# The Successful Management of New Technology Projects

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Abstract: If we are to meet the challenges of countering climate change and environmental degradation, the projects community will be required to deliver hundreds and perhaps thousands of new technology projects over the next 25 years. Under the best circumstances, that would be difficult. But circumstances are far from ideal because the industry has delivered very few technologically innovative projects over the past 25 years. The purpose of this article is to remind the community about the practices and approaches that are essential to delivering these projects well.

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## History and Motivation

When IPA was getting started in the 1980s, projects incorporating new technology were common to the point of being routine in the process industries. New technologies were bringing new products to market and lowering the costs of old products by finding new process routes and combining process steps. Most companies had substantial infrastructure for new technology development: active and well-funded research programs, development facilities for testing ideas at larger than bench-scale, protocols for assuring Basic Data[1] completeness and aiding Basic Data transfer from R&D to projects, and project teams that understood how to control the risks while delivering these projects on time. However, by the year 2000, new technology projects had become unusual in every sector except pharmaceuticals.[2] In the past 25 years, we have seen a few bursts of innovative activity in projects, usually in response to regulatory changes rather than profit-seeking opportunities. Other than that, the rate of innovation slowed dramatically as corporate managements shifted their focus to short-term profit and stock price maximization. Both new technology expertise and technology development infrastructure were substantially lost during the last 25 years.

In many parts of the process industries, we now find ourselves in desperate need of new technology expertise and knowledge of the practices that make new technology projects successful. IPA is evaluating new technology projects in renewables, low carbon solutions, and circularity that are failing—often spectacularly—because the basic practices required for new technology project success are not being followed. This situation itself is not sustainable and that motivates this paper.

The loss of expertise in new technology development and commercialization is all too apparent in recent projects. These projects are seeking to advance new renewable energy or recycling (circularity) projects that require moving the state-of-the-art. They are repeating many of the old problems we saw from some new technology efforts of 30 years ago:

- Underassessing the amount of technology advance that is implied in the development and thereby understating and under-appreciating the risks
- Discovering the need for piloting the technology far too late in the development cycle of the first commercial facility
- Allowing the calendar rather than technology maturity[3] to drive the schedule
- Feeding pilot facilities with laboratory grade or simulated feedstocks rather than the more heterogeneous and messy feedstocks the commercial plant will employ

IPA's databases and research can provide the institutional knowledge of practices that has been lost but cannot substitute for the loss of people and new technology infrastructure within owner companies.

## New Technology Database

IPA's major projects[4] database includes just under 1,300 projects with some degree of technological innovation. Database projects with some form of new technology are the same size as non-innovative projects. However, the innovative projects are older on average by nearly six years, which reflects the decline in process industry innovation over the four decades covered by the database.

The degree of innovation varies substantially. About half of the 1,300 projects only employed new integrations of commercially established process steps. We consider this the most modest level of innovation, but also note that too many project teams view new integrations as not innovative at all, and that view is clearly wrong (as discussed below). The remaining half of the new technology sample includes at least one process step that is new in commercial use. A new step is one that requires new chemistry, uniquely designed equipment, or a new match of feedstock and commercially available equipment.

Almost a quarter of the innovative projects are what we call minor modifications to existing technology. These are instances in which any new steps are outside the "core" of the process

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[1] The "Basic Data" consist of the information set that informs the design of a facility. The Basic Data reflect the underlying science upon which the design rests. These data may be incomplete for a number of reasons, but when the technology is unproven in commercial use, the Basic Data must be developed or the project risks technical failure.

[2] Most new technologies in pharma involve new products that are usually manufactured in batch processes that may require no new equipment design.

[3] Technology maturity is measurable by the state of development of the Basic Data needed for a successful design. More about the Basic Data development later.

[4] A "major" project is one large enough or important enough that it is executed by the central projects organization rather than a site projects organization. The size threshold varies by company and industry sector.

or can be isolated or hedged with the option of replacing them with existing technology. In such projects, most of the heat and material balances (91 percent at the median) are known from previously implemented commercial technology and these projects typically have only one new step.

Major process modifications are the next step in innovation. Here the typical number of new steps is two and the portion of the heat and material balances based on commercial technology falls to less than 65 percent.

The highest levels of innovation involve substantially new and entirely new processes. These projects bring levels of innovation to the market that are both risky and very rewarding when they succeed. Such "pioneer" projects have created major companies from humble beginnings.[5] And occasionally such pioneer projects have brought humility to major companies. About 4 percent of the innovative projects in our database fall into these highly innovative classes.

## Assessing New Technology Correctly

When a team is formed to start scope development for a new project, one of the first activities should be an assessment of the Basic (technical) Data that will underpin the design of the facilities. The Basic Data consist of items such as:

- Details of the feedstock, including composition, physical properties and how they change during processing, contaminants, etc.
- Heat and material balances (H&MBs) for all steps in the process, including recycle
- Processing conditions for each step, including temperature, pressure, and residence times
- Yield charts around each step detailing the products, including contaminants
- Materials of construction requirements for each piece of equipment and processing material transport

And then we have the "quasi-Basic Data"—the immutable constraints under which the project will be designed. The quasi-Basic Data do not reflect the science behind the design, but heavily constrain the feasible design space:

- Site conditions, including site size constraints, soil conditions, and ambient weather conditions
- For brownfield projects, the as-built condition of existing facilities

Except for site conditions and as-builts, Basic Data development is not usually part of the scoping team's work. But any gaps in Basic Data may render scope development impossible. If any of the data are not available in a confirmed form from prior commercial facilities, the team must address the question of whether they are tasked with a new technology project. In some situations, the scoping team knows that their intended technology configuration has been applied before commercially, but they lack access to the needed data. If such access is impossible (e.g., a fierce competitor controls the technology), the effort may have to repeat the new technology development steps of the original developer while worrying the issue of patent infringement as well.

