QUANTITATIVE BENCHMARK FOR TIME TO MARKET (QBTM) FOR NEW MATERIALS INNOVATION: AN ANALYTICAL FRAMEWORK

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NEXIGHT GROUP

ENERGETICS
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OVERVIEW

The overarching goal of the Materials Genome Initiative (MGI)—"to enable the discovery, development, manufacturing, and deployment of advanced materials at least twice as fast as possible today, at a fraction of the cost"—is difficult to measure without first knowing the timeline for commercial deployment that today's new materials require. To address this knowledge gap, Milestone 2.3.3 of the MGI Strategic Plan[1] calls for benchmarking studies to quantify the time to market for materials.

To date, there has been no consistent methodology used across materials, applications, and industries for analysis of the time to market for materials innovation. Time to market for materials innovation varies significantly by material type, function/application, and industry. In addition, time to market is already evolving for many materials classes and is driven by many factors, including the application of MGI-like tools and approaches.

This report uses the following structure to evaluate existing time-to-market innovation models and put forward a proposed analytical framework for materials innovation:

1. Review and discussion of key existing time-to-market innovation models with respect to their utility as an analytical framework for materials innovation
2. Proposal of a new analytical framework tailored to the broad spectrum of materials innovation and incorporating the best elements of existing models
3. Assessment of the validity and value of this model in the context of two case studies detailing real-life materials innovation processes.

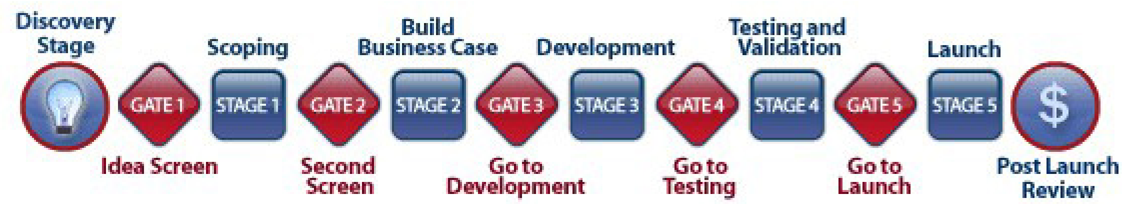
The resulting framework aims to establish a basis for future case studies as well as provide individual organizations with approaches and tools for self-assessment against relevant industry benchmarks.

1 EXISTING TIME-TO-MARKET MODELS

STAGE-GATE®

The Stage-Gate approach has been in use since its development in 1960, and is a "conceptual and operational map for moving new products from idea to launch and beyond". [2] It describes a series of project team work stages with intervening gates where go/no go decisions for project continuation are made based on specific criteria. A typical five-stage process is shown in Figure 1.[3]

Figure 1: The Stage-Gate Approach

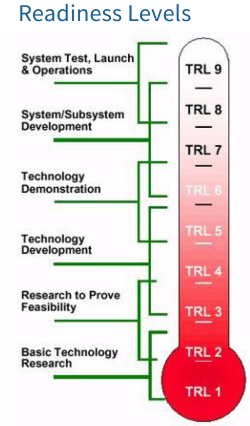


The first three stages—Discovery, Scoping, and Build Business Case—are often termed the "fuzzy front end" of the process, and in some refinements collapsed into a single stage. Likewise, Stages 3 and 4—Development and Testing and Validation—can be separate or combined depending on the risk and complexity of the project. The fifth stage—Launch—is the transition to the market.

The Stage-Gate approach is a useful construct for project management and highlights the important stages of a product-oriented activity. It does not explicitly address manufacturing-related areas, although these would be intrinsic to a successful product development and launch. In addition, the Stage-Gate process requires a significant effort on the definition and execution of the go/no go decisions at each gate. While time to market can be affected by decision-making bottlenecks, these activities tend to be more organizational in nature and less impacted by the predominately technical Materials Genome Initiative (MGI)-like development efforts.

TECHNOLOGY READINESS LEVELS

Figure 2: Technology Readiness Levels



Technology Readiness Levels, also known as TRLs, were initially developed by NASA as a measure of technical maturity in the product development process. They were subsequently adapted and used by the Department of Defense, Department of Energy, industry, and others to better reflect the needs of specific products.[4] The nine TRL categories of NASA's version are shown in Figure 2.

