Science Innovator's Handbook

A Cyclotron Road Special Project

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We consider this book a beta version. You are its initial audience and we are interested in any feedback you might have. You can send it to mc@cyclotronroad.org. Please refrain from commercial distribution.

Thank you.

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Preamble

It's time=zero. Welcome to your next experiment: your future.

There are countless books, blogs, and lectures on technology entrepreneurship. These are important and useful, as they cover many foundational concepts related to commercializing a new invention. But most of these resources were written for those developing software or consumer businesses. Driving science-based innovation from concept to product is different. It comes with a different set of challenges, and requires some different strategies. Moreover, the path and perspective of a scientist as inventor and entrepreneur is unique.

This handbook is written for individuals who have a strong command of a given technological innovation and expertise in its underlying scientific principles, but have had limited exposure to the key concepts and skills needed to commercialize a science-based product. The target reader is a Ph.D.-level scientist or engineer with an idea for how their research might turn into a product or business that can impact big industries like energy, electronics, biomedicine, transportation, or manufacturing.

Inventions rooted in scientific research face challenges above and beyond those that are encountered by traditional ventures. For starters, science-based innovation often incurs higher costs and requires more time for experimentation and development than other types of ventures. And if you are developing physical or biological products, you have the added challenges and risks of working with atoms instead of bits. Forget apps, you'll be charged with establishing viable manufacturing processes, supply chains, and distribution strategies. On top of all that, your invention may be most exciting in its ability to transform big industrial markets, but these are often dominated by a handful of entrenched corporate players and thus are notoriously difficult to penetrate.

With a background in science, you are already primed for some of the challenges that any entrepreneur faces. There are notable commonalities between translating an innovation into a commercial product and the process of advancing scientific research. In both cases, you test hypotheses and then observe and measure the results in a systematic and repeatable way. Tenacity and exceptional dedication are required for both pursuits, and neither are guaranteed to end in success. Failure is an equally essential element of both science and entrepreneurship.

But not everything will be familiar or comfortable for the scientist entrepreneur. Unlike in the laboratory, you probably won't have a good control group in an entrepreneurial venture. And while defining success in a scientific experiment is often an analytical process, there is seldom an obvious logic to measuring the success of a commercial project.

As scientists and engineers, you will bring specific skills and biases to entrepreneurship. Your background in research has instilled in you an innate understanding and appreciation for experimentation. You probably also have a strong commitment to seeking out fundamental truths, precision, and accuracy. All of these characteristics will serve you well, but there will also be moments when they are weaknesses.

That's because you are accustomed to looking things up, finding answers, running calculations or controlled experiments, and then concluding something with a high degree of precision. Outside the lab, however, you will have to make decisions based on imprecise and incomplete data, as will the people deciding whether or not to give you funding, evaluate your product, or partner with you.

Throughout the handbook, we offer tools and strategies aimed at helping you adjust to this new type of decision-making process, and to the myriad other challenges that you'll face while launching a venture rooted in a scientific discovery. There may not be a recipe to follow, but there are many lessons and guideposts that are useful in helping you find and remain on your chosen path—and in Chapter Two we offer a framework, called The Alignment Index, to help guide the process.

Let's Dig In

In the following four chapters, we will:

- Guide you through thought experiments to visualize a path to success. Because even if you manage to move your idea into the marketplace, that alone may not mean you've succeeded.

- Establish first principles and best practices for managing risks and keeping the four essential elements of any hard technology venture—technology, market, team, and finance—in alignment. Because even if you have the most promising invention imaginable, you cannot support a viable venture without ensuring you have a ready market, a strong team, and the financial resources needed to grow.

- Teach you how to identify the best market and create a manufacturing plan with the strongest economic potential. Because, beyond any societal benefit your product or service might impart, it still has to beat its incumbents in market metrics. It has to offer real value by being cheaper, faster, lighter, smarter, etc.

- Provide strategic advice on optimizing early-stage funding. Because money comes in many different colors and there is no single recipe for raising it. Your investors' business models will have positive or negative effects on your business. Early founders often fail to grasp this until it's too late.

Related to each chapter we've also provided resources, such as templates, guides, and exercises, that will help you turn the strategic advice we've assembled in this handbook into practice.

We hope you'll find this a valuable resource, and would love to hear your feedback on how to make it even better (send to mc@cyclotronroad.org). No matter what path you choose, we wish you luck on this exciting new journey.

Chapter One: Choosing Your Path

Bottom Line: There's no cookie cutter recipe for success—you need to spend time thinking about your path from day one.

Key Takeaways:

- Success doesn't look like one thing.
- Thinking intentionally and deeply about motivation is a critical exercise—especially at this early stage.
- We offer exercises to help you determine what success will look like for you, and some models for the specific pathways to improve your chance of success.
- Why you should start this journey with a t=0 meeting, and how to do it.

Concepts and Theories

I. Setting Your Personal True North

Success doesn't look like one thing. One person's interpretation of success can be vastly different—maybe completely opposite—from another's.

Most of our fellows at Cyclotron Road initially say that their biggest driver is to "put their technology out into the world" so that it can make an impact on how things are made, or how energy or data is stored or generated. Perhaps that tends to be how you describe your motivation, as well. But there are always adjacent and emotional motives. Commercializing an innovation, especially one based in hard technology, is so risky and life-consuming that those who do it are often also compelled by a fierce competitive streak, or maybe they believe they can reap big financial rewards, or they envision becoming titans of industry. These internal drivers are important, and you should identify the nature and strength of your own motivations.

We find that thinking intentionally and deeply about motivation is a critical exercise—especially at this early stage. As you progress on this journey, your time for reflection will be condensed and you might not have the luxury to change direction.

Identifying your personal mix of desired outcomes and motivations will set the parameters you need to make decisions, starting today, that will define the path you take.

The *why* will direct the *how*.

This is important because you are not starting this venture in a vacuum, and it's impossible to know what types of opportunities and crossroads will present themselves as the project evolves. For example, imagine we told you…

- Your product can get to market and make the societal impact you desire...but only if you first sell your product to customers who are interested in using it to make more lethal weapons for the military.
- You can secure $100 million in venture capital today, but only if you agree to give up control of your business at the next stage of development.
- You have a 50 percent chance of building a successful company that you control, but the outcome will take 20 years because you've ruled out venture capital as a financing option and have instead opted to bootstrap.
- Your company is twice as likely to be successful if you bring on an experienced co-founder and CEO, but that CEO might pull the organization into a direction you do not expect, may not want, and could even dislike.

These are obviously just thought experiments, but it's worth considering: which of these deals would you take? Why or why not?

In reality, something always has to give. You probably cannot navigate business-related obstacles and adhere strictly to all of your personal motivations at the same level of intensity. But what you ultimately consider a success will be dictated by these motivatations and desired outcomes. And that's why we think it's important to articulate, even if imprecisely, the set of end results for your venture that you would consider to be a success. We call this setting your personal "true north" because it provides a guiding direction that will help you make difficult decisions as you progress.

That said, setting one's personal true north can be surprisingly difficult. We find it helps to start by setting boundaries around what success would and would not look like for

you, both personally and professionally. Start by establishing your boundary conditions with this list of questions:

- Do you have any constraints on the uses of the technology you build or the markets you might serve?
- What scale of a business will you have to build to make this worth the effort?
- How quickly do you have to get there to be satisfied?
- What role do you want to have in the business moving forward? Are you willing to evolve dramatically to match what's needed for success in that role?
- What other personal constraints do you have e.g. regarding compensation, geography, etc.?
- Are you willing to trade control for an ability to learn/grow/scale faster?

Now that you've set those constraints, consider these additional questions:

- Which of the above are must-haves vs. should-haves vs. nice-to-haves?
- What do you think will be the biggest hurdles to achieving your win?
- And, getting back to the motivation question: How important is personal fortune/fame? What about competitiveness? Power? Is your personal driving force strong enough in one of these areas to win the day, or might you need a partner to complement your requirements, strengths, and motivations?

You may have moved through those questions speedily, or maybe one or many of them are stymying you or eliciting other questions or thoughts you had not previously considered. We've provided a worksheet in the Appendix that you can use to give some deeper thought and to document your responses.

II. Example Paths

As we mentioned above, there are various definitions of success, and various paths to get there, both for you as an inventor and for the venture you might create. To give you a sense of how your motivations and desired outcomes might influence your path, we'll try to classify some of the common pathways available to you as a scientist or engineer looking to move an innovation out of the lab and into the commercial realm. These are notional categories, but should help to illustrate that there is no single version of success, and that each pathway offers a different set of trade-offs, risks, and benefits. It's all about finding resonance.

Path 1: Go Fast and Big—You like a fast pace. But can your tech keep up?

Commercializing any hard technology will take a lot of resources. It's not hard to find examples of companies that grew big and fast, because venture capital is designed for that mode of growth, and ventures in this mode tend to garner a lot of attention. Raising significant funding can allow you to be highly productive from day one, and some would argue it's better to take a shot and fail fast than spend significant time being under-resourced. But what might not be as public is that oftentimes the founders of these startups must negotiate significant loss of value or control over the direction that the company takes. This is especially a challenge for hard technologies, which often struggle to create value at the superfast cadence of venture capital. But the prospect is appealing, for those few entrepreneurial teams that succeed on this path have the pride (and the financial reward) of seeing a new technology through, from idea to public company or large-scale acquisition.

Path 2: An Early Exit—It's a gamble, and the pay-off may come with trade-offs

You might instead work to set up your invention for an early handoff, through a license or acquisition. One key benefit of this path is that, when successful, it can serve up a quicker professional win for you and your team and leave your invention in the hands of a larger company with resources to develop it. But such transitions are hard to engineer and are highly dependent on timing and luck. And if you do succeed, you might find the handoff bittersweet, as you'll experience the ultimate loss of control—crossing your fingers in hopes that the acquiring or licensing company is structured to successfully commercialize the technology.

Path 3: An Alternative Route—Best for those with a DIY sensibility

You build the company slowly, eschewing venture capital because maintaining control over the enterprise is your main priority. It takes a great deal of time and patience (and, for most, a willingness to live on very little income). What does success mean in this scenario? That depends on your personal definition. Most often this path will lead to creating a smaller business, as it is hard to maintain large drive and ambition when operating in a resource-constrained mode for a long time. A smaller enterprise may very well satisfy your ambitions for lifestyle and impact in the marketplace. But if success to you means becoming a household name, or reaping huge financial rewards, the chances are slim. Very few large enterprises based on science have been built this way. Those that have are among the most influential on the planet, and perhaps you're the one to navigate the ship through the stormy seas to that destination. Just make sure you won't regret the journey if it doesn't work out.

Path 4: Open Source—Potential to change the world, and have a shaky business model

For many, the most important thing is seeing their ideas find practical application. So why not just open source? Many assume that open sourcing is the easiest, sure-fire way to get your technology into the world. But the risks are many: the community you are targeting might fail to embrace the technology, which means you won't have a viable business model through which to deploy it. Of course the payoff could be huge, and open source development can allow a core technology to evolve and become more influential, either within a specific market or across sectors, than it could have had you not opened it up.

Practical Guidance

I. Path Discovery

In the coming chapters, we will discuss the importance of Customer Discovery, which is basically the process of interviewing as many potential customers as possible in order to really understand how your product could bring them value. The Path Discovery process is not much different. Whereas the goal of Customer Discovery is to help you refine what products you build with your technology, the goal of Path Discovery is to enable you to define the type of leader and innovator you'll need to become in order to attain your personal vision of success.

While it does require introspection, this Path Discovery process should not be an insular undertaking. If you've already assembled some advisors, lean on them. But you should also make a list of entrepreneurial scientists or engineers who you respect—folks whose professional paths mirror in some way the one you think you'd like to follow—and ask each for a meeting or phone call. Extract from them as many insights and anecdotes as possible. What were the most consequential crossroads they encountered as they built up their organizations and how did they address them?

Hold on to and refer back to those meeting notes—you may find them increasingly valuable over time.

In the next chapter we'll establish the four basic elements—technology, market, financing, and team—that will determine the success of your venture. It might not seem obvious yet, but there are many important linkages between these elements and your chosen path. Yet, here is an important caveat: There are going to be times when those

linkages feel extremely stretched. For example, you may find yourself accepting funding with unwelcomed strings attached because the future of your venture will hang in the balance.

Spending this time early on, thinking about your preferred path, does not mean you will always remain squarely on it—the reality is that entrepreneurs spend a great deal of time managing risks, and in the process, they have to make hard decisions just to keep the business afloat. But if—and more likely, when—that happens to you, at least you'll make those sacrifices with eyes wide open and be thoughtful about which hills to die on and which to not. The long-term goal is that being thoughtful about your path discovery now will make it possible to look back in a decade and see that, all things considered, you've kept your personal true north heading.

Sidebar: Defining your role

Over the course of the the past four years, we at Cyclotron Road have guided more than 40 fellows through the process of building ventures. That requires thinking about what those ventures will look like, how they'll operate, and on what trajectories fellows want to launch them. But another question that is just as important to ask at this early stage is "What role do you want to play in this organization?" While founders often take the role of chief executive officer, you should not assume that—if you launch a commercial venture—you would become CEO by default. That job is heavily steeped in business operations and, for a startup, in fundraising.

It could be that your set of strengths and skills, combined with your preferred personal path, make you more tightly aligned with the role of chief technology officer. In that role, you could focus on honing the technology for a specific outcome or set of performance parameters, while a chief executive (who may or may not be a co-founder) focuses on finance- and personnel-focus duties.

Or you might find that you could continue working largely in the research realm—which presumably you've focused on the most until now—by serving as a chief science officer. In that role you may establish and test hypotheses around the potential for the technology you've developed thus far to further mature.

II. Find advisors

A board of advisors—not to be confused with a board of directors, which is a group of appointed shareholder representatives that is assembled after an organization is

established and has raised some funding—will be made up of individuals with expertise and experience germane to your path. (If your venture takes off, these people may or may not eventually join the board of directors.)

If you take the leap and launch a venture, advisors will help you make the myriad decisions you will face. There is a good chance you already have a select cadre of mentors or advisors to whom you've turned for guidance during your career. But in selecting advisors to help you navigate commercializing a technology, you should use a specific set of guidelines and examine where you need the most help.

Start by analyzing the strengths and weaknesses that you will bring to this venture, based on your experiences and base of knowledge. From there, it's an exercise of filling in those areas of weakness. There are four essential elements on which any hard-technology ventures fails or succeeds: the functionality of the technology; a ready and viable market for that technology; a sustainable financing model to grow the venture; and a strong core team that can keep those three elements moving in the right direction.

So, when you look for advisors, think about what experience, skills, knowledge and networks they would bring to these four main elements. Also, think about how they will serve as sounding boards and expert sources during your venture's quarterly meetings, starting with the very first huddle, which we call the t=0 meeting (more on that below).

Start by ranking the skills, experiences, or networks that you, or you and your co-founder(s), are most lacking and would benefit the most by fortifying. From there, create a wish list of candidates—your ideal advisory board. These might be individuals you already know, or they could be descriptions of phenotypes with skill sets that you can then seek out through your various networks or those of people you know and trust.

It won't happen overnight, but the sooner you start pulling in advisors, the sooner you can benefit from their experiences and resources. As you begin this process, set a goal of identifying three or four advisors who you'd want to pull into this venture.

III. Hold a t=0 Meeting

All of this is a lot to think about. But as we've already noted, now is the most advantageous time for you to invest in the contemplative exercises we've offered in the appendix. But in very short order you should also start planning out the transition from

pathfinding to doing. And for that, we recommend kicking off the journey into commercializing your technology with a t=0 meeting.