If the project will license technology, then most, if not all, of the Basic Data are an expected deliverable from the licensor. Sometimes the licensor's package is thorough and complete. However, for new and evolving technology, the licensor's package is often quite inadequate. The data may be revised multiple times during scope development, front-end engineering, and sometimes even in execution. The downside risk to the licensor of providing incorrect Basic Data is very limited; generally, they will have only their license fee at risk even though the downside risk to the owner can be an expensive facility that does not operate.

Many "energy transition" projects will depend on licensed technology. Therefore, it is essential that owners have the ability to evaluate licensed technology and the firm behind that technology to be successful. But the ability to effectively evaluate a licensing firm requires that the owner knows what a good Basic Data package looks like. Like everyone else, technology licensors tend to be short on high-quality engineers. Any requirements that are out-of-the-ordinary may be difficult to meet. When it comes to the first licenses issued for a new technology, the quality of the license package may be no better from a long-established licensor than a startup firm.

If there are significant gaps in the Basic Data for the project, the scoping team must pause its work and address a number of important questions:

- Exactly what data are missing?
- Who is charged with supplying the data?
- Do the data actually exist but are not yet supplied, or will the data have to be created?
- If the latter, what activities—development units, pilot facilities, etc.—will be required to develop the data?
- And, critically, how long will that take?

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[5] For example, the propylene oxide process developed by Scientific Design and Oxirane largely created Arco Chemical, which is today LyondellBasell.

Let me cite a simple but informative example. The project scope was dedicated wind power to green hydrogen to a hydrogen chemical carrier. A Basic Data issue arose late in scoping: Could the chemical carrier facility be turned down very rapidly in the event that the wind slowed significantly? If not, would they then face an emergency shut-down situation with all of its attendant problems? This had very important implications for the scope because they had no large source of back-up power. If a rapid turndown could not be made, they were looking at installing large amounts of very expensive backup power, either batteries or diesel, or they would have to consider a completely different design. This single Basic Data item delayed the completion of scope development by over six months.

In the example above, the data required existed but were not in the hands of the team. New technology data often do not exist at all when needed and will, therefore, have to be developed. Whenever that situation exists, the project includes new technology. How worried should the team be? If the new technology element is in a single step for which a conventional technology exists, then the risk can be substantially mitigated by allowing space to revert to the old technology if the new technology does not operate as expected due to late or faulty Basic Data. In any other case, the team should be seriously concerned and should often pause their work.

## Dealing With New Integrations of Proven Technology

The most common form of innovation in the process industries is first-time integration of commercially proven technologies. This form of innovation is nearly universal in the initial renewables and circularity projects. Feedstock preparation steps are usually old technology in biofuels projects, for example. But the feed prep step has not been used in conjunction with the particular biofuels process before. Integrating green hydrogen with a new carrier chemical is another example of a new integration.

In our experience, project teams often do not consider new integrations to be technological innovation. That makes the project development teams less likely to carefully scrutinize how the steps will work together. In continuous processing, any step that has a different reliability or uneven flowrates creates serious difficulties. This often requires intermediate storage or holdup capacity that was not expected.

**Table 1** shows why teams should worry about new integrations. Even after taking any effects of commercially new steps out, new integrations add substantially to project difficulty. Each new integration is associated with added cost growth, more time in startup, and poorer operability. Also shown is the effect of new integrations on a critical element of Basic Data, the basis for the heat and material balances. Each new integration is associated with a drop in the percentage of heat and material balances that could be derived from previously operating units. I suspect that the magnitude of the loss is actually considerably larger than the teams reported because they often found out later that the H&M balance numbers were not reliable.

New integrations mean that the Basic Data are incomplete even if no strictly new technology is introduced. One of the challenges of new integrations is that development facilities are largely moot—the first-time integration has to be done at commercial scale. While building a pilot could help, it is never done unless some of the other steps are new in commercial use. The development of the Basic Data (the heat and materials balances in particular) comes down to a conceptual engineering exercise. Simulators may be very helpful, especially if only liquids and gases are involved. Although new integrations rarely (if ever) trigger a substantial technology development program, the scoping team needs to understand how the Basic Data gaps will be filled before they finalize the design and pass the project to front-end engineering.

A good many renewable and decarbonization projects will involve multiple new integrations of commercial technology: green and blue hydrogen, some biofuels, carbon capture and

| Factor Affected by New Integrations | Effect of Each New Integration* | Statistical Robustness |
|---|---|---|
| Cost growth from authorization | 2.7 percent | 0.04 |
| Time added to startup | 0.5 months | 0.007 |
| Loss of production months 7-12 after startup | 4.7 percent of nameplate | 0.02 |
| Reduction in percent of the heat and mass balances known from prior commercial facilities | 2.5 percent | 0.0001 |

*All results controlled for new steps

Table 1: New Integrations Add Difficulty

sequestration. From a technology standpoint, these projects will look deceptively straightforward. But almost all of the early projects will be new to the project team and to the company. And many of the projects are attempted at very large scale because the subsidies associated with these projects require it. Unless Basic Data are thoroughly developed for these projects, they are likely to experience severe operability problems. And if the government subsidies are based on output rather than a capital subsidy, that will mean a large financial loss.