In application, TRLs are often grouped to produce more concise scales or classifications. In one adapted version, just four research levels are identified: Basic Research (TRL 1-3), Development (TRL 3-5), Demonstration (TRL 6-7), and Early Deployment (TRL 8-9).[5] Many organizations find consolidation to broader classifications to be a more practical application of the tool.

MANUFACTURING READINESS LEVELS

Manufacturing Readiness Levels, or MRLs, are a set of definitions that assess manufacturing maturity, risk, and readiness.[6] The MRL system is also presented on a numerical scale, which enables comparison and evaluation in concert with the TRL scale. In the case of the most current implementation of MRLs, a 1–10 scale is used with definitions as shown in Table 1.

Table 1: Manufacturing Readiness Levels

Manufacturing Readiness Level	Definition
MRL 1	Basic Manufacturing Implications Identified
MRL 2	Manufacturing Concepts Identified
MRL 3	Manufacturing Proof of Concept Developed
MRL 4	Capability to produce the technology in a laboratory environment
MRL 5	Capability to produce prototype components in a production relevant environment
MRL 6	Capability to produce a prototype system or subsystem in a production relevant environment
MRL 7	Capability to produce systems, subsystems, or components in a production representative environment
MRL 8	Pilot line capability demonstrated; Ready to begin Low Rate Initial Production
MRL 9	Low rate production demonstrated; Capability in place to begin Full Rate Production
MRL 10	Full Rate Production demonstrated and lean production practices in place

The MRLs are further parsed in terms of nine different "threads" that make up the many dimensions of successful manufacturing. One of these is a "Materials" thread that includes aspects such as materials maturity, availability, supply chain, and special handling issues. This provides a useful and somewhat more detailed framework for considering the manufacturing aspects of the materials innovaton process.

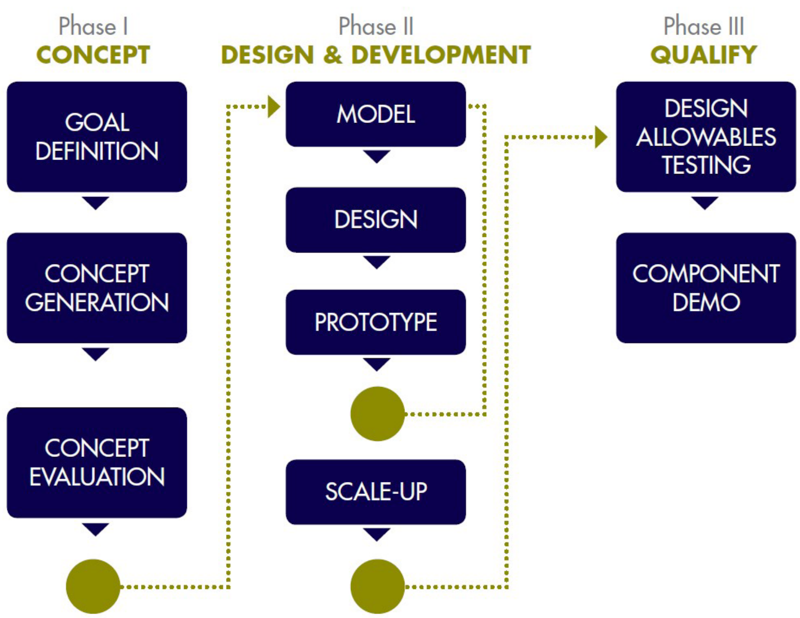
Notably, some organizations have developed combined readiness scales. For example, the European Association for Research and Technology Organizations (EARTO) has published an analysis of TRLs and incorporated other considerations, including manufacturability as well as market and organizational issues, into a combined scale.[5]

QUESTEK STAGE-GATE PROCESS

QuesTek Innovations LLC has adapted the Stage-Gate process to their materials innovation work.[7] As shown in Figure 3, it is a three-phase process with three associated gates (indicated by green circles).

The Concept phase (Phase I) incorporates three substages: Goal Definition, Concept Generation, and Concept Evaluation. This phase relies heavily on inputs from the end user to establish the design goals. QuesTek uses its computational materials design-driven capabilities to generate approaches that meet these goals and evaluates each approach computationally or at the bench scale. The gate is a design review with the customer to determine whether or not concepts should move into the Design and Development stage.

