are to be tested, nor what targets are to be demonstrated.
- The budget table is rather high level. Based on the NRL cost share level, the project seems almost like a NRL project rather than being primarily a Packet Digital led project. Some granularity on how the NDIC funding will be allocated across team partners would have been valuable.
- Also valuable would have been an indication of which tasks each of the partners (there are more than 6) is to participate in.

Reviewer 3A (Rating: 4)
I've mentioned my concerns above around the PV cell technology development. So here I'm marking a score based upon the overall project effort, which seems feasible given the prior progress made by this team on this project.

8. **The proposed purchase of equipment is: 1 – extremely poorly justified; 2 – poorly justified; 3 – justified; 4 – well justified; or 5 – extremely well justified. (Circle 5 if no equipment is to be purchased.)**

Reviewer 1A (Rating: 5)
Note, while no equipment purchases were called out, software costs were noted. There was not enough data for me to exercise judgement.

Reviewer 2A (Rating: 5)
- Based on the provided budget, It appears that no equipment is to be purchased in Phase III.

Reviewer 3A (Rating: 5)
There seems to be a strong effort here to leverage existing resources rather than acquire new equipment.

9. The facilities and equipment available and to be purchased for the proposed research are: 1 – very inadequate; 2 – inadequate; 3 – adequate; 4 – notably good; or 5 – exceptionally good.

Reviewer 1A (Rating: 5)
The use of a local UAS test range for a fly-fix-fly iteration is a key attribute supporting their costs and tight 12-month schedule.

Reviewer 2A (Rating: 5)
- The team has all necessary equipment and infrastructure to carry out the Phase III tasks, as evidenced by its successful efforts in the first two phases.

Reviewer 3A (Rating: 5)
Per the earlier comment about the team, part of what makes them impressive is their access to appropriate existing resources and facilities.

10. The proposed budget "value"[1] relative to the outlined work and the financial commitment from other sources[2] is of: 1 – very low value; 2 – low value; 3 – average value; 4 – high value; or 5 – very high value. (See below)

Reviewer 1A (Rating: 5)
Cost shares spread interest to all parties, and meets the stated rubrics for funding a minimum of 50% from outside sources.

Reviewer 2A (Rating: 5)
- The team has proposed a ~63% cost share for the $1M project, measurably surpassing the required 50% to the $375k in funding requested.

Reviewer 3A (Rating: 5)
The co-investment from NRL is significant and represents a good opportunity for ND dollars to be leveraged in support of good research and innovation.

[1] *"Value" – The value of the projected work and technical outcome for the budgeted amount of the project, based on your estimate of what the work might cost in research settings with which you are familiar.*

[2] *Financial commitment from other sources – A minimum of 50% of the total project must come from other sources to meet the program guidelines. Higher priority is to be given if the application has private industry investment equal to or at least 50% or more of total cost.*

Section C. Overall Comments and Recommendations:

Please comment in a general way about the merits and flaws of the proposed project and make a recommendation whether or not to fund.

Reviewer 1A ***(Fund)***
I recommend funding.

First, I would ask the council to seek legal views on the distribution of intellectual property. While the final statement on the proposal says basically that the company retains all rights for patents, at the very least some of the interface connections were not funded by the company. If rights to the interfaces between major components were retained by the state, future good ideas could be sought and connected/exchanged if an 'open systems architecture' was retained. I think the State of North Dakota should get some intellectual property rights for funding this high risk endeavor.

Second, some of the claims were embellished. Saying 20-25 people would be supported is only true if one assumes partial activity (ie. they don't work a full year). Regardless, it is still a worthy proposal to see if the integration of technologies can yield a new device!

Reviewer 2A ***(Funding May Be Considered)***
The project has made great progress in its first two Phases on the solar souring power management system. A critical flaw in the project is the new admission that the multi-junction cells that have been the focus of the NRL work are not cost viable for commercial UAS application. One would have expected this to be determinable in the first phase of the project, so it is disappointing that the team has brought this to life at such a late stage in the work. The proposed pivot towards commercial crystalline silicon cells as a more viable cost competitive replacement is not ideal since such cells fall considerably short of the efficiency targets of this proposed program and are generally not based on flexible or conformal formats. Thus, even if the 20% efficiency of c-Si cells was acceptable, there is still a significant hurdle to make them compatible for conformal application to a UAS wing. Some very limited flexible c-Si cells exist, but these are far from the requisite efficiency the team has targeted, and certainly not as cost competitive as their commercial counterparts that are rigid.
Another external factor that has considerably reduced the project value is the FAA limit of 400ft for UAS vehicles. This has removed the possibility to implement the solar souring algorithms that the team has developed to significantly increase flight times. In effect, this now limits the value of the project to offsetting of non-renewable fuel sources. Overall, the project has realized several of its system goals, but the major issues in the solar cell cost and performance will likely prevent the project from realizing any measurable economic impact after the Phase III effort.
As a result, I do not recommend this project for funding. Despite good progress on the souring power management system in the first two phases, the major setback of cost viability of the MJ solar cell and FAA imposed 400ft limit considerably limit the value of the project in meeting the NDIC goals. Should the team be able to articulate specifically what jobs will be created and sustained beyond the Phase III, along with what lasting economic impacts are likely, even if the solar cell development is limited to 20% efficiency with rigid cells, then perhaps it might make a

case for receiving the requested funds. Without such a strong case, it does not seem the project value is sufficient to justify funding of Phase III.

Reviewer 3A ***(Fund)***
While I have concerns around the feasibility of the solar PV development efforts in this timeframe, and the indirectness of the fit here for ND in particular, it's a worthy effort being led by an impressive team of collaborators. I recommend funding the effort.