## New Technology and Project Risk

New technology increases the risks of an overrun of the authorization estimate and increases the risk that the resultant project will not operate as planned. Interestingly, new technology has no apparent relationship with schedule slip or execution time in projects.[6]

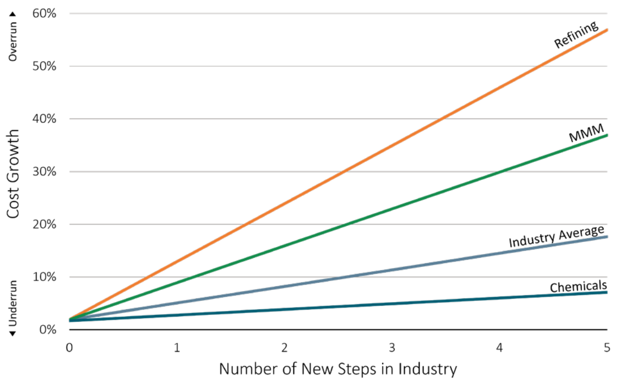
### Cost Risk

Every measure of new technology that IPA maintains points to greater cost risk with new technology. I am sure this result surprises no one. Each new step in a process increases cost overruns by an average of 3.1 percent.[7] Each new integration has an average effect of 2.7 percent. Even when the technology is not new to the industry but is new to the company using it, cost growth increases by 8 percent on average.[8]

If contingency setting practices were working correctly, we would see contingency increasing to offset all or most of the added cost risk. There is indeed a positive relationship between contingency and new steps and other measures of new technology, but the amount by which contingency is increased is far short of what is needed to offset cost growth. For example, each new step in a process is associated with a 3.1 percent increase in cost growth but only a three-tenths of 1 percent increase in contingency.

I do not believe that this lack of contingency response to new technology reflects a lack of understanding of risk by project teams or estimators. I believe it reflects the extremely political nature of contingency setting in most project systems. Contingency in authorization cost estimates remains unchanged at 8 to 9 percent until the technology is “substantially new” or “entirely new” and then it averages only 11 percent, far short of what is actually needed.[9]

**Effect of New Steps on Cost Risk Is Sector Dependent**



Results are controlled for team integration, level of Front-End Loading completed at authorization, and project size

Figure 1

Cost overrun risks associated with new technology vary by industrial sector. **Figure 1** shows the relationship between new process steps and cost overruns from the final investment decision estimate (including contingencies and design allowances) to mechanical completion for different industrial sectors. There is almost no difference in average contingency percentages between sectors. The chemical sector sees less cost growth per new step because sector companies are generally more capable new technology developers.

**The petroleum refining sector** experiences the most rapid increases in cost overruns as a function of new technology; each new step is associated with an 11 percent increase over the authorization estimate. The refining sector has the lowest rate of technological innovation of all major industrial sectors that IPA works with on a regular basis. However, from time to time, changes in regulations force the industry to develop and apply new technology.

Two problems arise with this change in regulations. First, any company that has not applied new technology recently tends to lose the expertise required to do so successfully. Because refining only innovates occasionally, it is very difficult to hold new technology application expertise. Second, the new technology projects for refining are disproportionately regulatory compliance projects. As IPA has documented

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[6] This surprising result is an artifact of new technology projects often being very high priority, well-resourced, and schedule driven. About 30 percent of projects overall are schedule-driven—meaning that the team is authorized to spend more to reduce schedule. However, almost 50 percent of significantly new technology projects are schedule driven. We are not suggesting that this is a good practice, but it is a fact.

[7] Cost overruns are measured as the ratio of total capital costs incurred to the full-funds authorization estimate with controls for all price changes, scope changes (not design changes), and currency fluctuation.

[8] All relationships are statistically significant at 0.01 or less.

[9] We find the same lack of response in contingency to the level of project definition, which we call “front-end loading.” Each point on the FEL scale showing decreased project preparation is associated with a 2.6 percent increase in cost growth from authorization to completion (Pr.|t|<.0001). But the amount of contingency included in the authorization estimate increases by less than three-tenths of 1 percent, only about one-tenth of what is needed.

repeatedly over the years, compliance projects are the black sheep of industrial projects. Business sponsors usually do not care much about them because they cost money rather than make it. FEL is often delayed until the projects become schedule driven and contractors sometimes take advantage of the time squeeze.

This result for refining should be treated as a red flag for sustainability and decarbonization projects if they are viewed internally as compliance projects rather than as part of growing the businesses. Sustainability and decarbonization projects will require strong business sponsors, excellent and complete front-end work, and strong project teams. If they are approached in the same manner as compliance project historically have been, they will surely fail.