The goal of this t=0 meeting should be to answer a list of foundational questions, all of which are designed to paint an image of a successful outcome for you, both personally and professionally, once you've built your company. We've provided a guide for your t=0 meeting in the Appendix. *NOTE: You'll want to read this complete handbook before holding your t=0 meeting, because many of the questions and concepts in the meeting template may not be clear until you've digested all of the content here.*

As you'll see, it walks you through some of the same gate-setting questions we noted above, but it also goes deeper into the nuts and bolts of launching the venture. You may be the only attendee. If you have a co-founder, then certainly she or he will be there, too. And if you already have some trusted advisors (see below) lined up, it may also be appropriate for them to attend.

Stacked against the seemingly endless list of endeavors ahead of you—from building a team, to fundraising and creating a business plan, to refining and commercializing your technology—we are fairly certain you will not feel compelled to spend the considerable mental energy and time needed to research and arrive at answers to the questions provided above. Do it anyway. Based on everything that we have learned, through our own experiences building companies and those of the fellows we've advised here at Cyclotron Road, we are confident that if you do not wrestle with these core decisions and preferences early on, you'll be sorry. And your startup is very likely to suffer.

One more important note: Write it all down. You are going to want to (or, at least, you should) refer back to the notes you take at the t=0 meeting for years to come. Whether you're a devotee of Evernote, or prefer dictating voice memos, or have pledged allegiance to a pen and notebook, be sure to keep thorough notes and document this path-finding process.You will very likely find referring back to these early notes extremely useful as you get further into the commercialization process.

Your t=0 meeting can serve as a launching point for regular quarterly meetings that you hold with your core team and advisors as you start to grow your company. The quarterly meeting is, of course, a stalwart of corporate structure. But at first blush, the suggestion that you ought to start holding board meetings might seem analogous to suggesting someone offer a piano concert despite never having played the instrument.

Cyclotron Road is a strong advocate for initiating quarterly meetings when a company is at an embryonic stage—in fact, it is a core component of the program we provide to our

fellows. Don’t imagine sitting around a vast mahogany table, pointing to hockey-stick charts. And of course, you are a long way from assembling a board of directors for this venture—that will happen by necessity as you bring on investors or by choice as you scale up the organization. Still, you should approach the t=0 and subsequent quarterly meetings as serious events. By the time you build up a formal board and begin holding quarterlies with it, you will be practiced and confident in the ritual.

Chapter Two: Elements of Risk

Bottom Line: This journey is about creating value. For an early-stage venture that means managing risk related to your technology, market, finance, and team.

Key Takeaways:

- Identifying and managing risks is of paramount importance for early-stage ventures, and risk does not just mean technical risks.
- Do not spend the bulk of your energy refining your technology. If you can't find a market, finance the venture, and build out a team—and derisk each—your technology won't matter.
- Frameworks exist to help you chart this process, but they are either overly prescriptive or fall short of what startups in the hard sciences need.
- You can't force alignment across the four elements. But use your advisory board as a sounding board.

Concepts and Theories

I. Risk and Value

This chapter is all about risk. Not risk in the rock climbing context or not wearing safety glasses context but in the context of transforming a research advance or innovation into a commercial product. In this context, risk can be broadly defined as the likelihood that an actual outcome will differ from the expected or desired outcome. This concept can be applied across all aspects of your venture, as we'll see below. The subject of risk fills volumes of books. Indeed, you could earn an advanced degree in risk management.

The purpose of this chapter, however, is to help you begin to think strategically about risk and its relationship to the creation of value. In the context of a commercial venture, value is created by making something new that a customer is willing to pay for. At the early stages of any commercial venture, risk reduction and value creation are directly proportional. In Chapter Three, we'll dive deeper into quantifying your potential for value

creation. Here, our aim is to empower you to identify and frame the risks related to commercializing your technology such that they will remain in view at all times. If they're in your view, they can be measured. If they can be measured, you've got a much better chance of mitigating them, and, by doing so, increasing the value you offer to the marketplace.

Risks exist along multiple axes at once: technology, market, finance, and team. Ultimately, the success or failure of your venture rests on your ability to create value and reduce risks across all of these axes. The technological innovation itself is just one piece of the puzzle.

As we discussed in the first chapter, it's important to realize that "creating value" can take many forms. At Cyclotron Road, we have some fellows who define their success as nothing short of creating a new market and a billion-dollar enterprise, while others would be satisfied becoming a supplier, selling their IP to existing corporations, or being acquired by a larger company because of their world-class team. Each may be a valid end goal, rooted in a scientific discovery, but the path—the strategy, tactics, and objectives—needed to succeed look quite different.

No matter what path you select and regardless of the desired outcome you want for your venture, technology, market, finance, and team are the foundational elements on which you should begin building a strategy for risk reduction and value creation.

Here's why:

- Technology: you can't have a viable product or business if your tech doesn't work.
- Market: you can't have a viable product or business if no one is willing to pay for it.
- Finance: you can't have a viable product or business if no one will invest the funds needed to develop your innovation into a thing of value, build its supporting infrastructure, and manufacture it at scale.
- Team: you can't have a viable product or business if you don't have a team that can succeed in putting the pieces together.

Take a moment to reflect on how much you've considered these interlinked elements in the past, either through an academic or industrial lens.

II. Finding alignment

Most scientists falsely assume that it’s not worth getting in the weeds on markets or financing models until you can demonstrate that the technology works. Meanwhile, many business folks would have the opposite (and equally flawed) perspective: that it’s not worth fussing around with technology unless and until you can prove that there are viable market and financing dynamics to justify building the tech.

The best science-entrepreneurs understand that each of these cardinal elements is related to the others, and that advancing their understanding of any one element can help inform and optimize their strategy in advancing another.

But the bigger goal is not to simply mature each area independently. Rather, it is to advance each element in alignment with the others. This will prevent you from investing valuable time, energy, and resources in solutions that are only partially viable. This may require you to spend less time in the lab developing your technology, which might feel uncomfortable. But keep in mind that without securing funding, finding a ready market, and planning for team-building, your technology, frankly, won’t matter.

Of course, you will never completely mitigate all of these risks, and it is not likely you will manage all of them precisely and equally, at the same time. Risk, after all, is a defining characteristic of any new venture. However, aligning your progress and managing risk across all four of the essential elements reduces the overall risk of your venture. Think of the tilting board game, where the player must move a ball through a labyrinth, while avoiding ubiquitous holes, by lowering or lifting all four sides of the box in a coordinated fashion. If you imagine each side of that box representing one of those four elements and think about moving the ball forward (that is, advancing your idea from a concept to a commercially viable product) you start to understand why it is so important to keep technology, market, finance and team in constant alignment.

In the game, the first rule is to hold all four sides steady and consider how to optimally leverage them in order to advance. Likewise, in a venture you always need to hold and keep in mind the impact of your activities around technology, market, finance, and team. Second rule: To move the ball forward at any given point, you have to hold some sides fixed and tilt in a direction you want to advance. Likewise, in a venture, you have to prioritize which element you should most critically advance at any given moment (while holding the others fairly fixed).

Alignment doesn't mean that you have to do everything at once. Alignment just means that you don't want one element to get way out of sync of the others.

III. Case Study—Sepion Technologies

Let's walk through an example of what happens if you fail to advance all four elements in parallel. One of Cyclotron Road's early fellows, Pete Frischmann, came into the program armed with an exciting new ionic membrane technology, which he had proven in the lab could offer a first-in-kind ion transport capability. After spending months engaged in Customer Discovery (a process we'll explore in the next chapter), Frischmann had concluded that the best market opportunity was in enabling a new class of ultra-lightweight lithium sulfur batteries. Having validated the market opportunity, he was confident his biggest priority in Cyclotron Road was to build a prototype lithium sulfur battery.

Within the first quarter in the program, it became clear that the hypothesis for his business made sense in three of the four areas of development: technology, market, and team. But when Frischmann spoke with investors and corporations focused on the battery market, he heard the same thing over and over. Sure, they said, if you had a mature product today, the market would love to buy a lithium sulfur battery. But building on his component innovation to develop a mature lithium-sulfur battery product would require enormous amounts of capital, on the order of hundreds of millions of dollars. And given a choice, investors would much prefer to invest in the next generation of lithium ion technologies, because batteries made from that chemistry were already supported by a strong supply chain and had showed such a fast pace of improvement that it would likely beat out lithium sulfur for the vast majority of applications.

So while Frischmann had a great idea for an end product based on his technology, market and team, he was unlikely to succeed because the odds of being able to finance the product development were not in his favor. Based on those early learnings, he refocused the technology, and identified new market opportunities which allowed him to keep the other elements—growing his team and raising funding—at pace, while still leveraging his core innovation. Had Frischmann not assessed whether he could keep financing in alignment with the three other elements, his startup might have spent years developing a lithium sulfur prototype, only to then learn that no one would be willing to fund later stage development, where costs would grow considerably, in order to get his innovation to market.

Of Note: Lean Launchpad and Stage-Gate

It's worth noting here that we are in no way pioneers when it comes to creating a framework to help entrepreneurs plan and scale their ventures. For example, the Lean Launchpad framework, which focuses on customer discovery, market analysis and lean manufacturing, has gotten traction in the tech space, broadly. The Stage-Gate framework is designed to help entrepreneurs advance from a prototype to marketable product using the concept of incremental stages, and entry to each requires clearing a gate or proof point.

So why hasn't the Lean Launchpad or Stage-Gate methodologies worked for startups founded by scientists and engineers and based on scientific innovations? We think Lean Launchpad focuses too heavily on sales and marketing and not enough on technology development, team-building, and financing. Stage-Gate, on the other hand, is solely focused on the process of prototype and product development. These are all incredibly valuable. But hard-tech innovation requires a highly-integrated effort that places equal importance on all four of the essential metrics of the venture: technology, market, finance, and team.

Practical Guidance

I. The Cyclotron Road Alignment Index

Advancing any one of the four basic elements of a tech venture takes a tremendous amount of time and resourcefulness. Doing so with all of them in lock step is a remarkable effort, and a process that can be very difficult to manage. That's why we've developed a framework that will help you track the maturity and alignment of your technology, market approach, team development, and financing strategy.

The Alignment Index defines the spectrum of commercial maturity, from conceptual to first product deployment, and is meant to be a guide for hard-tech entrepreneurs as they forge their ventures. This is not meant to be prescriptive, and it is important to remember that no framework is perfect. (Also, some of the terms on the index, such as "gap analysis" or "TAM-SAM-SOM" might not be familiar to you but you will find simple definitions through a quick web search, or in Founder's Playbook).

Your job is to frame this initial technology-market-finance-team foundation for your enterprise, then drive progress and reduce risks in each of these can't-fail areas, while recognizing and exploiting the critical interplay between them.

The Alignment Index is divided into the four main elements, running horizontally left to right. Corresponding with each element are common activities and milestones, in order of maturity, running vertically from left to right. You might not be familiar with many of the items on the list. That's fine, for now. But you should at least gain a rudimentary knowledge of each because as the technical founder you will at least want to understand what they are.

As you see, the index sets five levels of progression across each element—for example, level one under market includes conducting market surveys and setting a hypothesis around the value proposition of the product you plan to develop. By level five, that hypothesis would be tested, the business model validated, and the venture should be collecting customer feedback and deploying a customer service plan.

Using the index, you can self-evaluate the level of risk for each of those milestones, using a red-yellow-green scale. Again, since risk reduction and value creation are directly proportional at this stage of a venture, the more green you see across the index, the more value you are generating. We find that it's often not useful to fixate on getting greens; the more immediate goal is not to try to move all four elements forward in as close to unison as possible, while keeping an eye on anything that is firmly in the red.

Start by evaluating your current maturity level corresponding to each element—technology, market, finance, and team—based on the activities you've undertaken and the milestones you've reached. What are your biggest risks in each of the four elemental areas? Remember that the level of risk reduction is often proportional to value creation, but not always—there are some areas where you can accept a higher level of risk over a longer period than others. Also remember that being far more or less mature in any one area, compared to others can itself be a source of risk.

It can be useful to approach this methodically. Write a list of objectives that track directly to reaching a milestone on the index, and set hypotheses that you can test in order to advance toward each objective within each element. Having a list of incremental goals under each element will help you meter your progress and hold yourself accountable to driving maturity in each category. Also, prioritize your time and be sure to communicate your status and progress effectively to your partners, advisors and, (once you have some) investors.

Over time, as you advance in each area, pause to reflect on whether the complete picture of your enterprise makes sense. Can your goals and strategy on tech, market, financing, and team all come together into a coherent and viable narrative? You might not have the experience or perspective to answer that question, so we suggest bringing it to your experienced advisors. If you do not yet have a group of such advisors you can turn to, it's time to start finding some.

The index is worthless by itself. The key is in how you use it. This is not meant to be a recipe, just a reference chart to keep an eye on once in a while. Most important is that you have a mindset of creating value and reducing risk, and advancing maturity with alignment across these areas.

Sidebar: Bolt Threads—Think Differently

David Breslauer has a Ph.D. in bioengineering and co-founded Bolt Threads in 2010 to commercialize synthetic spider silk to sell into the $2.5 trillion apparel industry. The firm has raised significant capital and is working to scale up its production, but the transformation from a scientist to an entrepreneur hasn't been an easy one. "Entrepreneurs are risk takers," Breslauer told Forbes. "[My co-founder] Dan and I are actually risk averse. We see things as science experiments."

Not all scientists and engineers are risk averse by nature, but they are trained over many years to be guided by evidence-based criteria. Building a venture and raising funds to support it, however, often has to happen at a much faster clip than scientific research. Successful entrepreneurs, therefore, are really good at identifying and mitigating risks across their ventures. They're not risk takers, that's a false narrative. In fact, successful entrepreneurs are risk killers.

Chapter Three: Customer Discovery and Techonomics

Bottom Line: You may have a made a striking research discovery that led to an exciting invention. But to build a successful commercial venture, that discovery or innovation must become a product that can be sold to a customer for a profit.

Key takeaways:

- To sustain a business, any product or process must satisfy a basic principle: value must be greater than the cost.
- Both value and cost need to be quantified to assess the viability of a product for a given customer. Techonomics shows you how to get started with that analysis and use Customer Discovery to validate your conclusions.
- Building a cost model early will help to focus your research efforts on the most important problems, and can save you significant wasted time and effort in the lab.

Concepts and Theories

I. Economic Opportunity

Bringing a new scientific innovation from a concept to a commercial product can take years and sometimes millions of dollars in research and development, especially if your idea involves machines, devices, or materials, and your customers are in industry. At Cyclotron Road, our mission is to move these types of innovations out of the lab and into the world. In this chapter, we're going to show you how to evaluate the economic variables that ultimately determine whether or not a product will be profitable.

Techno-economic analysis, or TEA, is an established practice of assessing the economic viability of a product or process technology in a given industry. TEA is typically deployed as part of the Stage-Gate process for managing new product development within the realm of established technologies and industries, but it is an equally important tool for guiding the development of a new technology that, like yours, is still at the lab stage.

Beth Zotter, Cyclotron Road's TEA expert, developed her own take on this method, called Techonomics. It combines some of the basics of TEA with Customer Discovery—a process we'll describe in this chapter—allowing you to connect your innovation to an economic opportunity, even at a very early stage in its development. You can use Techonomics to begin answering essential questions that will shape the future of your technology or venture. For example, who is the customer for your product and what is its value to their business? Will the cost to produce your device or chemical compound or process technology be less than the price they are willing to pay? Until you can respond to those questions with informed estimates, you cannot ensure that there is a market for your product, or that you are even working on the right parts of the technology problem.

We advocate for integrating Techonomics into your effort from the very beginning. It will very likely alter the project in fundamental ways that will change the course of your research and development, often saving you significant amounts of wasted effort and cost. From our experience, it will likely reveal that some of the technology risks and milestones you think are most critical may not be worth pursuing, while other, less obvious elements are more critical to developing a useful and viable product.

