TRLs serve as metric in gauging progress

The process can be practically used to shorten the time before new technology can be commercialized in the oil and gas industry. First of a two-part series.

Peter Lovie, **James Pappas** and **Tom Williams**, RPSEA

Country music singer Kenny Chesney has a hit song that says "I went home at 2 with a 10 and woke up at 10 with a 2." Similar subjective choice variations can also be said about the technical readiness level (TRL) process used by a variety of industries to determine the maturity level of a technology and often then for gauging its commerciality. The process has been successfully used for years, although the scale, definitions and process varies, and there is now some science and logic to it. It can be practically used in the petroleum industry in gauging technological progress and commerciality of new developments.

To the technology developer, his or her baby may look like a "10," but investors worry about the nightmare of waking up with a technology that in the market is a "2." And for those investors—or company managers—there's a serious need for some science to the metric if a long-term relationship is at stake.

Continuing the country music theme, investors seriously want to "know when to hold 'em, know when to fold 'em, know when to walk away, know when to run," as Kenny Rogers sings in "The Gambler," and TRLs can be a metric to help make that call.

The American Petroleum Institute addressed the need for TRLs in a recommended practice called API RP 17N. Leading oil companies employ TRLs as a tool to track technology development on an ongoing basis and to guide toward desired outcomes; Total has been a pioneer in that. In Houston the oil company-led deepwater technology consortium DeepStar has employed TRLs in similar ways in recent years. Before that, NASA, the U.S. Department of Defense, the U.S. Department of Energy (DOE) and the U.S. nuclear industry all developed their own scales of TRLs. The practice has seen wide application by similar organizations outside the U.S.

The Research Partnership to Secure Energy for America (RPSEA) has determined the TRL process can assist it in prioritizing its R&D efforts to meet its goal to attempt to not only develop technologies that improve U.S. reserves and productivity in a safe and environmentally friendly manner but also demonstrate their effectiveness and lead to commercialization. Examples from four projects illustrate RPSEA's use of TRLs.

Relative Level of Technology Development	Technology Readiness Level	TRL Definition
System Operations	TRL 9	Actual system operated over the full range of expected mission conditions
System Commissioning	TRL 8	Actual system completed and qualified through test and demonstration
	TRL 7	Full-scale, similar (prototypical) system demonstrated in relevant environment
Technology Demonstration	TRL 6	Engineering/pilot-scale similar (prototypical) system validation in relevant environment
Technology Development	TRL 5	Laboratory scale, similar system validation in relevant environment
Technology Development	TRL 4	Component and/or system validation in laboratory environment
Research to Prove Feasibility	TRL 3	Analytical and experimental critical function and/or characteristic proof of concept
Basic Technology Research	TRL 2	Technology concept and/or application formulated
	TRL 1	Basic principles observed and reported

FIGURE 1. The nine-level TRL scale used by the DOE—more 'down to earth' than NASA—still lacks practical definition for E&P. (Reference: DOE G 413.3-4A 9/15/2011. Source: RPSEA)

Value to regulators, investors and end users

Regulators accepting a new technology/system in a high-risk permit application may use TRL values as a metric on technology maturity to help in this kind of difficult decision. Investors making risk-based decisions similarly may find TRLs to be a useful, quantifiable measure as opposed to solely relying on industry judgment by people they know.

The industry frequently conducts a hazard identification exercise called HAZID before a new project is commissioned, a subjective exercise employing subject matter experts (SMEs) in a process that has made a significant contribution to improving safety and reducing risk. The same can be said for TRLs.

Objective or subjective?

There is a distinction here between: (i) subjective choices based on a single nonexpert opinion, (ii) focus groups used in political or market research assessments, (iii) carefully weighed views from a panel of experts and (iv) absolutes such as the laws of physics. TRLs fall under category (iii). A standard, pre-agreed scale of what defines each TRL is used to calibrate and hence coordinate the judgments of a panel of experts making TRL determinations.

