

Commercializing two-dimensional materials beyond graphene

Graphene is widely studied for potential application in electronics and processing due to its unique electromagnetic and transport properties. Graphene is one member of a class of two-dimensional or layered materials. These materials include *single layer hexagonal boron nitride*, *single-layer transition metal dichalcogenides*, *few-layer topological insulators* (including *stanene*), *silicene*, *germanene*, and their chemical derivatives, to name just a few. Graphene has a massless Dirac electronic dispersion which results in its extremely high electron mobility.

New 2D and layered materials have promising electronic, magnetic, optical, transport, and physical characteristics arising from their physicochemical and geometrical atomic structure that could complement graphene's properties. For example, two-dimensional materials can be easily deformed, which may allow their properties to be tuned by their shape or mechanical conformation. The remarkable characteristics of two-dimensional materials invite interdisciplinary research by chemists, engineers, physicists, mathematicians, biologists, and others which could lead to breakthrough composite materials and yet-to-be-discovered functionalities.

Your CEO is interested in using your company's expertise in nano materials, processing, and devices to develop innovative technologies leading to commercial products that rely on two-dimensional materials beyond graphene. Because the company wishes to be a leader into the marketplace with your new technology, applications related to thermoelectric generation or room temperature superconduction will not be considered for your proposal. Using your background, your job as CTO is to develop an approach to create commercial value that relies on the unique properties of at least one two-dimensional material beyond graphene in support of the company's newly defined strategic plan.

Field-effect transistors and other well-established devices are discouraged in this proposal. What is sought is a disruptive new technology that relies on the unique properties of two-dimensional materials beyond graphene that are not available in commercial or well-studied materials. The company is anticipating this to be a rapidly expanding emergent market in the next five years, so developing cost competitive and practical technologies to create high return on investment for the company is required.

Your job as CTO is to deliver a complete proposal with your plan for the company to compete in this area to your CEO by your Monday morning, March 31st deadline.

YOUR DELIVERABLE

Your task is to write an internal proposal for your corporate officers describing your approach to this issue. The proposal should include the following:

- Executive summary (one page)
- Risk assessment roadmap form (one page)
- Full proposal (15 pages maximum)
- Appendix A: Bibliography (no page limit)
- Appendix B: Ranked list of intellectual property documents examined (no page limit)

Most Importantly – The significance and novelty of your creative solution, one that moves the boundaries of knowledge outward, will be the primary assessment focus of your review panel. The list below is just a minimum list of issues you might consider. There may be many more. The point is that your proposal *should contain the evidence* needed to make an effective and compelling case to your CEO in order to insure that she/he makes the right decision.

At a minimum, be sure you address all of the following:

Current Science and Technologies - What is already being done in this area by other researchers, companies and governmental institutions? Describe the current state-of-the-art for both the science and the implementation. Use diverse resources such as science literature, journals, conference proceedings, the internet, patents or other sources of existing public knowledge. **Cite all references you use and use quotes for any word-for-word transfer to your report.**

Your Design Approach – What is the basis for your design approach to the problem? Why is your product better than existing products? What product attribute(s) allow market penetration to achieve profitability? Address scientific *and* engineering aspects of these questions.

Testing and Qualification - Describe a set of tests you will use to demonstrate that your approach is effective and that your implementation of the solution will launch successfully.

Cost Analysis – Identify cost and market issues that will impact the pricing strategy of the solution you have proposed. Consider such things as: the major cost items that would impact the implementation; which elements of your implementation solution would be handled in-house versus externally-sourced; major risk elements that could drive up costs if the primary path item fails; costs of IP licensing needed, etc. Provide justification and/or reasoning behind your decisions. Estimate manufacturing cost for the total system as the product reaches mature product stage, so the marketing team can determine potential market size. Avoid subcontracting manufacture or assembly of any proprietary component outside the company, because the CEO is concerned with potential IP leakage.

Intellectual Property – In Appendix B, list in rank order of importance **all** commercial, academic, and governmental IP sources that were consulted while formulating the answer, including reference data. For instance, include the patent number; title; inventor name; and assignee name for a patent. Discuss the 3 most significant IP documents affecting your approach to your solution in the 15-page document. Compare strengths and weaknesses of these approaches relative to your own. Recommend how these IP threats should be handled.

Hint – Clearly state your hypothesized solution. Identify its innovation(s) and advantages relative to state of the art. Describe both existing data, and work needed to support each aspect of the hypothetical solution. Consider theoretical, fabrication, and characterization aspects: for each, identify software/equipment and methods to use, parameters to vary, anticipated outcomes, and possible alternatives in the event of unsatisfactory results. Discuss material, process, device, and systems aspects of your solution. *Refine* your hypothesized solution as you accumulate information and prepare the manuscript. **Remember:** clearly distinguish what is known from what is hypothesized or not known. What is needed to distinguish the important things to know?

Reference the 2014 PhD Candidacy Exam Guidelines document for general instructions.