Our goal here is to show you how to use Techonomics and Customer Discovery to stay focused on the biggest opportunities, and aim your technology toward a market where it makes an impact.

II. The First Law of Techonomics: Value>Cost

The most important job for any entrepreneur, regardless of the types of products she sells or the customers she's targeting, is to create value for a customer. The same holds true for you. Your job is not to sell a technology, it is to create customer value.

Customer value is the economic benefit that the customer gets from using a new product, whether that is a new manufacturing process, a new component in an existing product, a technology that can reduce waste, or something else that lowers costs or improves a business process. Let's say you've got an idea for a new type of battery. What's the value of that innovation? It could be high power, durability, or longer life, but probably not all of them equally. Depending on where that battery is used—whether it's in an electric car, a flashlight, or an industrial sensor—the advantages of your innovation may be very different. But regardless of your technology's specific advantage, there is a basic principle that governs its economic viability: value has to be larger than cost.

That value needs to be higher than cost might seem obvious, but for new technologies, both sides of this equation can be hard to estimate. Failure to get it right is the downfall of many promising ventures in technology.

This isn't just about keeping your company afloat, it's also about supporting the entire ecosystem of logistics partners, parts manufacturers, fabricators, and all of the parties that contribute to your product's production and delivery—also known as your supply chain. If the value is much higher than the cost, there is room for multiple links on the supply chain to exist where each company is making a profit. Commercialization is only successful if everyone along the supply chain makes a profit.

III. Validating and Quantifying Customer Value Through Customer Discovery

As an entrepreneur, you will hear the term Customer Discovery quite a lot. It is basically a fancy way of saying "talking to potential customers" and its purpose is to help you validate that there is customer value in your product. Customer Discovery is a major tenet of the Lean Startup methodology and the I-Corps program (see sidebar), which provides a useful framework to force this way of thinking.

If you are aiming to put your innovation toward improving a commodity product like a bulk chemical or a 9-volt battery, this part is easy, because the need and the value of those products are already established by the market. So, if your technology is an indistinguishable replacement (also known as a "drop-in") for these commodities, your value proposition is likely very clear. But for other types of technology applications, such as creating a new type of product or process, or improving the performance of an existing one, you'll have to do some Customer Discovery to test the value proposition.

You may believe that your innovation could lower a manufacturer's energy consumption, or offer utilities a new method of producing or storing energy, or offer a semiconductor manufacturer a way to lower production costs or boost chip performance or memory capacity. But there's no way to know whether or not those value proposition hypotheses are correct without actually talking to potential customers. Assuming your innovation will land in fertile soil is one of the biggest—and most foolish—risks an entrepreneur can take. As Steve Blank, founder of the Lean Launchpad, always says: "Get out of the building!" You will not find your first customers by sitting at your desk.

Keep in mind that Customer Discovery is not just a qualitative process. Your conversations with customers will also help to improve your quantitative estimate of the value you can provide to them (the dollar value you first guessed at above). Combined

with an estimate of your own cost of production, which we cover below, this will determine whether that product is viable, or whether you need to pivot to find an alternate application or customer for your technology.

Roots of Discovery

Eric Ries, who started founding software companies in his Yale dorm room during the mid-90s, created the Lean Startup methodology, popularized through his best-selling 2011 book, The Lean Startup, which is very focused on qualitative market assessments. The methodology is a rebuttal of what he saw as the tendency of technology startups to try forcing their products into the marketplace rather than starting with Customer Discovery and market analysis to inform where they best fit.

Steve Blank is a serial entrepreneur and long-time champion of this methodology, which he used in developing an educational course on entrepreneurialism. Dubbed the Lean Launchpad, it is taught at a number of major universities and was used as the basis for the National Science Foundation's Innovation Corps, or I-Corps program, which since 2011 has taught thousands of scientists the basics of moving a concept into a commercial product and has been expanded to the National Institutes of Health and the Department of Defense.

A major tenet of both Ries's and Blank's guidance for launching commercial venture is Customer Discovery. It has become a prominent term in the modern entrepreneur's lexicon, and it refers to the process of speaking with as many potential customers as possible to understand what business problems are. Once you know this, you can assess whether the product or process you're developing could solve those problems, in other words, whether your product has a real value proposition. (Customer Discovery is one part of a larger process that Blank developed, called Customer Development.)

The act of Customer Discovery requires that you go out and meet with scores of people who you might wish to convert into your customers—but importantly, your goal is not to sell them on your product or solution. In fact, it's not about selling anything. It's a process to identify the most promising applications of your technology, based on interviews with people who know your target market.

Practical Guidance

I. Standing at the Intersection of Technology and Market

The purpose of Customer Discovery is to avoid building a product or service that nobody wants. The purpose of using Techonomics is to create cost and production

models to avoid building a product or service that nobody can afford—or one that can't generate a big enough profit.

But deciding on an application to pursue may require narrowing your focus and shelving (for now, at least) some applications that might really pique your scientific curiosity. It might also force you to reevaluate the path you initially wanted to take as a leader or business. (As discussed in Chapter One, there is not one single entrepreneurial path, but many.)

Say, for instance, your goal has been to get your technology into the marketplace through an open source model—your role as a leader would be to introduce the technology but then let users really shape its trajectory. Through Customer Discovery, you might learn that the business models of your most promising potential customers are not congruous with the open source licensing or consulting model you'd been hoping to deploy.

Or maybe it becomes clear that your initial product vision was spot on—but not for the industry you had planned on. Perhaps you've developed a means of producing off-grid energy in a cheap, sustainable way and the most interested and willing initial customers are not homebuilders in the developing world, as you'd hoped, but rather energy companies that want to use your technology to offset diesel generators at remote oil wells.

Here's another scenario: you might find the original plans for application and target customer are in line—and that you will offer tremendous value proposition and have a ready stream of customers—but none of that matters because you simply will not be able to make a profit. Or perhaps the material you have been trying to optimize in the lab to boost performance only represents a tiny fraction of the total cost, while another component of your system dominates the bill of materials and makes the whole system uneconomical.

You get the point. It can be really challenging to come to these types of reckonings, but that is sometimes where founders find themselves when they get to the intersection of technology and market.

So, before you dig into the next sections, on defining performance specifications and Techonomics, watch this short video in which Steve Blank lays out the initial planning steps for the Customer Discovery process.

Here you will find the whole opus of Steve Blank's series, and clicking through some videos will give you a flavor for the whole Customer Discovery process. Of particular interest to you as scientists, however, will be this short excerpt from a Lean Launchpad NSF I-Corps course at the University of California, San Francisco, wherein principal investigators testify to the value of Customer Discovery.

But the most important step you will take in this process will be to actually start doing Customer Discovery.

II. Defining the Product: Performance Specifications

Unlike with software, you can't just sit on a sofa and hack away at your laptop to quickly develop your prototype and test it with customers. So how are you meant to get their reactions to what you're building?

Well, if you're making a device, a new process technology, or new material, you can use a standard industry product descriptor called a performance specifications page, or a spec sheet, in place of a prototype. The spec sheet is a simple one-page document that defines your product and links your technology's key performance parameters with the ultimate value proposition for your customer.

At Cyclotron Road, we've noticed that many technologists wait too long before forcing themselves to reduce a set of specifications to paper because they are not sure exactly what the product or application should be. Any one technology innovation could be applied to dozens of different products, and the end user of each of those products will have different requirements. So it's hard to figure out where to start. That's ok. What's important is that you start somewhere and sooner rather than later. It's up to you to find the most promising route to a valuable product, starting with a strong hypothesis, and then shifting and adapting based on the learnings from your customer discovery activities.

Creating a spec sheet can help you lock in on a product hypothesis, and it can be a critical tool to get the feedback you need from customers before there is a real product or prototype for them to try out. You might go through this exercise and find that your technology can't actually meet your target customers' performance needs. If that happens, you've likely saved yourself a lot of time and frustration. And you can quickly move on to another hypothesis.

One way to think of a spec sheet is as the resume your product brings to the job interview to see if you can get the job done.

In the Appendix you will find an example of a spec sheet for a product from an industrial company: a diesel generator made by Cummins. It may not be the type of product your innovation will evolve into, but it's a very useful reference and will get you started thinking about what key measurements and features you will want to include in your own spec sheet. We recommend collecting spec sheets from companies whose products and/or target market are similar to yours.

Building a spec sheet will force you to define a set of product performance parameters that will clearly be valuable. But you can't sell investors or customers on your product without also convincing them that product can be manufactured and sold with a sustainable profit margin. In order to prove that, you need to determine your costs. Now that you have a set of specs and performance parameters, you can work backward to determine the viability of manufacturing it, through basic cost calculations and modeling. Those same models will also let you see how various product design choices impact the cost and value of the product. We'll delve into this exercise in the next section.

III. Making the Product: Cost Calculations and Modeling

Here at Cyclotron Road, we hear a lot of scientists say it's too early to estimate cost because of all the unknowns. But in our experience, helping dozens of scientists and engineers move their technologies to market, doing this work early will keep you from hitting dead-ends and turn your attention to better opportunities for your technology—just as building a spec sheet at this early stage can. Your first production cost estimate will be a simple back-of-the-envelope calculation you can do by hand.

The next step will be to build a more detailed cost performance model that links the product design with the cost of production and the product's estimated value. This model will use simple equations and variables to show trade-offs between product design choices, and their resulting impacts on cost and value, to show where your technology has the highest (and lowest) potential for commercial success.

To dig in, check out Cyclotron Road's Techonomics instructional videos and, once you're ready, download the cost performance models available on the site.

IV. A Case Study in Techonomics

Jill Fuss and Steve Yannone, Cyclotron Road fellows and co-founders of biotech startup CinderBio, avoided doing cost modeling for a long, long time. “I called myself a reluctant cost modeler,” says Fuss. They wanted to spend time improving their technology, not wading through spreadsheets. But they eventually learned that spending a little time crunching numbers upfront ensured they’d spend less time trying to make their product economically feasible.

Today, armed with simple cost estimates to do things like investigate new products or markets, and production cost models to see how tweaks to their methods or inputs can change CinderBio’s economics, Fuss and Yannone are believers.

“Cost modeling has guided our science,” says Fuss. For example, a major issue surfaced from one of the first cost-estimates CinderBio made. “We created a pie chart of our production costs and realized that just one component accounted for half of the pie,” she says. “That was a problem.”

Responding to those types of hurdles sometimes requires that she and Yannone go back to the lab and adjust their methods, while other times substituting, say, one growth media for another can solve a cost problem. But without the fast estimates and responsive models, it would take them untold days or months—and likely a great deal of trial and error—to uncover and address those types of production issues.

Cost modeling has paid dividends in other ways, too. “We still do back-of-the-envelope calculations all the time, for things like looking at new applications, new markets or new opportunities. It lets us see if there’s anything there worth pursuing,” she says. “In fact, we ended up killing a whole application that a partner of ours was interested in pursuing. We penciled out the numbers and it made no economic sense.”

Plus, CinderBio has won grants whose purposes are, in part, to perform research aimed at improving the company’s cost economics. So, in some ways using cost models has helped them grow their business, not just keep it on a good track.

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Here are some insights, gathered from Fuss and other Cyclotron Road fellows, as well as program team members, that can help you get the most out of production cost estimates and models.

· Modeling is an ongoing process; you’ll never be done with it but it will always make things clearer.

· Making quick estimates and using models to investigate different scenarios can help you make decisions that would be hard to make without these quantitative guides.
· Using these tools forces you to track different inputs and vendors and provides a means of objectively scoring them based on costs.
· It's important to be very thorough about always dating and documenting changes as you make them in your spreadsheets, in order to avoid confusion and to be able to compare outcomes.

Additional Resources

- In addition to working through the Techonomics exercises, the ARPA-E Tech-to-Market website offers a number of useful guides and templates.
- Steve Blank has archived many of his talks and presentations on customer discovery process on his website.
- Talking to Humans by Giff Constable is a very brief but useful guide to planning, conducting, and deriving useful insights from customer interviews, as part of your Customer Discovery process.
- In the Appendix you'll find a presentation from Yet-Ming Chiang, a material scientist, MIT professor & co-founder of energy storage tech startup 24M, and Ryan Boas, a senior director at Applied Materials, which highlights the importance of shifting from thinking purely about technology to using a robust cost model to tune the direction of your R&D when commercializing technology for impact.
- In the Appendix you will also find an example spec sheet.

Chapter Four: Fundraising Basics

Bottom Line: Money comes in many colors and with different types of strings attached, so you need an appropriate strategy for fundraising a hard-tech venture. Venture capital is critical—it can make or break your venture—so you need to be exceptionally thoughtful about if or when you use it to finance your venture.

- To succeed in fundraising, you have to understand and activate what motivates people to give their money away.
- Your investors' business models will have positive or negative effects on your business, either explicitly through terms of the investment or implicitly through the steps you must take to keep them happy. Early founders often fail to grasp this until it's too late.
- For early stage science ventures, the question of whether or when to take traditional venture capital is critical—it has a fixed cadence of value creation and increased fundraising that can make or break your venture if well or poorly timed or aligned with the rest of your story.

Concepts and Theories

I. Fundamentals of Startup Investing

The previous chapter highlights the importance of obeying the laws of capitalism by determining the feasibility of turning a great scientific idea or innovation into a real and profitable product or process. This chapter covers the basics of capital sources and funding models, which are important to learn because even after arming yourself with a strong techno-economic analysis and cost model, and finding a market or two for which your product or process could be exceptionally valuable, you could ultimately fail unless you raise the money needed to build the business.

The first law of investors is there are no hard and fast rules about who invests, how or why; you can find counterexamples of every generality described below. However, investors want to know that the entrepreneurs they fund understand the game they are

playing. It's important, therefore, for you to understand the fundamentals of startup investing, as well as the various types of investors and what guides their decision-making.

Understanding the rudiments of financing is just as important as the work you'll do to evolve your technology into a product of value with a ready market. Without a strategy for funding your venture, there won't be a venture to fund. But in addition to having a foundational understanding of funding mechanisms, keep in mind that a viable financing model must be aligned with your three other vital elements: technology, team, and market. That is why we think The Alignment Index, described in Chapter Two, is such an important reference point—keep checking in with it to ensure that all of these essential elements of your organization remained aligned and strong.

II. Startup Financing 101

Any organization could seek the money it needs to operate from one or more of three broad categories: equity, revenue, and debt.

- Equity is based on selling stock of your company to various sources—these could be friends and family, or an angel investor or a venture capitalist—in exchange for the money you need to grow the organization.
- Revenue is money your organization earns in exchange for selling a product or service. There are a few types of revenue, such as product revenue, service revenue, or development grants and development.
- Debt is any type of loan or credit you need to pay back to the lender. Debt sources include friends and family, banks, or venture firms.

None of these forms of funding are necessarily good or bad—but biasing toward any one type might be a good or bad decision, based on your timing and the trade-offs that accompany each type of funding—and there are always trade-offs! So, it is vitally important that you put serious consideration into who you court funding from, when you court it, and why you're going after funding.

Selling equity means giving up a small or large percentage of ownership of the company, but it can allow you to move more quickly and flexibly than without it, and provide you with cashflow without debt hanging over your head.

Revenue is great, of course, but oftentimes there is a gap between chasing it and landing it, and your company could fail before you get to reap the rewards. Or you might decide to go after revenue by selling one product even though your long-term goal is to

introduce another product or service to the market. That approach could work well, or it could serve to be a greater diversion of your time and resources than it's worth, in the long term.

And finally, taking debt can be a good move because it provides an operational runway and lets you retain ownership of the organization. But of course, you've got to pay it back. And if you can't pay it back, you're out of business.