Figure 3: Questek Stage-Gate Process



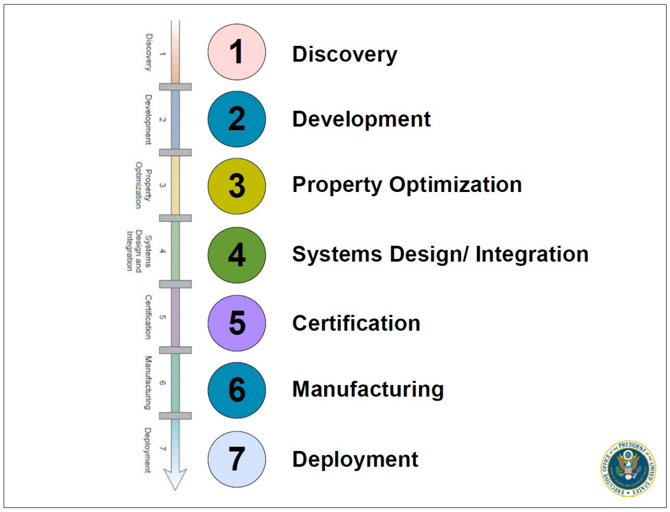
The Design & Development phase (Phase II) includes two major sub-stages: Model/Design/Prototype and Scale-Up. The first sub-stage involves modeling, designing, and prototyping Phase 1's concepts through an iterative process and culminates at a gate where the prototype's properties are assessed before moving on to the next sub-stage. Scale-Up—or moving the product into commercial-scale production—is critical to the success of materials innovation products, which can face challenges shifting from the lab scale into a large-scale manufacturing environment.

The Qualify phase (Phase III) is similar to the "Launch" stage of the standard Stage-Gate process. It includes two sub-stages—Design Allowables Testing and Component Demo—which reflect high-performance, often aerospace-dominated applications in which QuesTek's materials have been implemented in thus far. As a result, this framework may be too specific to QuesTek's products to be effectively used in other materials innovation applications.

In addition to the Stage-Gate process implementation, QuesTek also uses the Technology Readiness Level framework as a measure of the maturation of materials innovation.

MATERIALS GENOME INITIATIVE MATERIALS INNOVATION PROCESS

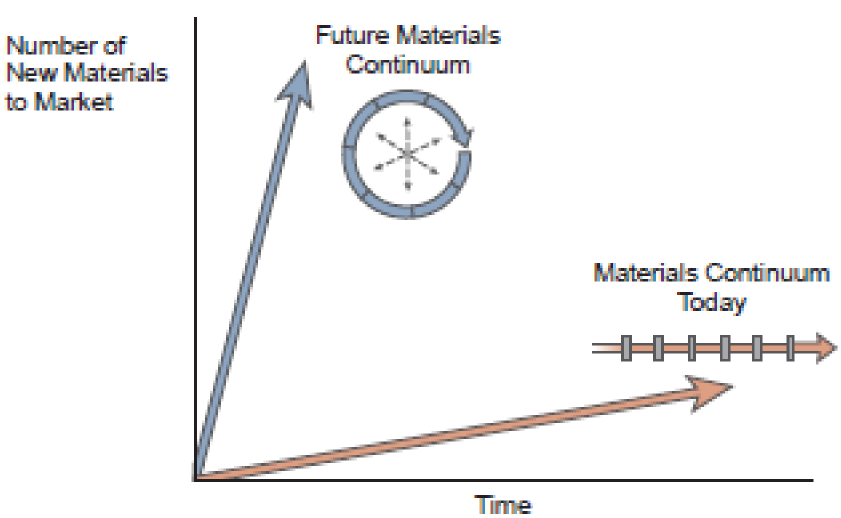
Figure 4: Materials Genome Initiative Materials Innovation Process



The Materials Genome Initiative white paper[8] presents a seven-stage materials innovation process (see Figure 4), although it does not provide a description of each stage nor references to the source for the model. While the model maintains the general flow of steps of the Stage-Gate process and reflects aspects of materials-specific activities, it appears to focus on high-performance systems, due to its inclusion of discrete steps for Systems/ Design Integration and Certification, which are not universally part of materials innovation. It is also unclear how a Certification step can occur prior to a Manufacturing step, as most certification processes require a stable manufacturing process to be established first.

