

TECHNICAL REVIEWERS' RATING SUMMARY

R035-A

Preparation of Graphene-Modified LifePO₄

Cathode for Li-Ion Battery

University of North Dakota

Principal Investigator: Xiaodong Hou

Request for \$238,366; Total Project Costs \$486,238

<u>Rating Category</u>	<u>Weighting Factor</u>	Technical Reviewer			<u>Average Weighted Score</u>
		<u>1A</u>	<u>2A</u>	<u>3A</u>	
1. Objectives	9	4	5	4	39.00
2. Achievability	9	3	4	3	30.00
3. Methodology	7	3	5	3	25.67
4. Contribution	7	2.5	4	4	24.50
5. Awareness	5	2	5	3	16.67
6. Background	5	3	4	3	16.67
7. Project Management	2	4	5	4	8.67
8. Equipment Purchase	2	4	4	4	8.00
9. Facilities	2	3	4	4	7.33
10. Budget	2	3	5	4	8.00
Average Weighted Score		154.5	225	174	184.50
Maximum Weighted Score					250.00

OVERALL RECOMMENDATION

FUND	x	x
FUNDING MAY BE CONSIDERED	x	
DO NOT FUND		

R035-A
Preparation of Graphene-Modified LiFePO_4
Cathode for Li-Ion Battery
Submitted by University of North Dakota
Principal Investigator: Xiaodong Hou
Request for \$238,366; Total Project Costs \$486,238

- 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: 4)

The objective is to optimize the process to produce LFP/graphene composite, and is clearly stated.

Reviewer 2A (Rating: 5)

The proposal does a very good job of laying out a) the idea; b) why the idea has specific ties to North Dakota; and c) what the likely impact will be for North Dakota

Reviewer 3A (Rating: 4)

The objectives and goals of the proposed work are in accordance with the goals of North Dakota Industrial Commission/Renewable Energy Council. In this proposed project, an economically feasible method is proposed for *in situ* synthesis of graphene-modified LiFePO_4 cathode using the humic acid extracted from leonardite (North Dakota's natural source) as the graphene source. Proposed work could result in low-cost graphene synthesis from leonardite based humic acid, which could help achieving the goals of North Dakota Industrial Commission/Renewable Energy Council.

- 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)

There revised preparation procedure is much more achievable than the previous proposal. The unknown is whether the proposer will obtain the intended small particle size, which will not be known until they try it. It is unlikely to achieve their claim that their procedure of drying/high temperature treatment is superior to spray drying to produce small particles. This comparison is well known in the field for many other materials. Since it is not known yet whether small particle size is critically important, they may still be able to obtain materials that meet their electrochemical performance target.

Reviewer 2A (Rating: 4)

The introduction of any new materials science innovation into commercialization is fraught with challenges, and very often has been subject to major delays and cost overruns. But in this case, the proposal is limited to achievements that should be somewhat within the investigators'

control, being mostly lab- and pilot-stage efforts. So the idea of being able to accomplish these objectives within 8 quarters seems feasible, although still I'm sure with its own challenges.

Reviewer 3A (Rating: 3)

Proposed method for *in situ* synthesis of graphene-modified LiFePO₄ cathode is clear and easy to apply. Furthermore, achieving the humic acid extraction from leonardite seems to be the most challenging task of the proposed project. Proposed time and budget of the project are reasonable.

- 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: 3)

The proposed methodology is not innovative, but is achievable and on solid ground.

Reviewer 2A (Rating: 5)

Compared with many other proposals I see, this one seems very well grounded in detail, pragmatic logistics, and market/tech knowledge.

Reviewer 3A (Rating: 3)

In situ synthesis of the graphene sheets in LiFePO₄ could be considered as a more effective approach compared to graphene coating on LiFePO₄, which requires the synthesis of graphene in advance and additional post-coating process. However, the proposed approach for high-purity and metal-free humic acid extraction from the leonardite is not proven. Implementation of an efficient process for humic acid extraction from the leonardite will be the most critical success factor of the proposed project.

- 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: 2.5)

There is a reasonable chance that this technology will generate material suitable for internal consumption in Clean Republic, so that Clean Republic does not have to pay market price for the cathode material. Whether the product can successfully compete in open market is highly questionable. The proposer has not put forward a convincing technical or economic case for a broad market appeal.