One final note on the rudiments of financing any commercial venture: All types of financing—even "non-dilutive" sources such as government grants—are in various ways dilutive of your time and energy, even if they do not directly require that you sell shares in the venture.

As you start to consider how to fund your venture, it's a good time to think back to your t=0 quarterly meeting and reflect on the path you've started down. If taking a large investment and the contingencies that come with it are in line with your vision, great. If not, perhaps it's not the best approach to moving your technology forward.

III. The Who

Above, we explained the types of money you can raise, but it's also important to understand the various sources of that money.

Angel investors and venture capitalists invest with the aim of achieving multiples on their investment when a company is acquired or sells equity in the public markets. If your venture would need to raise many millions in order to bring a product based on your innovation to market, it may be that venture capital is your best or most tactically efficient option.

Philanthropists and foundations fund startups that are developing solutions to problems they care about and whose technologies they believe can have beneficial impact to society. Government agencies have the same goal.

Increasing shareholder value is the chief reason corporations invest in startups—however that value may come in various forms ranging from purely strategic to purely financial, and they might have other goals or constraints that govern the timing and size of investments, and the types ventures in which they invest.

Practical Guidance

I. The Why, When, and How

Here are three questions you'll want to consider when determining what kind of money to raise for your venture, how much of it you should try to raise, and when to raise it:

1. Why do you need to raise funding and how much do you need to raise?
2. What milestones (risk/value inflection points) can you reach with this money?
3. Who would be interested in investing next if you are successful in hitting those milestones?

Regardless of the source of funds, financing requires someone parting with their money. They will only do so if they—whether an individual or an organization—believe your venture will increase the value of that investment. Therefore, the key to fundraising is to understand the motivations and the business model of your funders.

We've found that what most frustrates scientists or engineers as they seek to raise funding is that the decision-making process of all funders has a lot to do with factors beyond lab data or spreadsheets. But that fact is immutable. Some of the metrics funders will use to make investment decisions are:

- Do you have the presence, leadership record, industry knowledge, and charisma that are likely to translate into generating returns on the investment?
- What is your venture's business model?
- Who else is investing in your venture? (Many investors do not want to be the first or only one to jump in.)

Success in financing requires that you identify and appreciate these other motivations for why investors will (or will not) part with their money.

II. When or Whether to Venture into VC

As your organization takes shape, you may start talking to venture capitalists who want to make a significant investment. You don't need to be glued to the Wall Street Journal to know that startups that raise venture capital are not guaranteed a wildly successful future. But neither are all VC-backed ventures doomed to become victims of the latest Silicon Valley hype cycle.

Regardless, chief among your concerns should be: Are the potential investors' expectations aligned with your own goals?

Venture capital is the primary source of funding for startups that have achieved some level of technical validation and commercial success, so it's worth understanding the VC business model and its implications on your business. The VC business model is based on raising money from limited partners (LPs) and investing that money into equity in startups when the value of the equity is low. The fund makes money and pays out the LPs by selling their equity at a later date, when the value of the shares is high. This is either when the startup merges with or is acquired by another company (mergers and acquisitions are generally called M&A) or when the startup makes an initial public offering (IPO).

However, neither of these outcomes are common for startup ventures. Most of them fail to create a return for the VC firms that invest in them. Therefore, in order for VCs to make money, they rely on the startups that do survive and thrive to be exceptionally successful. In fact, the VC business model requires that typically two or three investments in each portfolio return more than 10 times their initial investment. The other part of the VC business model is to raise a new fund every three to four years. The best way to do that is if their prior funded companies are raising new venture rounds every 12 to 18 months at higher valuations.

This means if you raise VC, the standard expectation will be that you raise increasing amounts of money every year and half or so, so you will want a clear line of site of what milestones your company needs to achieve to do so while consistently increasing your valuations and ending in a position to achieve some type of exit (either an M&A or IPO).

Given the focus on a sizable return, venture capitalists are likely to push you to go after the largest possible market or most lucrative application—regardless of what path most interests you. Looking beyond that, venture capital and its business model can have significant positive and negative effects on any startup that pursues this funding route. On the positive side VC money is the most flexible in terms of how it is used, readily available for the right types of companies, and often is connect to a network of influential people that can help with hiring, customer acquisition, and fundraising. The negative side is that if your company’s technology, market, or business model don’t end up fitting into the VC model, then the misalignment often leads to a loss of control, significant dilution, or even lawsuits. Entrepreneurs often don’t realize that the protective provisions and board structures that get set with the first closing of venture capital force the entrepreneurs to work towards finding a way to fit their innovation into the venture capital business model.

There is a great deal more to learn, including the process of due diligence, negotiating term sheets, and other important considerations. There is no shortage of books and other resources that provide more detailed guidance on the process of raising venture capital. We recommend starting with Venture Deals: Be Smarter Than Your Lawyer and Venture Capitalist, by Brad Feld and Jason Mendelson

III. Chart Your Fundraising Journey

The chart below provides an overview of the top benefits and potential downsides of these funding sources for ventures commercializing innovations rooted in the hard sciences.

	P R O S	**C O N S**
Angel Investor	➕ Focus is on early-stage ventures ➕ Deals are generally done more quickly than conventional VC ➕ Investors are often former entrepreneurs who can offer guidance	➖ Investment size smaller than venture capital, so transaction and relationship costs can be high ➖ Motivations of individuals are more varied and harder to predict and manage than institutional investors ➖ Dilutive, meaning you will be selling the angel the right to buy shares in future equity

Venture Capital (and unique forms of VC, such as those made by impact investors)	➕ Can raise a lot of money and build a venture quickly ➕ Limited constraints on how money can be used ➕ Once invested, a firm can be highly motivated to see you raise more money from others ➕ Firm may offer useful business advice and/or access to its network	➖ May lose control of venture based on board structure or contract provisions ➖ Dilutive, meaning that you will sell equity in venture and give board seats to investors ➖ VC will bias toward a fast cadence of growth and value creation in order to match the business model, which may not always be best for your business ➖ Even without control or board seats, investors can be bothersome and possibly litigious
Government Grants (funders include Small Business Admin. (SBA); ARPA-E; DARPA)	➕ Non-dilutive ➕ Aligned with pre-commercial R&D for which the risks, costs, and timing remain highly speculative ➕ Can later help raise funding by adding credibility to venture (within limits, see cons) ➕ May provide runway to further research and development	➖ High administrative burden ➖ Many constraints on use of funds/activities ➖ Capped amounts of $ available (versus VC) ➖ Can cause working capital gaps ➖ Reliance on grants could paint venture as "grant mill" ➖ May distract venture from most effective product or business development focus

Philanthropic or Foundation Funding	➕ Non-dilutive ➕ Aligned with pre-commercial R&D for which the risks, costs, and timing remain highly speculative ➕ May provide runway to further research and development ➕ Potential access to useful network of funders	➖ Administrative burden ➖ Funder may not understand the technology or business you are developing ➖ Funder not likely motivated by commercial outcome of your technology and could unintentionally bias business toward an unsustainable model in pursuit of philanthropic goals
Corporate Venture Capital	➕ Same benefits as venture capital ➕ Investment comes with industry cred ➕ May provide access to the corporate's in-house experts and/or infrastructure ➕ May lead to valuable partnerships with the corporation	➖ Funder not purely motivated by commercial outcome of your technology or business ➖ Funder can be looking to glean information for their own ends ➖ Could have divergent interests if your tech becomes a potential threat ➖ Could potentially limit/discourage interaction with other potential corporate partners

Joint Venture with Corporate Partner	➕ Can give you instant credibility in target market if made with right partner ➕ Intellectual property created by joint venture could be positive for your venture ➕ Potential for fast and strategic growth ➕ Potential first customer providing early revenue ➕ Can leverage off superior resources for research, marketing, etc.	➖ Can take long time and expense to negotiate the complexities of a joint venture, which may ultimately fall through ➖ Intellectual property created by joint venture could be negative for your venture (loss of sole IP) ➖ You will need funding or assets to contribute to the joint venture ➖ Could potentially limit/discourage interaction with other potential corporate partners
Revenue	➕Non-dilutive ➕ You have a product and are selling it -- no better proof of value ➕ It makes you attractive to potential partners ➕ Reduces reliance on other funding avenues	➖ Can take a very long time to begin generating revenue, compared to taking investments or loans ➖ Revenue alone rarely comes at the optimal time or magnitude needed to invest in building and growing your business at any time ➖ Can be highly inconsistent and hard to predict
Debt	➕ Predictable money without selling equity in venture ➕ Limited strings attached about how/when/where you spend the money	➖ Lenders very unlikely to invest in pre-revenue ventures ➖ Failure to achieve your debt covenants can lead to total loss of control of the company ➖ Can prevent use of certain grant programs

Use the pros/cons chart as a handy reference, but note that this chapter is only meant to introduce you to the basics of funding a commercial venture. As with every other topic we've covered in this handbook, you will find myriad other resources for how to best fund a startup.

In fact, we've only just scratched the surface when it comes to funding from these various sources. Our goal here is to provide a basic overview.

Appendices

Chapter One Appendix T Equals Zero Meeting Template

Chapter Two Appendix The Alignment Index

Chapter Three Appendix I. Chiang Boas: Beyond the Back of the Envelope

Chapter Three Appendix II. Cummins Spec Sheet

Venture XX
t=0 Meeting

Name
Date

Agenda

1. Defining success
2. Identification of barriers and risks
3. Creating value

1. Defining Success

What does a win look like for you?

Consider…

- Do you have any boundary conditions on the tech you build or markets you serve?
- What scale of a business will you have to build to be worth the effort?
- How quickly do you have to get there to be satisfied?
- What role do you want to have in the business moving forward?
- Are you willing to trade control for an ability to learn/grow/scale faster?
- How important is personal fortune/fame:

Which of above are must-haves vs. should-haves vs. nice-to-haves?

What do you think will be the biggest hurdles to achieving your win?

Can you name a founder whose journey you would like to emulate?

What does a win look like for you?

:

Personal	Project/Venture
Long-term:	Long-term:
Short-term:	Short-term:

What does failure look like for you?

Hypotheses to test

HYPOTHESIS

EXPERIMENT

VALIDATION / ACTION ITEM / FOLLOW-UP QUESTIONS

(REPEAT)

2. Identification of Barriers and Risks

What are the biggest risks and skepticisms you will face in building your business?

Consider…

- Technology: why your tech might fail to achieve target cost/performance?
- Market: why the market might fail to adopt your tech?
- Finance: why your company might fail to secure adequate financing?
- Team: why your team might fail to deliver credibility or results?

What experience, skills, knowledge, or networks will be key for your advisory board?

Are there any specific people (or phenotypes) that you would ideally recruit as advisors?

Identification of Barriers and Risks

Biggest risks and skepticisms?

Technology:

Market:

Finance:

Team:

Advisory Board (to assist in identifying risks/barriers)

Wish List:

Strategic: key advisor skills/experiences/networks:

1. Priority 1:
2. Priority 2:
3. Priority 3:

Opportunistic: key individuals who you trust or have already expressed interest:

4. Candidate 1:
5. Candidate 2:
6. Candidate 3:

3. Creating Value

What do you know about your first product?

Consider…

- Who will be your first customer?
- Why will they buy your product?
- What are their alternatives?
- What if they decide to do nothing? Will they experience significant pain?

If asked, could you write a spec sheet for your first product today?

Can you quantify the value your product will create and how much it will cost to produce?

THE ALIGNMENT INDEX
Early-stage hard-tech development framework

cyclotronroad

Risk levels: red ●, yellow ●, green ●

THE ALIGNMENT INDEX

	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5
TECHNOLOGY	**RESEARCH**	**CONCEPT**	**FEASIBILITY**	**PROTOTYPE**	**PRODUCT**
Product	○ concept defined ○ literature reviewed ○ state-of-the-art reviewed ○ key differentiator identified	○ tech risks defined ○ tech dev plan created ○ min viable product hypothesis ○ tech performance goals	○ tech performance demo ○ components demo ○ first product defined ○ basic engineer design ○ engineering analysis ○ failure mode analysis	○ system design ○ major equipment list ○ safety assessment ○ min viable product demo	○ scale up plan ○ site evaluation ○ commissioning ○ failure mode analysis ○ first product launched
Intellectual property	○ provisional patents	○ IP landscape analysis ○ blocking IP identified	○ IP strategy ○ core IP filed	○ defensive IP filed ○ licenses secured	
Cost-performance analysis		○ back-of-the-envelope cost estimate	○ first order cost model ○ process flow diagram ○ bill of materials	○ cost model sensitivity analysis	
MARKET	**RESEARCH**	**OPPORTUNITY**	**BUSINESS CASE**	**VOICE OF CUSTOMER**	**PRODUCT VALIDATION**
Market	○ market surveys	○ TAM-SAM-SOM	○ market requirements doc ○ value chain analysis	○ detailed market segmentation	
Business		○ biz model hypothesis ○ market entry point	○ biz model validation ○ regulatory risks addressed	○ supply chain analysis ○ sales channels identified	○ sales cycle validated
Customer	○ value prop hypothesis ○ customer discovery	○ customer validation ○ value prop validation ○ performance specs defined	○ demo plan and partner ○ product pricing ○ product spec validation	○ first customers	○ customer feedback ○ quality assurance plan ○ customer service plan
TEAM	**ADVISORS**	**CORE TEAM**	**BUSINESS TEAM**	**EXECUTION TEAM**	**GROWTH TEAM**
Team	○ founders ○ team gap analysis	○ hiring plan ○ core team hires	○ business dev team	○ product dev. team	○ management team ○ sales / sales support team
Advisors	○ advisory board (>2)	○ relationship gap analysis	○ advisory board (>4)	○ board of directors	
Partners	○ potential partners id	○ initial partnership screen	○ relationship agreements	○ suppliers ○ co-developers	○ sales channel partners
FINANCE	**SCOPING**	**NON-DILUTIVE**	**SEED FINANCING**	**REVENUE PLAN**	**COMMERCIAL FINANCING**
Financials	○ accounting set-up		○ 3-year budget	○ funding plan	
Non-dilutive funding	○ ID agencies, programs ○ DUNS, SAM, etc. ○ grant applications	○ ID program managers ○ grant awards	○ financial statements	○ follow-on grants	
Private investment		○ elevator pitch ○ opportunity pitch deck (seed) ○ financing plan	○ seed financing	○ business pitch deck	○ commercialization financing
Revenue			○ JDA, NRE, LOI, MTA	○ revenue projections	○ purchase order