The MGI white paper states that the discrete nature of the seven stages and their execution by "different engineering or scientific teams at different institutions" with few opportunities for feedback between stages is an impediment to the pace at which the process moves forward. While recognizing that some steps need to be sequential (e.g., Certification cannot occur before Systems Design), the MGI model is proposed to be more circular in its approach, allowing "design, systems engineering, and manufacturing activities to overlap and interact" to reduce time to market (see concept in Figure 5). However, it is difficult to see how this type of model could be implemented in practice; actual case studies indicate that the more linear approach is closer to reality.

Figure 5: Conceptual acceleration of materials innovation envisioned through the Materials Genome Initiative



2 DEVELOPMENT OF AN INITIAL QBTM MODEL

The initial OBTM model built upon existing time-to-market models to create a four-stage framework applicable to a range of materials innovations (see Table 2).

Table 2: Materials Genome Initiative Materials Innovation Process

Stage	Step	Activity	QuesTek Stage-Gate Connection	TRL/MRL Overlap	Proposed Materials Readiness Level
Discovery	START	Intent to seek a new material for a given application or end use is articulated	"Goal Definition"	TRL 1-3/ MRL 1-3	MatRL 1
	PROCESS	Experimentation and modeling at bench or lab scale	"Concept Generation, Concept Evaluation, Model, and Design"		
	END	Candidate material composition(s) or chemistry(ies) are identified			
Development	START	Synthesis of candidate material composition(s) or chemistry(ies) for application or end-use testing is begun		TRL 4-6/ MRL 4-6	MatRL 2
	PROCESS	Scale-up, including lab and pilot scale synthesis and evaluation	"Prototype" and "Scale-up"		
	END	A materials composition/ chemistry and synthesis approach are identified for transition to commercial manufacturing scale			
Manufacturing	START	Trials of selected materials composition/chemistry and synthesis at production scale for manufacturing are begun		TRL 7-8/ MRL 7-8	MatRL 3
	PROCESS	Production trials, product and process evaluation and modification	"Design allowables testing"		
	END	A production-scale process and resulting product is finalized and standards established			
Deployment	START	A commercial product is available		TRL 9/ MRL 9-10	MatRL 4
	PROCESS	Application-specific tailoring and supporting technology development	"Component Demo"		
	END	The product is used in the first commercial application			

The following considerations informed the development of the model:

1. The nomenclature for the four stages reflects the structure of the Materials Genome Initiative goal: discovery, development, manufacturing, and deployment

2. This model decreases the granularity and number of stages relative to typical Stage-Gate or the MGI models to focus on the four main elements. Correspondence to the QuesTek stage gate process is noted in the model description, as it is most closely aligned with materials innovation.

3. To quantify time to market, the beginning and end points of each stage are needed. For the proposed model, they are treated as occurring as a sequential series even though there can be overlaps in real cases.

4. The proposed model recognizes the relevance of the TRL and MRL designations, especially as materials are ultimately incorporated into products and manufacturing systems, noting the approximate corresponding TRL/MRL designation for each stage. In addition, the model proposes a Materials Readiness Level, or MatRL, designation for each stage as a possible approach from better integration with the TRL/MRL construct. Again, a lesser degree of granularity is needed for this more general model.

3 ASSESSMENT OF THE INITIAL QBTM MODEL

Two approaches were taken to evaluate the initial QBTM model: QBTM webinars and Materials Innovation Case Studies. Feedback and findings from these two activities informed the final iteration of the proposed model.

QBTM WEBINARS

Two webinars, identical in content, were presented on October 2 and October 14, 2015. Titled "Time-to-Market Materials Innovation Models: An MGI Benchmarking Project," the webinars presented background on time-to-market materials innovation models as well as the initial proposed model. These webinars allowed attendees to provide feedback via an online chat function. The webinar recording is available at https://www.youtube.com/watch?v=yXeVOawM_zU. No inputs that changed the proposed model were received.