Reviewer 2A (Rating: 4)

The ability to use ND-based resources is key, and the innovations are drawn from local research, which is important. The ability to partner with ND-based manufacturing for early market entry is also a plus, and that has direct impacts on economic benefits as well. I do worry that, as good of a company as Clean Republic seems to be, tethering to them as a business party may inherently limit the applicability of this innovation which would seem to have much broader potential use. But if the intention is that Clean Republic is a launching pad but then the innovation would be licensed with other, bigger manufacturing concerns worldwide, that then makes sense.

Reviewer 3A (Rating: 4)

High-purity and metal-free humic acid extraction from the leonardite for fabricating low-cost graphene is substantially important for specifically addressing North Dakota Industrial Commission/Renewable Energy Council goals.

- 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 little discussion of the broader research activity in this general area of lithium ion battery cathode material, especially with respect to the competitive landscape of related technologies. The ones mentioned are those on the market, not those under development.

Reviewer 2A (Rating: 5)

I learned a lot from the proposal and came away after reading it (and additional secondary research) feeling like the potential here is real. The revisions in the proposal further bolster my rating here.

Reviewer 3A (Rating: 3)

The PI's awareness of current research activity and published literature is adequate for fabrication of high-capacity graphene modified LiFePO_4 cathode materials and synthesis of low-cost graphene using humic acid extracted from leonardite.

- 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: 3)

The proposer does not have experience in electrode material development or introducing new manufacturing capability in battery. Their general technical background is good and should be helpful for this research and development.

Reviewer 2A (Rating: 4)

This is a strong research team with good qualifications, and a local partner in Clean Republic with real world business knowledge. One gap is potentially in large-scale manufacturing – Clean Republic is a downstream customer of cell manufacturers and as such may have limited ability to engage upstream manufacturers around the optimization of the technology. This gap wasn't really addressed in the revised proposal, but I'm not trying to be pessimistic on this score either, just calling it out as an area that will require special attention.

Reviewer 3A (Rating: 3)

The PI and other investigators have enough experience on lithium-ion batteries and LiFePO_4 cathode materials, and their background related to the proposed work is adequate to fulfill proposed tasks.

- 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 4)

The proposer has experience in commercial technology development and commercialization, although for a somewhat different product.

Reviewer 2A (Rating: 5)

Seems pragmatic, as far as early stage research goes. The revised proposal has helped flesh this out.

Reviewer 3A (Rating: 4)

The project management plan is quite clear. A well-defined milestone chart and standards for proposal success are provided. Schedule and financial plan of the proposed project are elaborated significantly. Plan for communication among the investigators is not clear in the proposal.

- 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: 4)

The proposed equipment are needed to conduct the proposed research.

Reviewer 2A (Rating: 4)

They are being smart to minimize the amount of new equipment that must be purchased, utilizing existing equipment and facilities instead. Most equipment to be purchased seems relatively small and re-purposeable.

Reviewer 3A (Rating: 4)

The proposed purchase of equipment is well justified to realize the proposed experimental studies.

- 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: 3)

Together with the requested equipment, the facility is adequate for the proposed work.

Reviewer 2A (Rating: 4)

Seem like well-qualified facilities.

Reviewer 3A (Rating: 4)

The facilities and equipment available and to be purchased for the proposed research seems to be more than adequate to achieve the proposed tasks.

10. The proposed budget “value”¹ relative to the outlined work and the financial commitment from other sources² 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: 3)

If securing another external funding source is successful, this is a good leverage of ND fund. Otherwise, it is unclear what is the leverage.

Reviewer 2A (Rating: 5)

Of particular benefit is the financial support being provided by Clean Republic.

Reviewer 3A (Rating: 4)

The proposed budget is acceptable. The financial commitment from other sources is adequate.

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 (Funding May Be Considered)

The revised research methodology makes the proposed work more likely achievable technically, although the economic estimate is very optimistic. However, it also eliminates much of the innovation. The proposer has made a reasonable case for development for internal consumption to support their current product. Whether this would be successful competing in the open market is unclear, and the case is not strong.

Reviewer 2A (Fund)

This is one of the more impressive proposals I have reviewed. The revised proposal simply bolsters this impression.

Reviewer 3A (Fund)

If successful, the proposed work could ensure better dispersion of graphene in LiFePO₄, which will lead to better capacity and cyclin performance. In addition, the proposed work introduces an economically more feasible method for the fabrication of graphene-modified LiFePO₄ cathode by in-situ synthesis of graphene in LiFePO₄. Effective humic acid extraction from the leonardite is

the most critical task of the proposed project. I would recommend funding this proposed project to support the research studies on optimization of high-purity and metal-free humic acid extraction processes for high-performance graphene-modified LiFePO_4 cathode fabrication.