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Beyond Back of the Envelope

Yet-Ming Chiang
Ryan Boas

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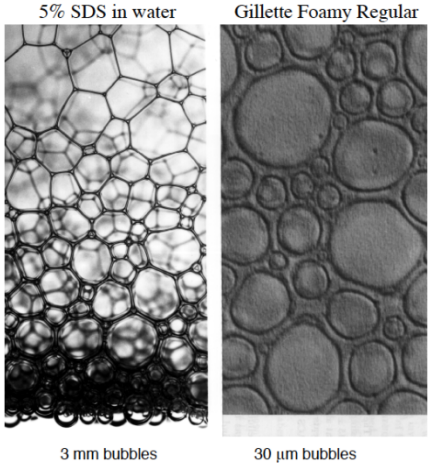
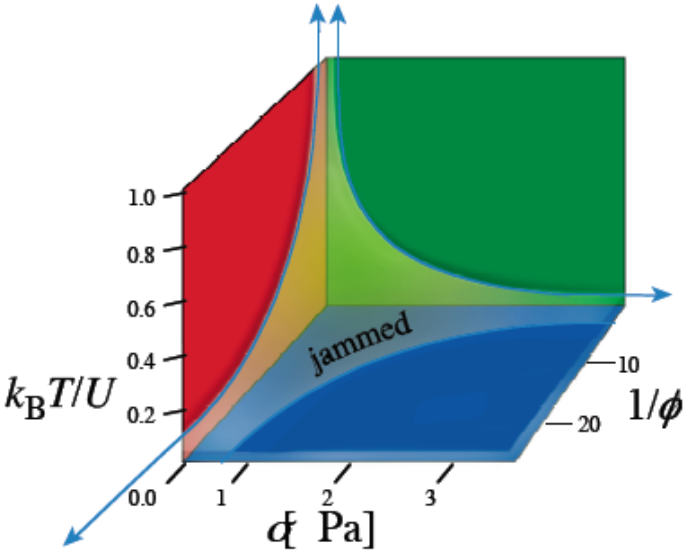
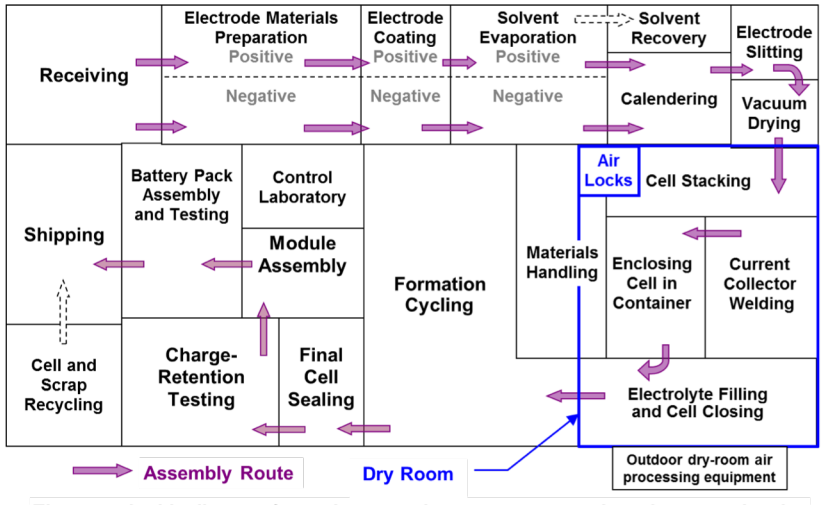
Out of the comfort zone

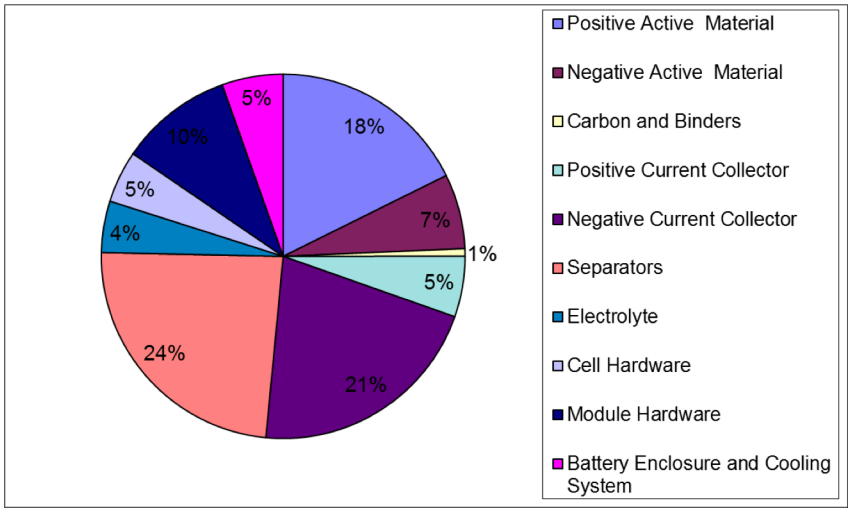
Research





Business





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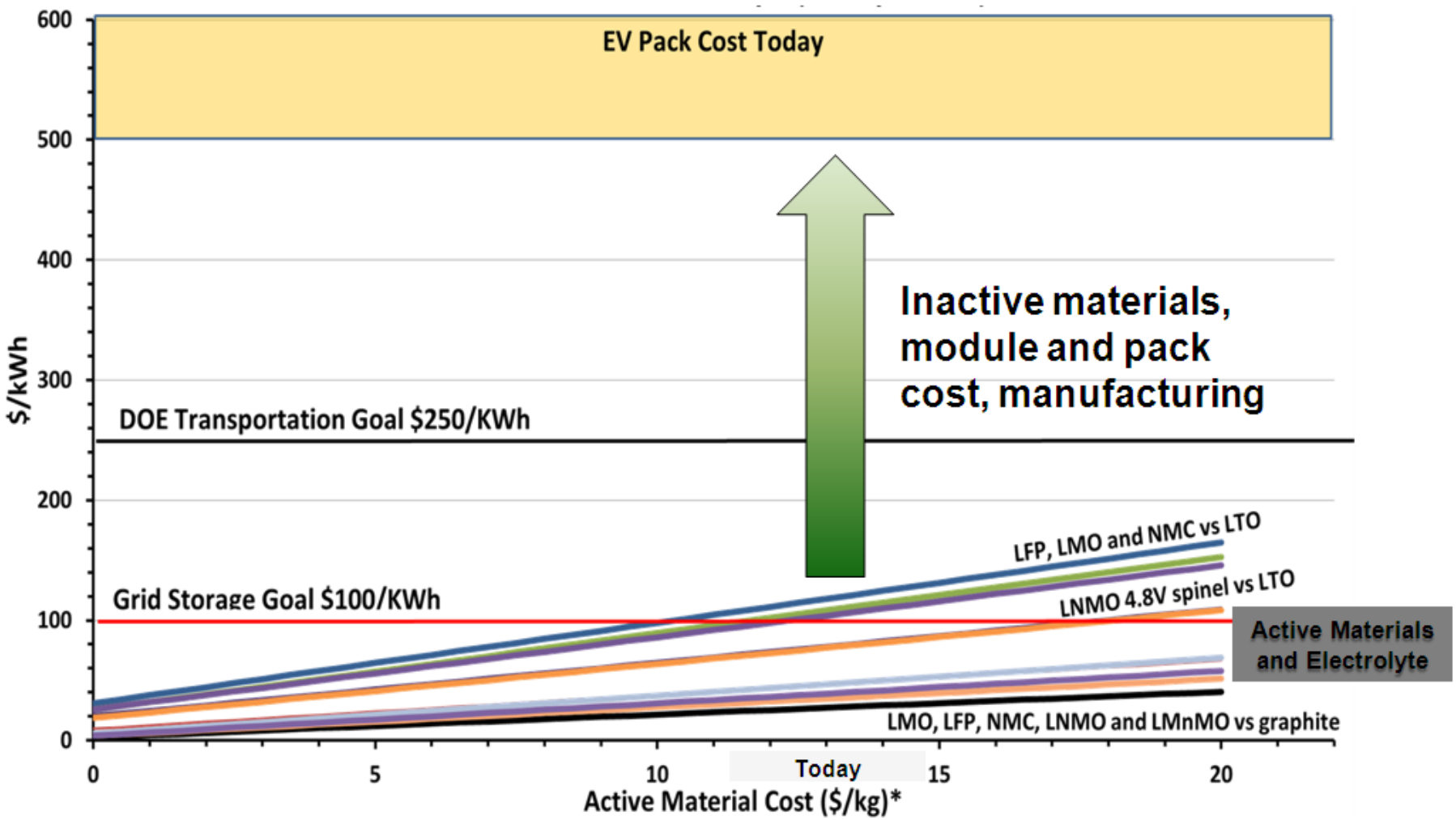
Attacking the Right Problem



* Assumes cathode cost = anode cost

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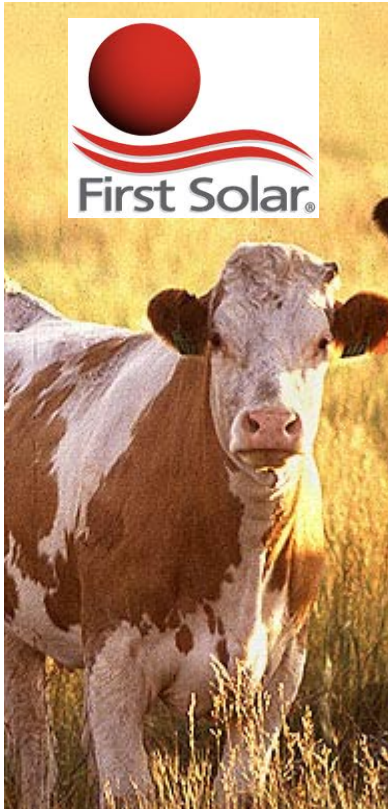
“Thinning the herd”- Dec. 3, 2008

240+ thin film PV companies

One clear success



Note: Public domain image. USDA 5/19/2003

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Live and Die By Your Cost Model

- Be fluent in the concepts and mechanics of cost modeling
- Use cost modeling to avoid the 4 most common pitfalls of technology development
- Build your own cost model

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BASIC CONCEPTS

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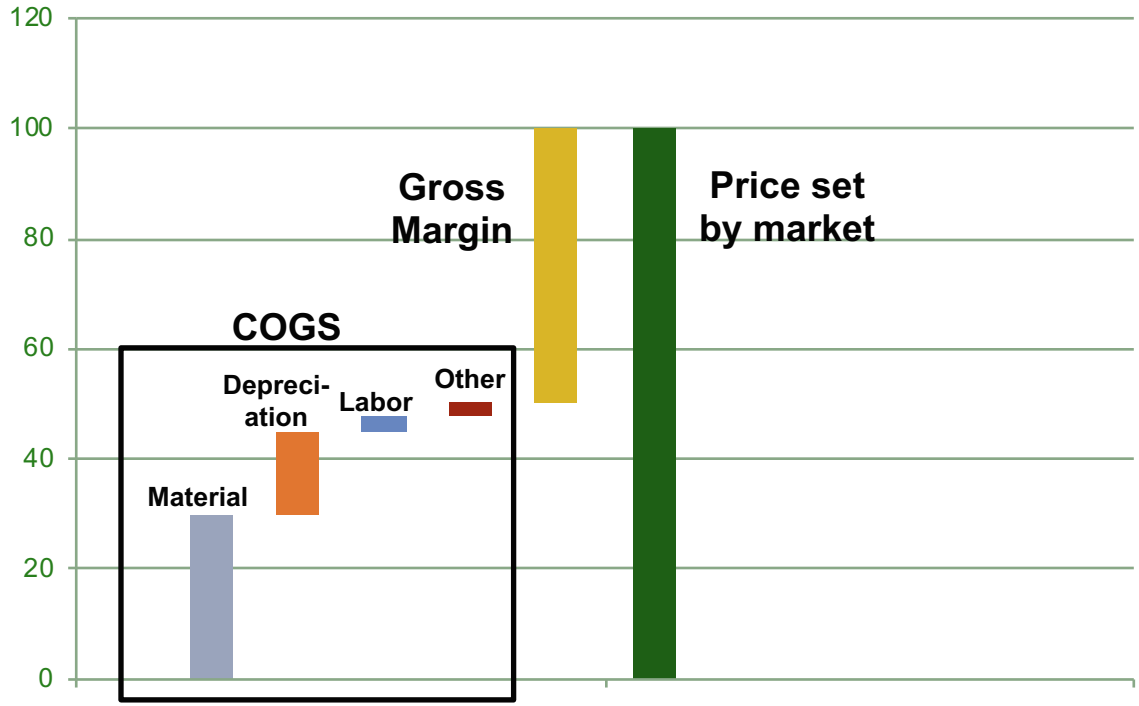
Price – COGS = Gross Margin



Definitions

- Price – What the market pays
- COGS – Cost of Goods Sold
  - Materials
  - + Depreciation
  - + Labor
  - + Other

- BOM – Bill of Materials
- Note: Materials ≠ BOM

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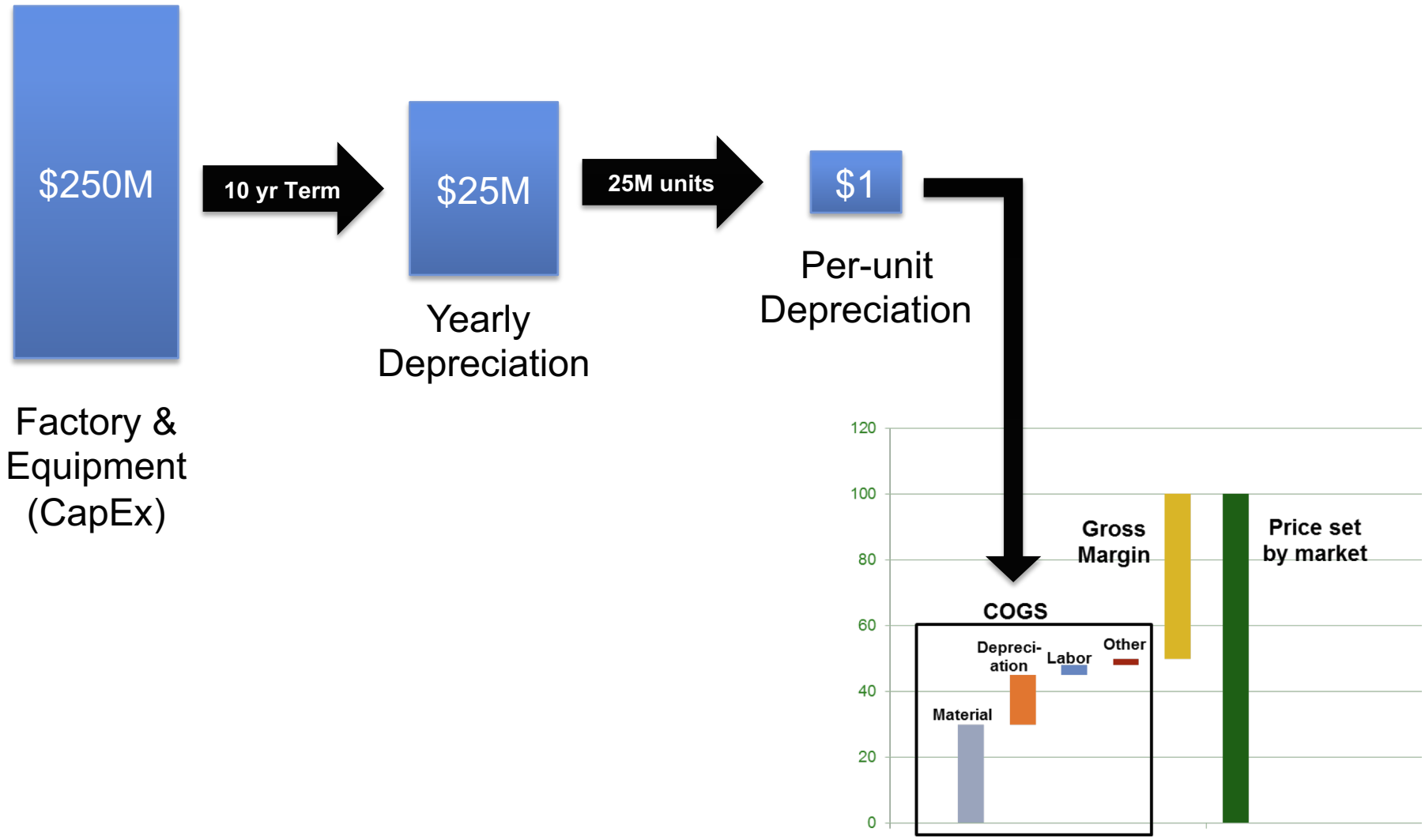
Depreciation = amortized CapEx



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Integrate Cost & Performance Models

		Material A	Material B
Cost Model	COGS ($)	$750	$1,000
Performance Model	Energy (kWh)	2	2
	Life (cycles)	3,000	10,000
Integration	**Life cycle cost ($/kWh)**	**$0.13**	**$0.05**

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TOP PITFALLS

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The 4 most common pitfalls of developing technology without a guiding model

1. Attacking the wrong problem
2. Misunderstanding state of art and trajectory
3. Idealizing system costs and manufacturing
4. Blind to system sensitivities

© Andrew Dunn, 24 September 2005.