MATERIALS INNOVATION CASE STUDIES

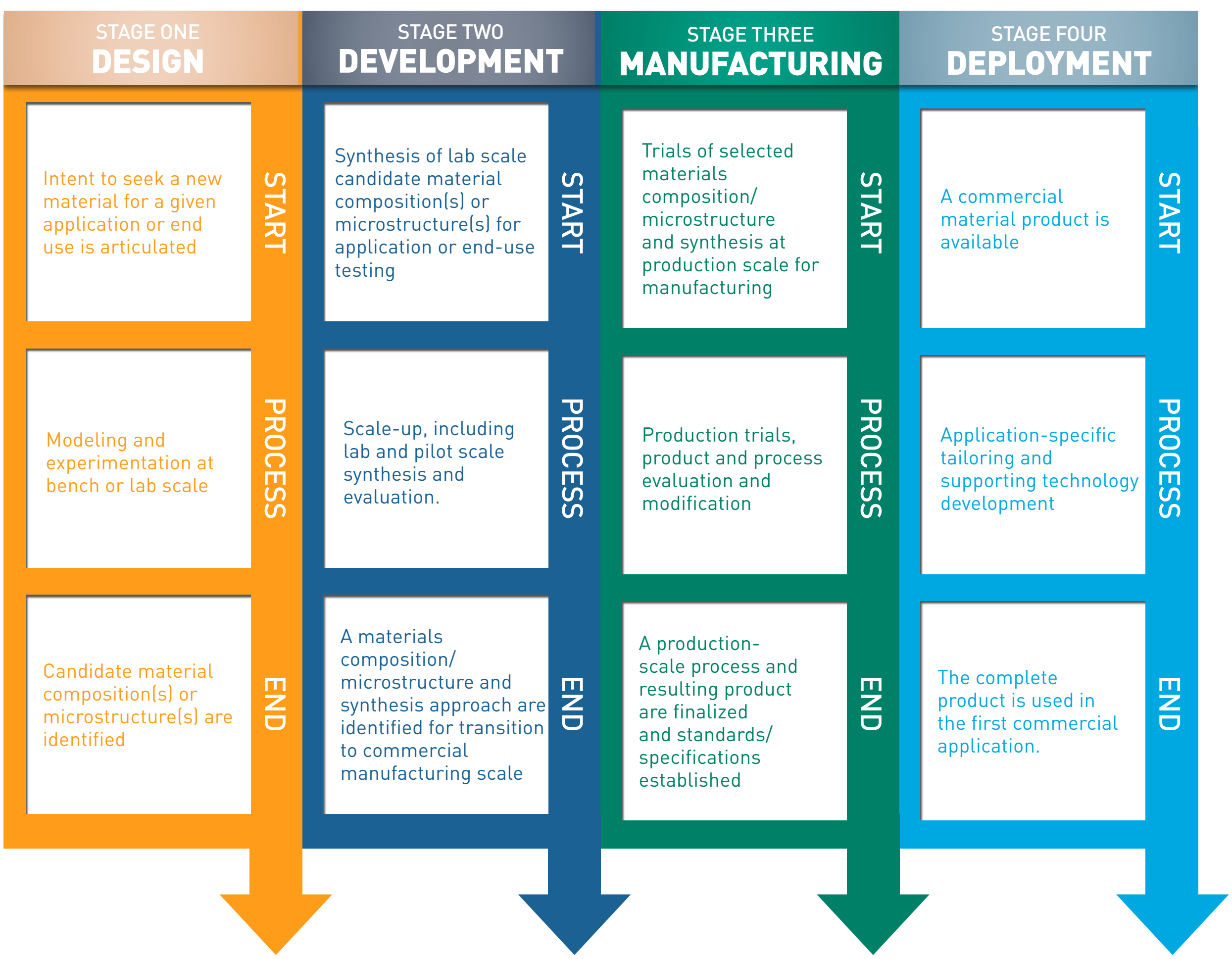
In a separate activity, two materials innovation case studies were developed, one for a structural material (Ferrium® M54, a high performance steel alloy) and one for a functional material (Gorilla Glass 3®, a high performance glass). During the development of these case studies, the initial QBTM model was reviewed with external partners to obtain their feedback and analyzed in terms of its application to actual materials innovations.

A key finding from both case studies is that the Discovery stage in the initial model was not an accurate description of the earliest stage process for these two innovations. The term “Design” was recommended as a substitute, recognizing that at least in these two cases, the earliest stage efforts were more targeted and based on existing data and knowledge rather than an unexpected discovery. This is an important distinction, since the so-called “fuzzy front end” of the innovation process is often where much of the time variability from process to process resides.

4 PROPOSED ANALYTICAL FRAMEWORK FOR THE QUANTITATIVE BENCHMARK FOR TIME TO MARKET FOR MATERIALS INNOVATION

Based on the above discussion and with the modifications based on the materials innovation case studies, a final model resulting from this work is proposed in Figure 6.

Figure 6: Proposed Analytical Framework for Time to Market for Materials Innovation



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