**The mining industry** ranks second in terms of cost risks associated with new technology. The mining industry innovates more regularly than refining and their new technology projects tend not to be compliance projects. However, when the mining industry innovates, it is usually in the context of technology needed to process a new orebody. It is long established that innovation in the processing of solids is considerably more difficult than in processing liquids and gases. Innovative processing of heterogeneous (i.e., "run-of-mine" or ROM) solids is especially problematic.[10]

The core problem with innovations involving solids processing is that the Basic Data are often very expensive to develop and not very accurate once they are. Solids processing (and heterogeneous solids processing in particular) does not scale faithfully in many situations. For example, the particle size distribution produced by a small-scale crusher may be entirely different than that produced by a commercial scale crusher. Because solids can give rise to abrasion and erosion, solids are much more taxing on equipment than liquids and gases. Building a pilot plant large enough to provide accurate Basic Data may entail building at one-tenth or more of commercial scale, which is very expensive and time consuming. Transporting ROM ore to vendors for testing is done, but it is also expensive and therefore not widely practiced.

**The chemical industry** fares much better with respect to cost risk stemming from innovation. Although innovation in the chemical industry has declined over the past 25 years, it is still much more common in chemicals than in petroleum refining. As a result, more chemical companies have maintained R&D and new technology commercialization expertise than has refining. In addition, there are fewer compliance projects. Over 30 percent of major projects undertaken by the refining industry are driven by environmental regulations. Only 8 percent of major chemicals projects are driven by such requirements.

### Operability Risk

Far and away the important risk associated with new technology introduction is the possibility that the resultant facility will not operate as intended. Poorer than planned production seriously undermines project profitability and may vitiate the entire rationale for its development. Poor operability undermines the key goals of demonstrating the technology or enhancing the company's reputation. **Figure 2** illustrates how production tends to suffer as greater degrees of innovation are added to a project's scope.

**As Technology Steps Out,
1st Year Production Steps Down**

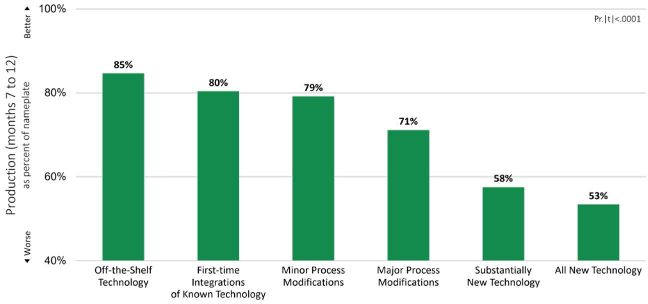

Figure 2

As shown in **Figure 3**, a key driver of operability problems in new technology developments is the type of material being processed. Innovating on liquids and gas processing technology is easiest. Operability does decline as a function of new steps being introduced but at a gradual rate of 2.6

**Innovation Effects on Operability Depend
on Materials Processed**

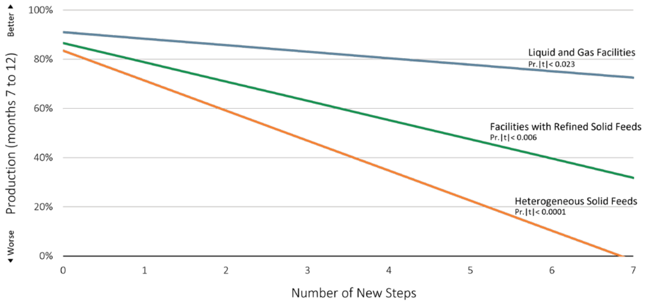

Figure 3

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[10] Edward W. Merrow, "Problems and Progress in Particle Processing," Chemical Innovation; 34-41; 2000.

percent per new step. The situation changes dramatically when a solid feedstock is introduced, even if that feedstock has been previously processed and is uniform. Each new step with such feedstocks is associated with a declined in operability of nearly 8 percent per step. The average production in the second six months after startup for a process with three new steps is only 65 percent of planned production rate. Given that the poor performance is very likely to last well into the second year of production (and perhaps beyond), the project economics are clearly damaged by that result.

The production penalty jumps again when the feedstock is a heterogeneous solid such as a "run-of-mine" ore, municipal waste, solid bio-material, or recycled material such as plastic. When such materials are processed with three new steps, the operability in the second six months is less than half of expected production. Time required to bring heterogenous solids plants with three or more steps just to steady-state operation averaged over a year. Obviously, a good deal of money was spent in startup. Highly innovative technologies processing heterogeneous solids have the highest incidence of "walk-away" plants—facilities that were never operated successfully. The lesson here is how much innovation one attempts in a single facility should be guided by the materials processed. A very highly innovative liquid or gas processing facility has a reasonable chance to be highly successful. The equivalently innovative solids processing facility runs a substantial risk of failing completely.

Allow me to cite a recent example of "heterogeneous" solids in a circularity project. The commercial project was launched without a pilot plant because the chemistry worked very well at bench. The project recycles a particular type of plastic back to the same product. They fed the bench scale reactor with "simulated" feedstocks. Mid-execution of the commercial plant, they made a discovery: people put some remarkable things into their spent plastic—old cigarette butts, dirt, chewing gum, and so forth. They discovered that one of the contaminants found simply could not be handled by their process chemistry and they had to stop and build a pilot plant to find a solution. Not a very happy result.