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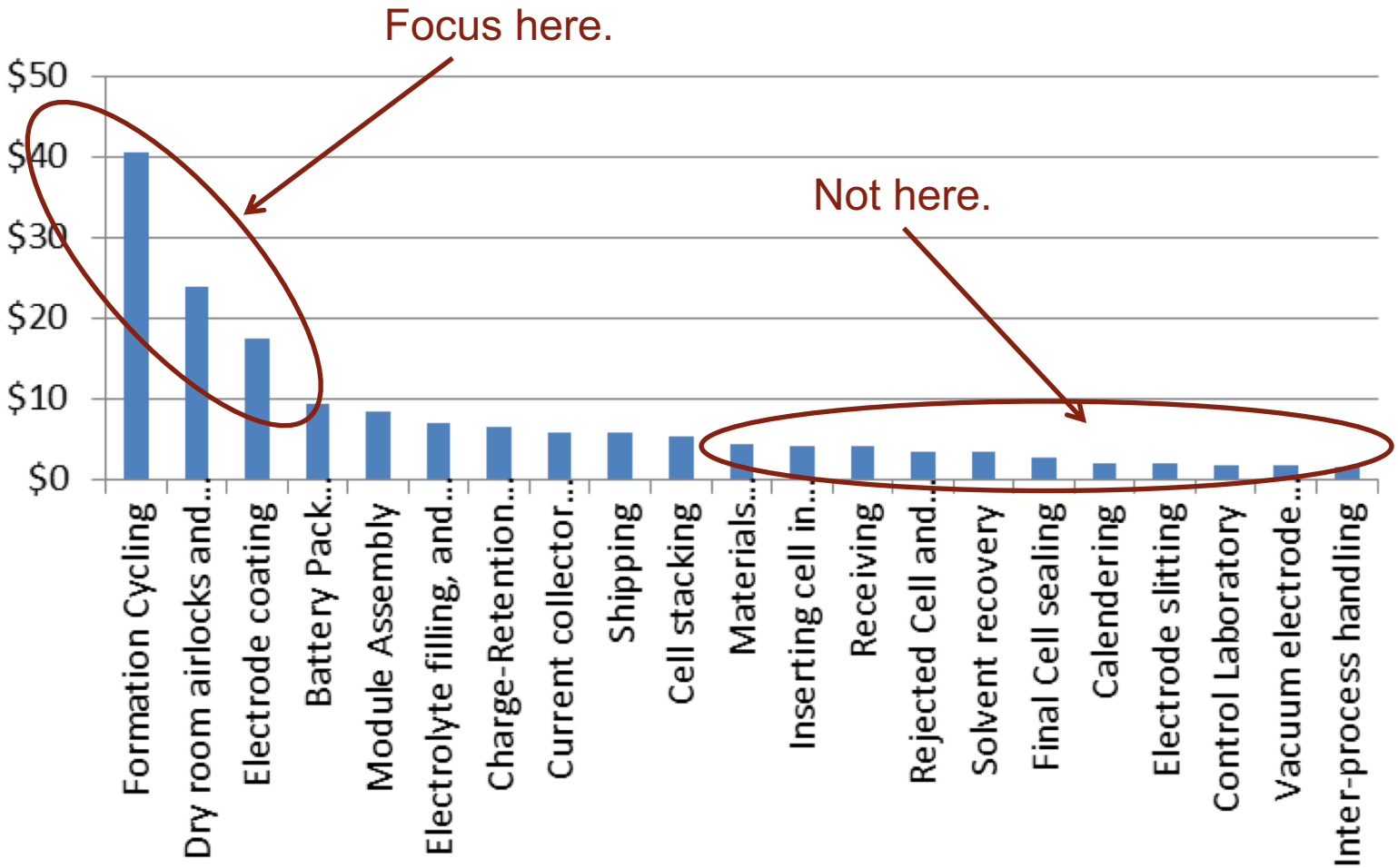
Attacking the Wrong Problem



Source: Argonne BatPaC, v1.0. Battery 1 selected with default values.

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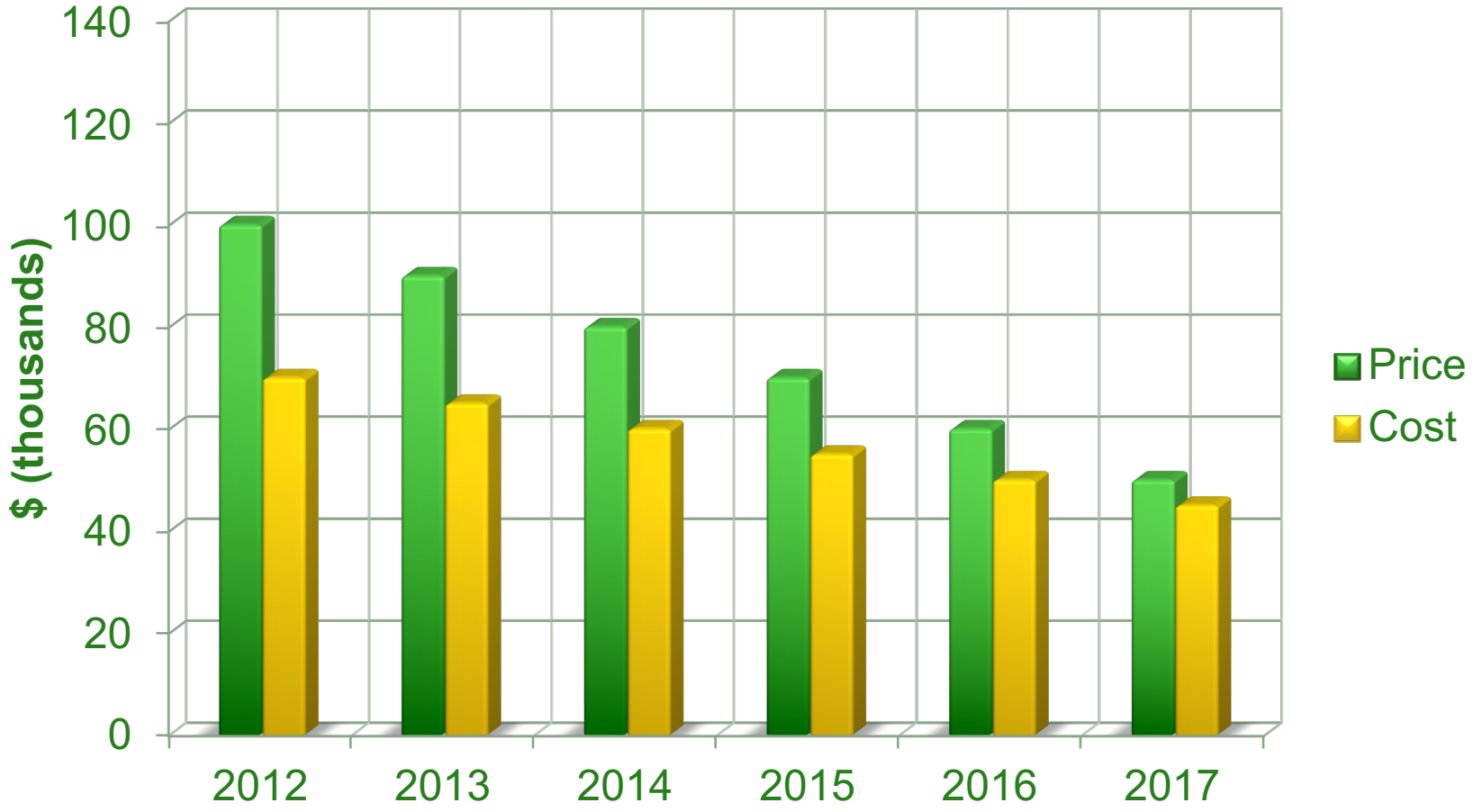
Misunderstanding Trajectory



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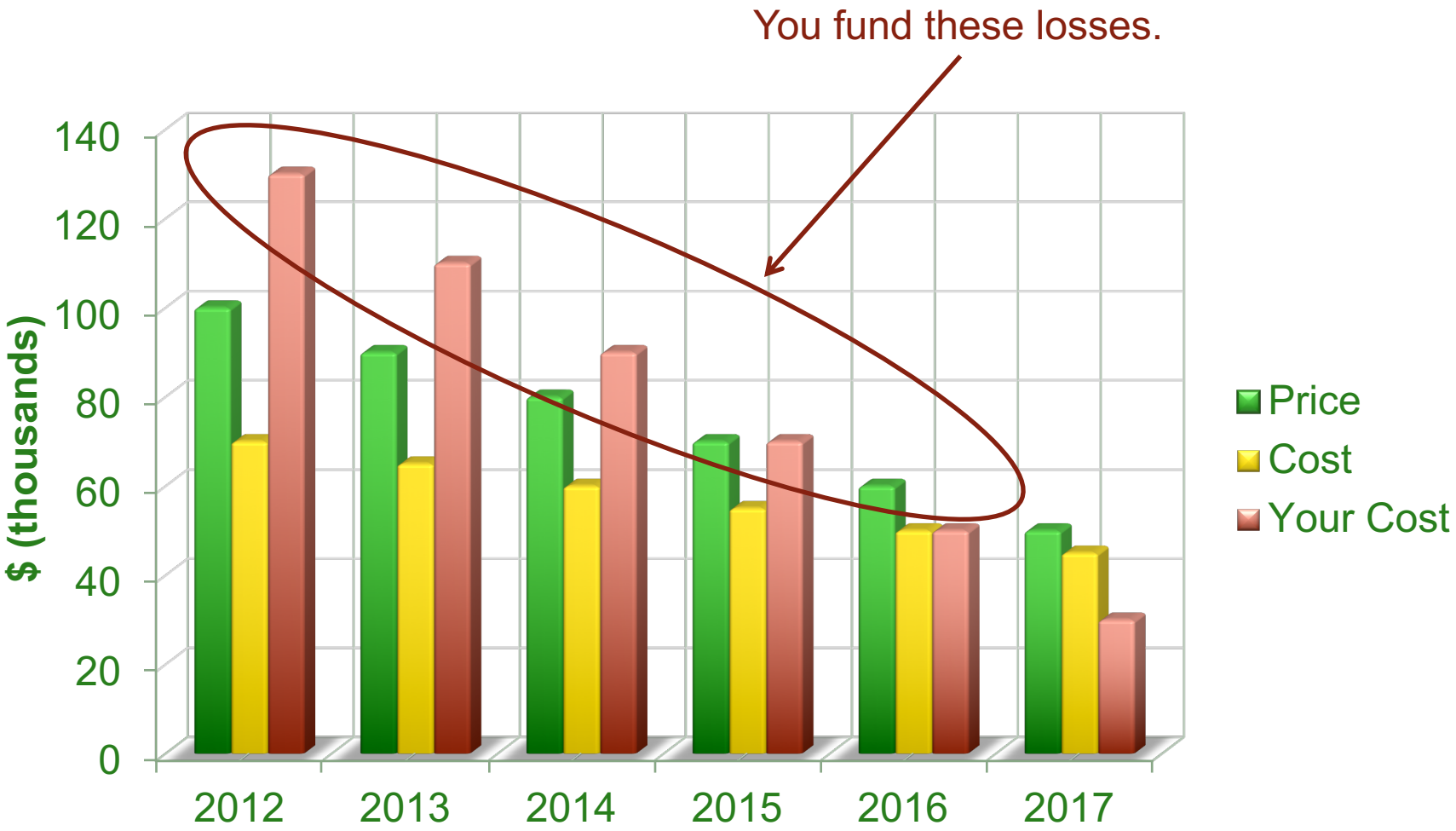
Your Position in Trajectory



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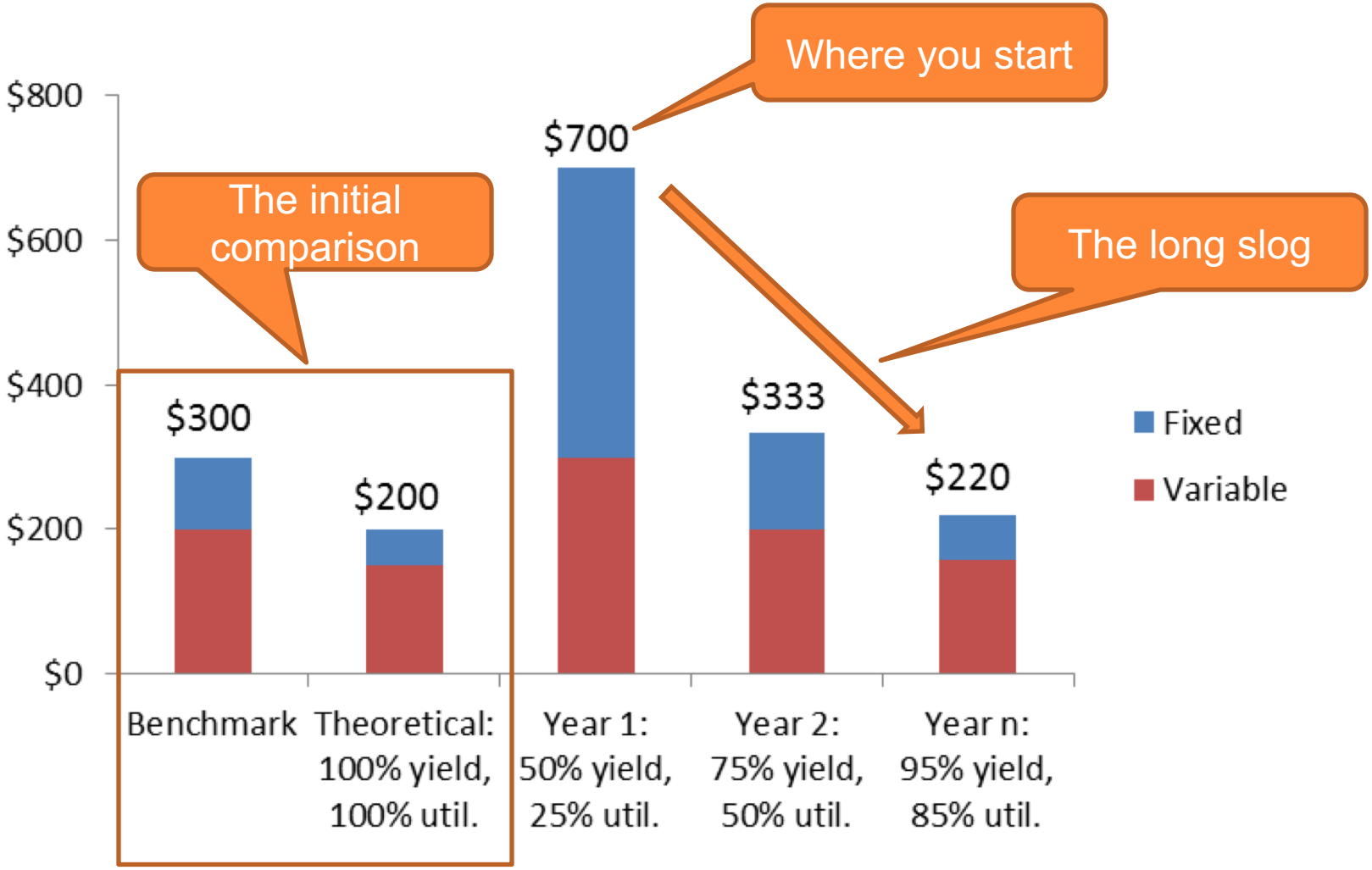
Idealizing: The 100% Fallacy