## The Role of Business Technology Strategy

Most companies in the process industries maintain a technology strategy for each business in which they participate. The technology strategy defines how the business seeks to position itself in terms of technology: leader, fast follower, or passive buyer. It defines how much the business is willing to invest each year in technology development and know-how. And the strategy defines what is done with that investment in terms of people resources, laboratories, and development facilities. The technology strategy also defines the development process that will be followed for any particular new technology work. That work process will define the practices to be followed, such as the development of a Basic Data protocol, whenever a project's development is missing Basic Data.[11]

The stronger the technology strategy, the easier it is for a company to innovate and the easier it is for a company to pivot to a new business in terms of technology strategy because the company has know-how in terms of technology innovation, regardless of the content.[12] In renewables, decarbonization, and other sustainability businesses, many IPA clients have not articulated a technology strategy for these businesses. This will hamper their ability to enter these sectors successfully.

New technology projects are usually an expression of a long-term business technology strategy. Historically, this has been especially true in the chemicals sector where access to leading technology is often seen as essential to success. New technology can lower the cost of manufacturing in existing product lines, be the pathway to introducing a new product, or permit entry into a technologically evolving business such as renewables. For firms with technology development expertise, entering a new business with new technology is often the most effective route to success because it allows the new entrant to compete successfully against incumbents.

When a new technology project is not an expression of business strategy, but rather a response to the needs of a single project or a response to regulatory pressure, the chances of having a successful venture decline dramatically. In such situations, the business does not have a commitment to the development of the technology as central to the business strategy and the willingness to spend the time and money needed to develop the technology in a sensible way is much less.

The most problematic situation is when there is no scope *without new technology* that renders a project sufficiently profitable to be authorized. New technology is seized upon as a solution to that problem. It is true that new technology often reduces the cost of an existing product. Reducing cost is the most common reason for new technology deployment in chemicals manufacture. But those cost-reducing new technology developments result from a business strategy to stay competitive, not from a desire to make an uneconomic project meet the hurdle rate requirement. If new technology is required to make a single project economic, the project is

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[11] The use of the Basic Data protocol will be discussed later in this paper.

[12] The most remarkable example in my career of a technology pivot was in the early 1990s when DuPont decided to develop a pharmaceutical business out of whole cloth. The company simply aimed some of its chemists and biochemists at developing new drugs and created a strong pharma business in a matter of a few years.

most likely simply uneconomic and should not be pursued. Hastily pursued new technology is likely to turn a marginally uneconomic project into a full-blown disaster.

## The Development and Commercialization Process

When looking to bring a new technology to market, start with a holistic approach to ensuring that all of the critical missing Basic Data will be developed in a systemic way. If the degree of step-out is a "major modification" or higher, it is almost assured that some development facilities larger than bench scale will be needed to produce the data. That means the timeline for the first commercial application of the technology will be considerably longer than for a non-innovative facility of the same size and type.

New technology for the process industries evolves from owner R&D, from licensors of technology, and from equipment vendors. Generally, equipment vendor developments are incremental, while owners and licensors generate most of the major advances. Many licensor developments are really joint developments by the licensor and an owner who has decided to be first-to-market with the new technology. A classic owner mistake in these situations is a failure to clarify the intellectual property (IP) ownership at the outset. The owner will usually end up largely funding the development effort and providing a great many ideas as well. Owners need to incorporate their IP rights from the earliest days of the effort. Otherwise, the owner is likely to discover that they funded the effort and contributed expertise and ideas, with only a discounted license fee as their reward.

If the processing mode is to be batch rather than continuous, the development process is generally easier and more forgiving. Basic data for batch processing do not have to be as precise as for continuous processing. Residence times for reactions can be ranges rather than points and can even be adjusted at commercial scale without much effect on operability unless the deviations are considerably longer than expected. Energy balances can often be fine-tuned at commercial scale as well. I do not want to suggest that innovation in batch process is always easy; there is lots of room for problems. But it is *easier* than continuous processing. So much of what we will focus on below pertains to continuous process facilities.

The first step in the process is to explore what sorts and sizes of development facilities will be necessary to produce accurate Basic Data for scoping and design. The classical step-by-step scale-up process is shown in **Figure 4**. Ideas start to take shape in somebody's lab, although the ideas themselves may spring from many sources. Sometimes it is an owner lab; sometimes a licensor lab; and sometimes the lab of a small company that will be acquired by an owner to secure the technology.

The first activities to test the feasibility of an innovation usually take place at what is called a "bench scale." Today many simulators are available to test hypotheses around processing behavior, such as computational fluid dynamics (CFD) simulators or HYSYS™[13] process simulation. Simulators are most useful where the materials being processed are fully known and homogeneous. They are less useful for solids and other multi-phase processing.

For some new technology developments, bench-scale and simulator confirmation of the new elements is sufficient to gain the information needed for reliable commercial design. For example, in our databases there is new technology development that jumped successfully from the bench to commercial with a scale-up of 350 *thousand* times. But that innovation was confined to two steps in a process and involved only liquid and gas processing.

**The Step-by-Step Development Process**

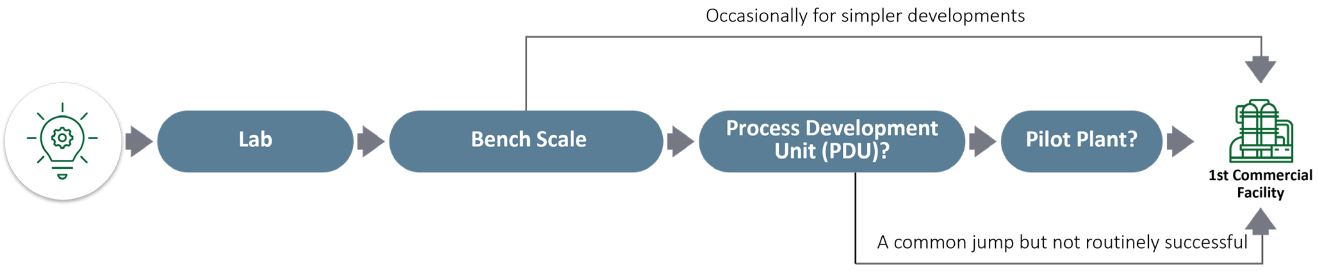

Figure 4

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[13] HYSYS is a registered trademark of Aspen Technology.