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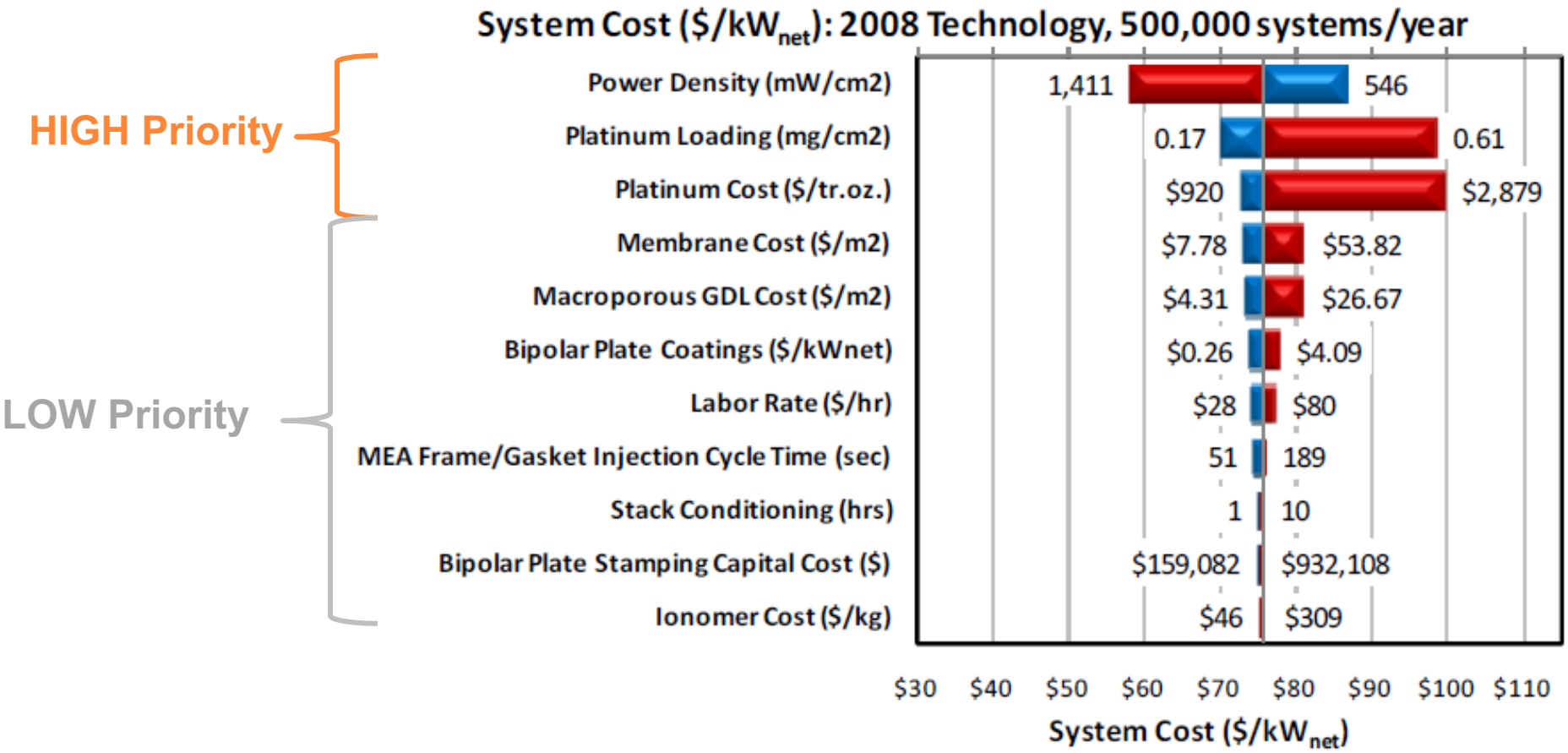
Misunderstanding Sensitivities



Tornado Chart Example for PEM Fuel Cells from: http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/mass_production_cost_estimation_report.pdf

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HOW TO GET STARTED

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Zeroeth Order – Back of the Envelope

A very simple back of envelope estimate is a great starting point.

1. Use raw materials costs to provide a rough lower bound on cost
2. Make optimistic guess of performance using modeling or lab results
3. Adjust roughly to accommodate balance of systems, yield, margins
4. Compare with state of the art (via experts, validated models)
5. Ask outside experts to give you their back-of-the-envelope assessment. Their intuition is highly valuable.

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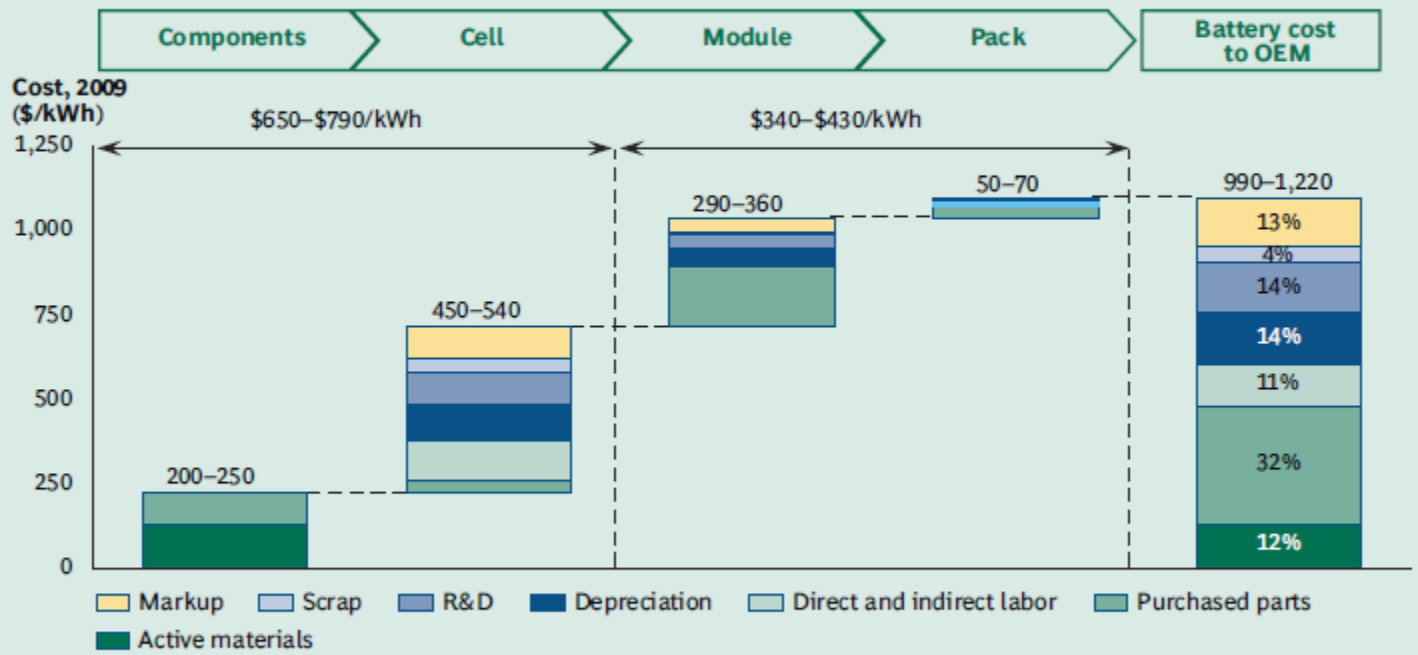
Zeroeth Order – Things you can Google

Exhibit 3. Batteries Cost OEMs About $1,100 per kWh at Low Volumes



Sources: Interviews with component manufacturers, cell producers, tier one suppliers, OEMs, and academic experts; Argonne National Laboratory; BCG analysis.
Note: Exhibit shows the nominal capacity cost of a 15-kWh NCA battery and assumes annual production of 50,000 cells and 500 batteries, as well as a 10 percent scrap rate at the cell level and a 2 percent scrap rate at the module level. Numbers are rounded.

Source: BCG

Google is a great starting point, but don't rely solely on reports, which can be erroneous or outdated – validate with experts in the field!

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First Order – Develop a base model

- A simple, but comprehensive model will be the workhorse for your technology development decisions.
- Model the physical parameters of your system
  - Model performance based on changes to those parameters
- Tie design parameters to materials and component costs
  - Use real cost data from reports or direct supplier research
  - Take care on volume assumptions
- Build a best-effort manufacturing model
- Apply industry-standard adjustment factors for balance of systems, yield, and margins
- Run a sensitivity analysis to see how design variables affect your key performance metrics
  - Make sure you know which performance metrics are valued by the market

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Cost/Performance Model

Cathode

Anode

Margin

Margin

Power Determining Parameters

Stack Geometry

Tank Geometry

Stack Material Costs

350
300
250
200

Number of Cells in Flow Stack vs. $\frac{P}{E}$

nCells

20000
15000
10000
5000

0.5
1.0
1.5
2.0

Fuel

PowerSpecific

Tank Material Costs

Slurry Material Costs

Slurry Composition

Hardware Material Properties

Slurry Material Properties

Above and Beyond BOM Costs

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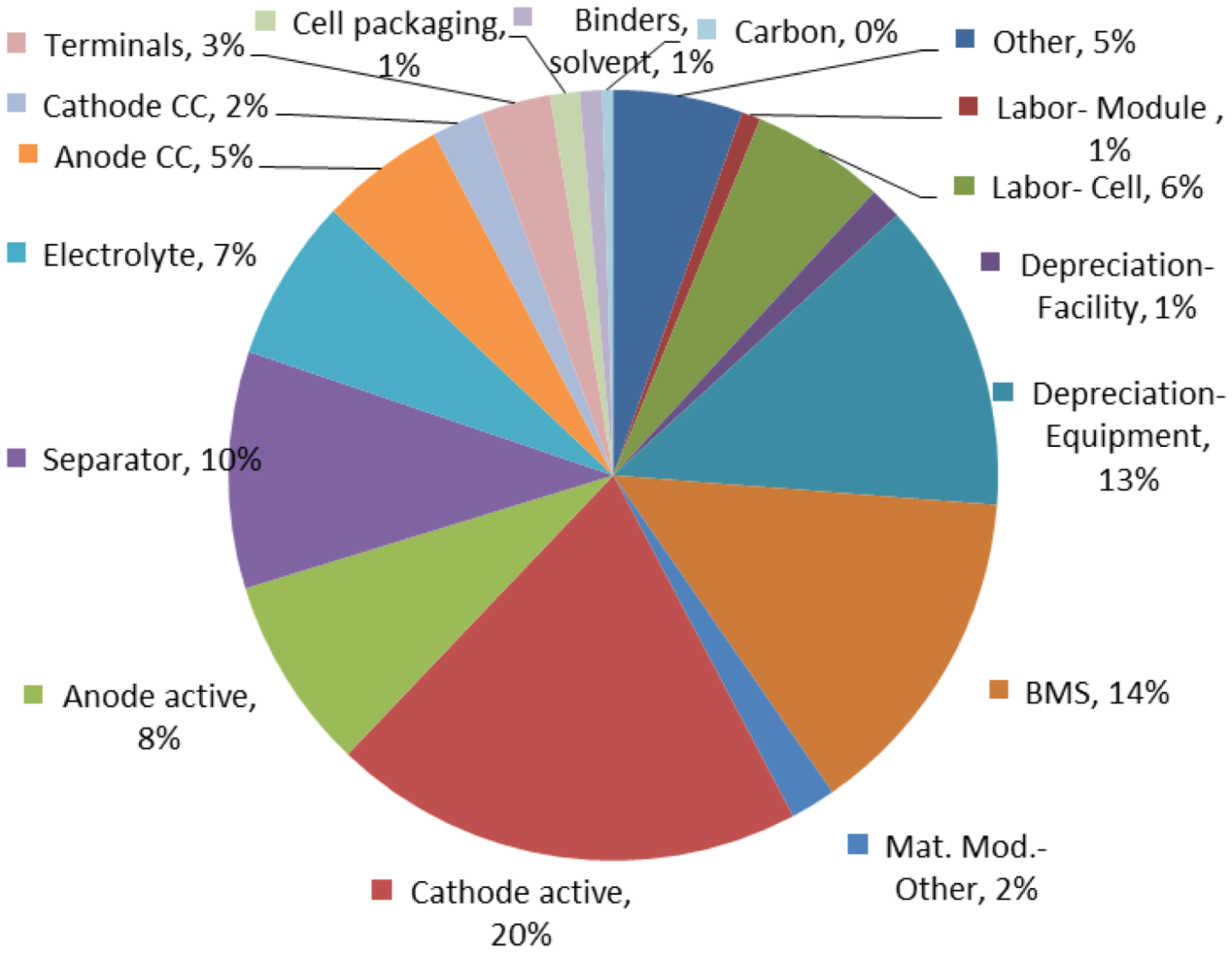
Argonne Battery Model Baseline



Argonne NATIONAL LABORATORY

http://www.cse.anl.gov/batpac/index.html

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Behind the Charts - Materials

3							
4	**System Chemistry Input**						
5	**Finished Cell Materials**					**Battery 1**	**Ba**
6	Positive Electrode, g			Weight %	Density		
7	Active material			89	4.78	84.57	
8	Carbon 1	SFG6		6	1.825	5.70	
9	Binder			5	1.77	4.75	
10	Void		Vol. %	32		-	
11	Total			100	2.749	95.02	
12	Negative Electrode, g			Weight %	Density		
13	Active material			95	2.24	60.18	
14	Carbon			0	1.95	-	
15	Binder			5	1.10	3.17	
16	Void		Vol. %	34		-	
17	Total			100	1.406	63.34	
18	Balance of Cell			Thick., µm	Density		
19	Positive foil, m^2		Al	20	2.70	1.187	
20	Negative foil, m^2		Cu	12	8.92	1.242	
21	Separator, m^2			20	0.46	2.278	
22	Electrolyte , L				1.20	0.0524	
23	Positive terminal assembly, g					8.4	
24	Negative terminal assembly, g					27.9	
25	Cell container, g			150	2.12	15.8	
26	Cell mass, g					491	
27	Length-to-width ratio for positive electrode					1.30	

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Behind the Charts – Manufacturing

1	**Manufacturing Cost Calculations**				
2	**LiNi0.80Co0.15Al0.05O2-Graphite**				
3					
4			**Battery 1**	**Battery 2**	**Bat**
5	**Annual Processing Rates**				
6	Number of batteries manufactured per year		100,000	100,000	1
7	Energy, kWh per year		357,143	714,286	1,07
8	Number of accepted cells per year		7,200,000	7,200,000	7
9	Number of cells adjusted for yield		7,578,947	7,578,947	7,5
10	Electrode area, m^2 per year		16,013,765	10,377,976	9
11	Positive active material, kg per year		695,162	1,399,387	2,1
12	Negative active material, kg per year		494,652	991,550	1,4
13	Binder solvent, kg per year		286,396	576,526	86
14	Dry room operating area, m^2		2,341	2,272	
15	**Direct Materials Costs**				
16	**Total Cell Materials per Accepted Cell**	**Yield, %**			
17	Positive Electrode Materials (dry), g	92.2			
18	Active Material		96.6	194.4	
19	Carbon		6.5	13.1	
20	Binder PVDF		5.4	10.9	
21	Binder Solvent (NMP)		39.8	80.1	
22	Total (dry)		108.5	218.4	
23	Negative Electrode Materials (dry), g	92.2			
24	Active Material		68.7	137.7	
25	Carbon Black		0.0	0.0	
26	Binder		3.6	7.2	
27	Binder Solvent (water)		26.5	53.2	
28	Total (dry)		72.3	145.0	
29	Positive current collector (aluminum foil), m	90.2	1.385	0.884	
[illegible]	[illegible]	90	[illegible]	[illegible]	