For any major new technology development, bench scale does not usually suffice to provide a reliable Basic Data. This is especially true if there are dynamic interactions between processing steps that are difficult to model accurately at very small scale. It is also the case when the way a processing step behaves is scale-dependent, e.g., when there are "wall effects" or if very precise processing conditions must be maintained over a large cross section, and for equipment such as fluidized beds where scale affects efficiency.

When bench scale will not suffice, a difficult decision must be made about whether to build a process development unit (PDU) and/or a pilot plant. A PDU usually consists of several steps in a process where the innovation is taking place. A pilot plant includes the whole process and is generally larger scale than a PDU. A pilot plant may exclude front-end or back-end steps if they do not have dynamic interaction with the steps being piloted. A "fully integrated pilot plant" includes all steps in the process including recycles. A fully integrated pilot usually makes product, but that is a secondary goal; the primary goal is information production.

The decision to build a PDU instead of a pilot is usually based on perceptions of cost and time requirements and in the hope that the less expensive PDU will suffice. Data around the PDU versus pilot decision are presented in **Table 2** for chemical processing new technology developments.

Building a PDU is about half of the cost of an integrated pilot on average. However, the time requirements are similar. The time needed to execute the PDU design and construction is slightly shorter, but the time to the start of data acquisition from the facilities is essentially the same. Counter-balancing the lower cost of PDUs is that they are much less likely to provide the needed Basic Data than the integrated pilot plants. Integrated pilots failed to achieve their information production goals 30 percent of the time; PDUs failed 60 percent of the time.

When a development facility fails to produce the Basic Data that were expected, that fact is usually clear to the development team. But it creates a very difficult problem: the R&D group has apparently failed to produce and there may be repercussions. Blaming R&D is likely to be unfair, but that does not change reality. Often businesses supplying the funding do not fully understand that development facilities are for the purpose of conducting *experiments*. Experiments can and do fail sometimes. If success of a PDU or pilot plant could be guaranteed, the facility would, by definition, not have been needed.

Among mature owners, the decision about which development facilities to pursue is the product of two analytic techniques: Value of Information (VOI) and Design of Experiments (DOE). VOI seeks to formalize the decision to buy more information or make a decision with the information in hand. VOI relates the payoff associated with information being produced versus the investment required to produce the information and considers the probability that the desired information will not actually result from the investment as a way to discount the investment. VOI should be used to assist in making the PDU versus pilot plant investment decision. The different information payoff probabilities from the different facilities should be a significant part of the VOI analysis.

Design of Experiments lays out the information required and then systematically relates that information to the information production procedures that need to be followed. DOE should be used in the design decisions for any development facilities that will be employed to guide ease of reconfiguration, instrumentation, and whether a PDU or integrated pilot plant will be employed.

## Attempting to Design Around Basic Data Holes

One of the classic mistakes in new technology development that we are seeing repeated in sustainability projects is attempting to overcome gaps in the Basic Data with "conservative" design. We tend to try this when we have decided not to build the pilot plant that we actually need. For

| Cost and Time Requirements | Integrated Pilot Plans | Process Development Units (PDUs) |
|---|---|---|
| PDU or Pilot Cost ($^{2024}$US$ million) | Median $15<br>Mean $59 | Median $8<br>Mean $30 |
| Execution Schedule Duration for Development Facility | Mean 18 months | Mean 15 months |
| Development Facility Cycle Time<br>FEL-2 through startup | Mean 29 months | Mean 28 months |
| Essential Basic Data Were Provided | 70% of the time | 40% of the time |

Table 2: Comparing Process Development Units and Integrated Pilot Plants

example, if there is potential for a catalyst fouling problem, we increase the reactor size or install a spare. If we see a temperature excursion in the bench reactor, we design for more heat exchange. If the yield charts from the bench-scale reactors show some side reaction contaminants, we oversize the separation step. We gradually design a facility that is very expensive with no real assurance that added design margins will mitigate the inherent design issue. As one wag put it, "We end up with a conservatively designed dead white elephant."

Here is a case study of what not to do. The project was a large biofuels project converting a range of feedstocks to sustainable aviation fuel. The technology had been applied previously by another company but the team had no access to the data from that project. The business and the project team decided to forego a pilot plant in the interest of speed and decided to scale from the bench scale. Here is what they did to mitigate risks:

- They added a second reactor because fouling was found in the bench reactor
- It was known that commercial feedstocks could contain contaminants that would deactivate one of the catalysts, but no exhaustive list of those contaminants could be developed; they added catalyst volume to mitigate
- At the bench scale, some feeds created reactor temperature spikes, so they launched a study during FEED to explore the issue
- The bench reactor used only laboratory grade feeds and no runs with real feeds

Deep into detailed engineering, they reluctantly concluded that they really could not close the heat and material balances and paused the project indefinitely. This team tried to substitute engineering muscle for Basic Data. It didn't work. This almost exact scenario has been repeated many times in new technology projects.

Usually, the way we find out that the Basic Data requirements were not met is when detailed engineering encounters questions that have no empirical answers.[14] If work proceeds, that finding is confirmed in operability failures. Only when the technology development is well-funded and highly disciplined is a disappointing PDU followed by an integrated pilot plant. Our data suggest that building an integrated pilot plant is generally a better investment than relying on a PDU to provide the needed data. The much lower failure rate for integrated pilots and great commercialization success more than make up for the higher cost.

**Figure 5** illustrates the timing of Basic Data arrival to the project team and the effects of late arrival on the commercial facility project. In the ideal situation, the Basic Data development would be completed just as the scoping team starts its work on the pioneer commercial facility. That would approximate the situation for most standard technology projects. Basic Data development can be completed too early. If a technology development has been completed

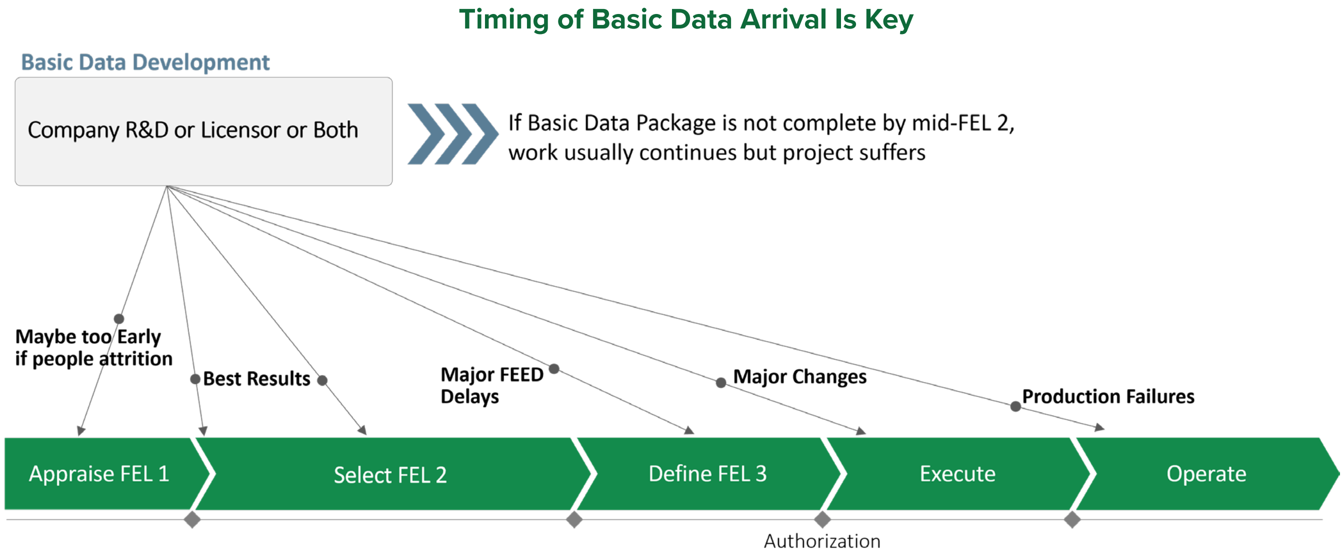

Figure 5

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[14] Basic Data holes are sometimes found during basic engineering, but more often they are found during FEED or detailed engineering. Basic engineering enables one to assume that the information is there because granularity is not required for basic engineering. But when one is working on the material balance tables on the P&IDs and lacks the detail to provide them, the hole in the Basic Data becomes painfully apparent.

and is “sitting on the shelf” waiting for an opportunity to be implemented, the expertise associated with the development will start to disappear. Very good documentation can mitigate the problem but never fully substitute for the knowledge of the developers themselves.[15]

In the more common situation, the Basic Data are not complete when the scoping team is formed to start the commercial facility. Arrival of the last essential Basic Data by the middle of FEL 2 can be accommodated. Later arrival will have damaging consequences. If the final design information arrives during FEED, significant delays in completing FEED are very likely as the information is integrated and work has to be redone. If the data arrive during detailed design, major changes and serious engineering schedule slip will result. If the data are any later, the risk of production failure increases significantly. The larger and more complex the project, the greater the effects of late Basic Data. Megaprojects cannot absorb late Basic Data shocks well at all.[16]

Even if the people who developed the technology are available, the hand-off from R&D to commercial development is not easy. Part of the problem is the use of different vocabularies by R&D and projects professionals. But the more serious and common problem is that R&D does not fully appreciate the extent and granularity of data required to design the commercial facility. Best practice is to include one or more technology developers on the commercial facility design team to promote good handover of the information. This is, of course, much easier if the development is done in-house. Full team integration with licensors is almost never achieved.

## Key Project Practices for New Technology Projects

### Use a Basic Data Protocol

The most effective tool in the transfer of Basic Data from data producers to project users that we have encountered is the Basic Data Protocol (BDP). The BDP is akin to a risk register for Basic Data. Unlike a basis of design document, the BDP is focused on what is *not* there rather than what is. Any element of Basic Data that is not in-hand as the project starts its early work is entered as an item. The Basic Data Protocol identifies any the missing technical information. The missing information is then married to the technology development process. How will the missing data be produced: By studies? By simulations? By a process development unit? By a pilot plant? How long will these things take? The BDP then helps set the pace at which scope development will be pursued and the priorities for different scope elements.