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Behind the Charts - Performance

Program for Calculating Performance and Materials Requirements					
LiNi0.80Co0.15Al0.05O2-Graphite					
	Battery 1	Battery 2	Battery 3	Battery 4	Battery
Calculated Cell Parameters					
Capacity, Ah					
Cell group capacity	13.5	27.2	41.1	55.1	69.3
Cell capacity	13.5	27.2	41.1	55.1	69.3
ASI Calculation					
Limiting current density, mA/cm^2	85	85	85	85	85
Limiting C-rate, A/Ah	27	27	27	27	27
Electrode system ASI for power, ohm-cm^2	50.3	32.3	30.2	29.3	28.8
Current collector resistance parameter, ohms	0.005409	0.005409	0.005409	0.005409	0.005
Current collector ASI, ohms-cm^2	0.526	0.679	0.900	1.124	1.351
Total cell terminal ASI, ohms-cm^2	0.261	0.145	0.115	0.099	0.088
Cell and battery terminal connections, ohms	0.000306	0.000306	0.000306	0.000306	0.0003
Total cell hardware and battery resistance, ohm-cm^2	0.877	0.882	1.070	1.277	1.49
Total cell ASI for power, ohm-cm^2	51.2	33.2	31.2	30.6	30.3
Total cell ASI for energy (C/3 rate), ohm-cm^2	66.0	57.1	55.6	55.1	54.9
Electrode Thickness calculation					
Thickness of positive electrode at target %OCV, µm	16.4	50.8	81.3	111.5	141.5
Thickness of negative electrode at target % OCV, µm	20.7	64.2	102.8	140.9	178.8
Positive electrode thickness at adjusted % OCV, µm	16.4	50.8	81.3	111.5	141.5
Negative electrode thickness at adjusted % OCV, µm	20.7	64.2	102.8	140.9	178.8
Cell Area Calculation					
Area determined at target % OCV	21,129	13,693	12,904	12,624	12,50
Area limited by max. allowed electrode thickness,	1,456	2,931	4,422	5,931	7,4
Cell area based on total ASI for power, cm^2	21,12	13,693	12,904	12,624	1

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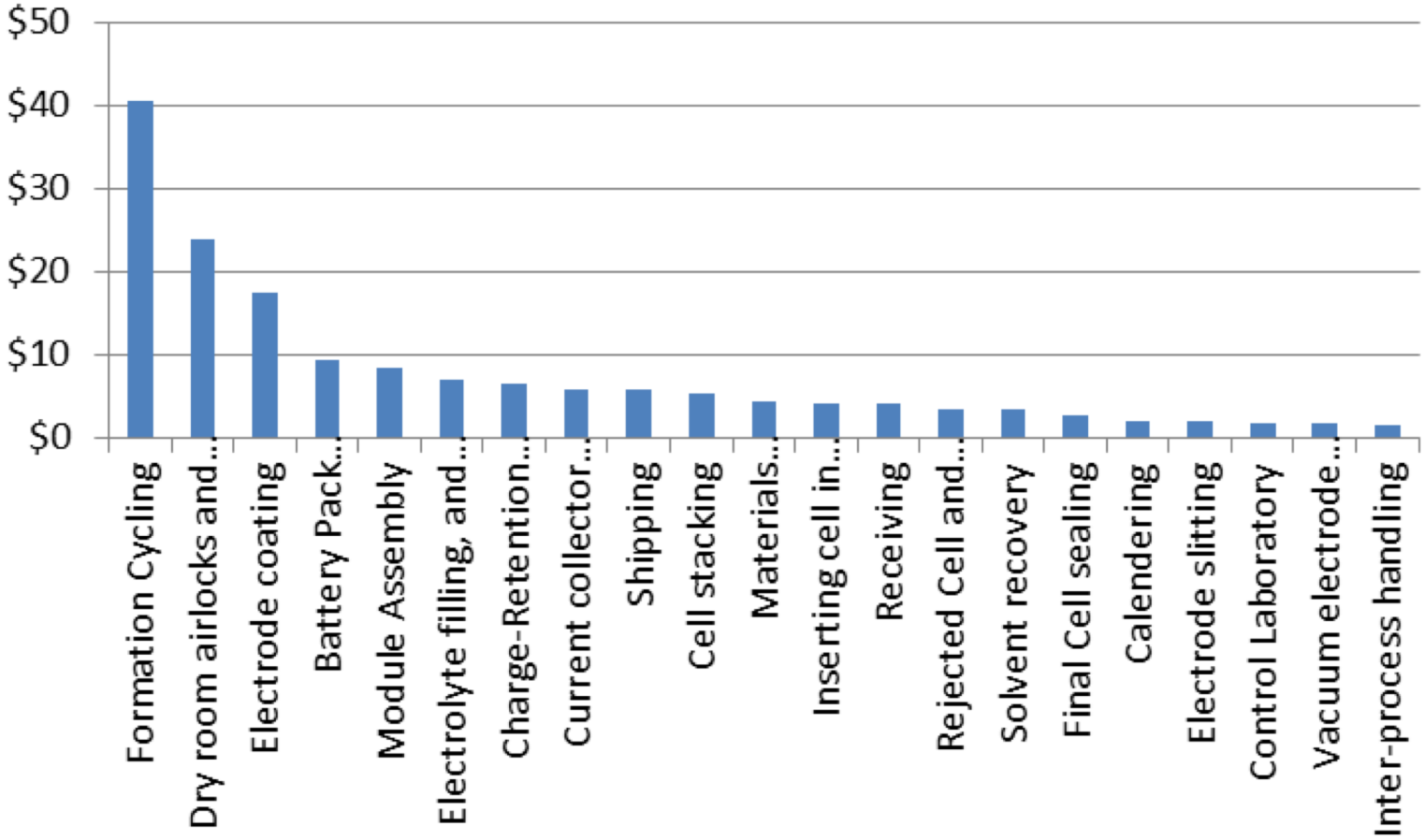
Capex Pareto



Source: Argonne BatPaC, v1.0. Battery 1 selected with default values.

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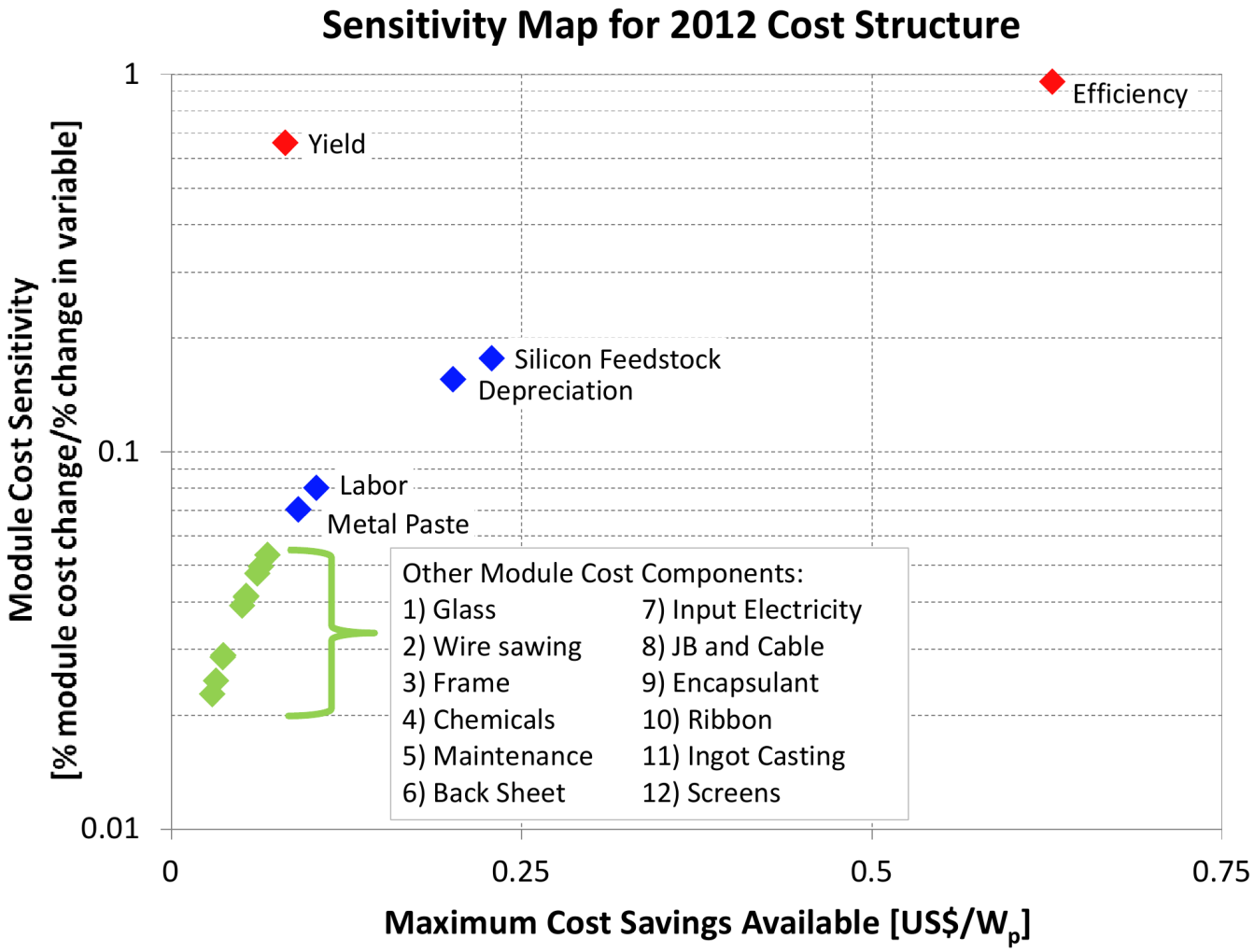
Sensitivity Analysis



D. M. Powell, M. T. Winkler, H. J. Choi, C. B. Simmons, D. B. Needleman and T. Buonassisi, *Energy & Environmental Science*, DOI:10.1039/C2EE03489A, 2012.

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Nth Order – Iterate and Expand

As the need arises, expand your model to include more complexity and detail

- Use your model to drive design of experiments and refine the model based on results
- Incorporate actual cost data for various projected volumes from specific potential suppliers
- Develop internal models for balance of systems, yield, and margins based on actual design, manufacturing, and go-to-market plans.
- Expand sensitivity analysis to help evaluate complex design trade-offs
- Consider building a robust interface to allow for protected sharing of your model with potential investors, partners, etc.

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Know Thy Lingo

- BOM (pronounced ‘bom’) vs. COGS
  - BOM is the bill of materials, applies to a single unit
  - COGS includes materials, depreciation, labor, other costs and is impacted by yield, utilization
- Price vs. cost vs. margin
  - Price set by market
  - Cost (COGS) is the full cost to manufacture your product
  - Margin is what is left to run the rest of the company and make a profit
- Yield
  - (Product that rolls off the mfg line minus damaged product) divided by (product that rolls off the mfg line)
- Utilization
  - The fraction of total factory capacity that was actually used. Total factory output divided by total factory capacity.
- Tornado chart
  - Chart that ranks the relative importance of cost inputs. Tells you what to focus on. Looks like a tornado (kind of).
- Pareto chart
  - Chart that shows individual contributions to cost in a ranked order.

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Summary

- Quantify industry price and cost trends
- Model COGS for your technology
  - Start early
  - Develop iteratively with best available information
- Be realistic about the progression from today to your future vision

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Thank You.

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KTA38-G5 Diesel Generator

Description

The KTA38-Series benefits from years of technical development and improvement to bring customers an innovative and future proof diesel engine that keeps pace with ever changing generator set requirements.

Recognized globally for its performance under even the most severe climatic conditions, the KTA38-Series is widely acknowledged as the most robust and cost effective diesel engine in its power range for the generator set market

Features

Aftercooler: Large capacity after cooler results in cooler, denser intake air for more efficient combustion and reduced internal stresses for longer life.

Fuel System: Cummins exclusive low pressure PT™ system with wear compensating pump and integral dual flyweight governor. Camshaft actuated fuel injectors give accurate metering and timing. Fuel lines are internal drilled passages in cylinder heads. Spin-on fuel filter.

Cooling System: Gear driven centrifugal water pump. Large volume water passages provide even flow of coolant around cylinder liners, valves and injectors. Bypass thermostats regulate coolant temperature. Spin-on corrosion resistors check rust and corrosion, control acidity and remove Impurities.

Cylinder Block: Alloy cast iron with removable wet liners. Cross bolt support to main bearing cap provides extra strength and stability.

Turbocharger: Cummins Turbo Technologies (CTT) exhaust gas driven turbocharger mounted at top of engine provides more power, improved fuel economy, altitude compensation, and lower smoke and noise levels.

Ratings Definitions

Emergency Standby Power (ESP): Applicable for supplying power to varying electrical load for the duration of power interruption of a reliable utility source. Emergency Standby Power (ESP) is in accordance with ISO 8528. Fuel Stop power in accordance with ISO 3046, AS 2789, DIN 6271 and BS 5514.

Limited-Time Running Power (LTP): Applicable for supplying power to a constant electrical load for limited hours. Limited-Time Running Power (LTP) is in accordance with ISO 8528.

Prime Power (PRP): Applicable for supplying power to varying electrical load for unlimited hours. Prime Power (PRP) is in accordance with ISO 8528. Ten percent overload capability is available in accordance with ISO 3046, AS 2789, DIN 6271 and BS 5514.

Base Load (Continuous) Power (COP): Applicable for supplying power continuously to a constant electrical load for unlimited hours. Continuous Power (COP) in accordance with ISO 8528, ISO 3046, AS 2789, DIN6271 and BS 5514.

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Product Specifications

	KTA38-G5		
Electrical Output (1500 rpm, 50 Hz)	Standby	Prime	Base
Gross engine output	970 kWm	880 kWm	656 kWm
Net engine output	937 kWm	857 kWm	633 kWm
Typical generator output	880 kWe / 1100 kVA	800 kWe / 1000 kVA	600 kWe / 750 kVA
Fuel Consumption (1500 rpm, 50 Hz)			
Full load (100%)	970 kWm	880 kWm	656 kWm
Half load (50%)	—	440 kWm	—
Quarter load (25%)	—	220 kWm	—
General Engine Data			
Type	4 cycle, Turbocharged and After-cooled		
Bore	159 mm		
Stroke	159 mm		
Displacement	38 L		
Cylinder block	12-cylinder,direct injection, 4-cycle diesel engine		
Battery charging alternator	35A		
Starting voltage	24V		
Fuel system	Direct injection, EFC (Electric Fuel control) governor		
Fuel filter	Dual spin on paper element fuel filters with standard water separator		
Lube oil filter type	Spin on full flow filter		
Lube oil capacity	140 L		
Flywheel dimensions	SAE 0		
Cooling Performance Data			
Cooling System Design	JWAC		
Coolant Ratio	50% ethylene glycol; 50% water		
Total Coolant Capacity	218.5 L		
Limiting Ambient Temperature	50°C		
Fan Power	20 kWm		
Cooling System Air Flow	18.9 m^3/s		
Air Cleaner Type	Dry replaceable element with restriction indicator		
Weight & Dimensions			
Length	3172 mm		
Width	1752 mm		
Height	2004 mm		
Weight (dry)	4990 kg		

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Base load (continuous) power (COP):

Applicable for supplying power continuously to a constant electrical load for unlimited hours. Continuous Power (COP) in accordance with ISO 8528, ISO 3046, AS 2789, DIN 6271 and BS 5514.

Certifications

This engine has been built to comply with CE certification.

This engine has been designed in facilities certified to ISO9001 and manufactured in facilities certified to ISO9001 or ISO9002.

Cummins G-Drive Engines

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