A project team member is assigned to keep track of the progress in generating the data and an accountable data producer is entered along with the expected arrival time. This process, which has been used by both chemical companies and petroleum companies, enables better planning and timing of scope development and makes it much less likely that key items will be overlooked.

A BDP is not just for projects that are introducing new technology. It is equally useful when the technology is new to the company or the scope will integrate existing commercial technology in new ways and the Basic Data with respect to those integrations do not exist or are not in-hand. Any area of scope in which the company is not deeply experienced should trigger the development of a BDP to ensure that work is not halted down the line in FEED or detailed engineering when it is suddenly realized that no one has the data.

### Integrate the Owner Team and Manage Continuity

We define an integrated team as one in which all required owner functions are active members of the project team from the start of scope development forward.[17] Full team integration is a necessary condition for effective front-end loading. If a function is not present on the team, that function’s work will not be done or will not be done well. When a team is not integrated, the operability penalty associated with each new process step being introduced more than doubles.

Continuity of core team members always benefits projects. However, in new technology projects, keeping continuity of the lead engineer position is critical to the operability of the project in the first year at least. Maintaining continuity of the project manager and construction manager positions is essential for schedule and cost performance but has no discernible effect on the critical operability outcome. The R&D team that developed the new technology also needs to be available through startup.[18]

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[15] We see this problem frequently in oil and gas developments. It is common in some companies to complete the investigation of the reservoir (the Basic Data for the development) and then have the potential project sit in a queue waiting for a scoping team to move the development forward. The information hand-off without people is very problematic.

[16] See Edward W. Merrow, *Industrial Megaprojects: Concepts, Strategies, and Practices for Success*, 2nd edition, John Wiley & Sons, Hoboken, 2024.

[17] Margit Jochmann and Luke Wallace, *Setting Up Teams for Success*, IBC 2007, IPA, March 2007.

[18] We define the end of startup as steady-state operations of all facilities.

### Do Complete Front-End Loading

Front-end loading (FEL) is a key element of any project, large or small, standard or new technology. For new technology projects, good FEL is essential for maintaining cost control of the project. A single point improvement in IPA's FEL Index reduces cost growth by about 3 percent on a standard technology project. For a project with 4 new steps, the effect on cost growth jumps to 6 percent and to 9 percent per point for projects with 5 new steps. Poor FEL and new technology interact to make cost growth much more severe.

Many new technology introductions are aimed at reducing the capital cost of making an existing product, especially in the chemical industries. Those investments in new technology do in fact reduce capital costs, but only if FEL is good. As FEL quality declines, the cost reduction effects of new technology disappear. Cost growth eats up all of the savings, thereby undermining the purpose of the new technology introduction.

### Introduce Commercially at Smallest Feasible Project Size

There is an old proverb around new technology: "Make your mistakes at a small scale, and make your money at a large scale." It is amazing how often that sage advice is ignored as we undertake new technology projects at megaproject scale. Scaling up technology that has been proven in commercial use is much easier than the first commercial introduction. Nonetheless, we are seeing cutting edge renewables and decarbonization projects in the multi-billion-dollar class before much smaller versions of the technology have been commercially proven. This is sometimes driven by poor communication about risks between the C-suite and the project level and sometimes by the desire to gain "green cred" with scale. This is a losing strategy as poorly operating green megaprojects damage both reputation and green cred.

### Avoid the Compliance Project Syndrome

As new regulations force companies to invest in decarbonization and circularity projects, these projects may come to be seen as compliance projects. Throughout the process industries, regulatory compliance projects are developed and executed much more poorly than their money-making counterparts. The root cause of the problem is clear: poor and non-existent business sponsorship of the projects. The lack of business interest is understandable. Who wants to sponsor a project that is seen from the outset as having negative value? Because sponsorship is weak, compliance projects often start late vis-à-vis the regulatory deadline in order to defer cash outlays. They are poorly front-end loaded as a result and are more likely to be schedule-driven and constrained relative to profit-making projects during execution. Contractors sometimes exploit this situation to extract excess profits.

Owners will need to position sustainability projects so as to avoid the compliance project syndrome or a great deal of money will be wasted. In practice this will mean that the projects need to be highly visible at the C-suite level and suitable rewards made available to sponsors and project leaders for good performance. New technology projects cannot succeed without solid business guidance and support.

## Wrapping Up

After a long period of declining innovation, the process industries have now entered a new phase in which the ability to develop and deploy new technology successfully will become essential to corporate health or even survival. Those abilities must be embedded in owner personnel if companies are going to succeed. That in turn means rebuilding the new technology development organizations inside owner companies. Vendors and technology licensors will do some of the new technology development work, but the heavy lifting will have to be done by the owners with in-house staff.

Reviving new technology development and commercialization expertise will be a positive for process industry companies beyond their sustainability projects. Advancing technology makes more profitable and robust companies. The decline in innovation over the past 25 years has not been driven by any change in fundamentals; advancing technology is still a path to being a more successful company. The change has been driven by changes in corporate executive incentives that reward the short-term over the intermediate and long-term. If one's time horizons are quarter to quarter and tenure only about 5 years, research and development and technology strategy lose their appeal.[19]

**How Can IPA Help?**

Contact us to learn more about how your company can deliver successful new technology projects:

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