The TRL methodology was originated by Stan Sadin at NASA in 1974. In that era NASA was faced with developing many new systems where "failure was not an option," but there was little precedent to go on. The urgency of a search for a method to improve success for new developments from the early stages through execution along the lines of the TRL concept did not have to be space-related for the methodology to be of value; 50 years later the concept is used in many industries.

The NASA TRL scale evolved as a nine-level scale to cover technology development stages from a new idea to a reliable working embodiment of the new technology along the lines of Figure 1. The DOE has had its own typical development process, leading to an adaptation of the nine-level scale with a set of definitions that better suited DOE projects but lacked proper practical definition for the upstream oil and gas industry.

	TRL Designation	
Conception	TRL 0	**Unproven Idea** (paper concept, no analysis or testing)
Proof-of-Concept	TRL 1	**Proven Concept** (functionality demonstrated by analysis or testing)
	TRL 2	**Validated System Concept** (breadboard tested in "realistic" environment)
Prototype	TRL 3	**Prototype Tested** (prototype developed and tested)
	TRL 4	**Environment Tested** (prototype tested in field realistic environment)
	TRL 5	**System Integration Tested** (prototype integrated with intended system and functionally tested)
Field Qualified	TRL 6	**Technology Deployed** (prototype deployed in field test or actual operation)
	TRL 7	**Proven Technology** (production unit successfully operational for >10% of expected life)

FIGURE 2. The seven-level TRL scale adopted by RPSEA is used for technologies being developed for the petroleum industry. (Source: RPSEA)

It became clear to TRL users that the language used in the definitions of each TRL was important to enable the scale to be applied practically on the ranges of technologies within RPSEA's ultradeepwater program. RPSEA adjusted its TRL scale to better suit the characteristics of projects with a somewhat different set of TRL definitions and with language somewhat similar to the API RP 17N scale but more tailored to petroleum industry systems as opposed to hardware. It is a seven-level scale adopted from DeepStar because it was felt that the language of the definitions worked well and was used by many people in the industry community, embracing everything from relatively small investments to very large investments in the ultimate embodiments of technologies examined. The RPSEA TRL scale is shown in Figure 2.

The broad value of TRLs may have been underestimated. Part 2 of this article will demonstrate TRL use of a fit-for-purpose process for gauging technology progress—one that is simple and consistent and that provides value, recognizing how focus on process over function can compromise the intention.

A TRL process that can be easily understood by service providers, investors, research consortia and governments will increase the likelihood of commercialization of needed technologies.

Practical guidelines

Experience with TRL votes has shown that understanding the TRL process is based on SMEs that had a background in field development activities such as drilling, well services and production facilities, all of which see a fairly broad application of a variety of technologies that were recent or even relatively untried. It is suggested that at least five and not more than about a dozen SMEs be used to perform the TRL analysis. Adding more SMEs may get cumbersome, and fewer than five may result in "group-think." The SMEs might be individuals who would use the technology but cannot be enthusiasts for the technology or, worse still, be "sales monkeys" working for the originator of the technology. Responsible, professional independence is obviously critical.

It is recommended that a knowledgeable, professional and open-minded facilitator with no vested interest in the technology be chosen to lead the discussion and assessment. The facilitator is not essential but can often draw out the thinking of the SMEs.

Another principle that had to be addressed: The TRL needs to be an individual opinion and not that of the SME's employer. In effect, the TRL vote is part of a survey.

The value of that "survey" is dependent on the background of the people who take it. A panel of SMEs with operating companies, service providers, manufacturers, academia and consultants that might choose to use the technology in their core business is likely to be more significant than a panel of generally knowledgeable people.

There is significant research backing up the quality of judgment made by a panel of well-qualified experts—the Delphi Method developed by Rand Corp. for the U.S. Air Force Strategic Air Command in the 1950s and 1960s. The Delphi Method was used on national security matters quite separate from technology. It relies on isolated opinions from SMEs of established judgment and frame of reference to assess a situation that may not have any proven guidelines or precedents, with objectives of seeking maximum quality and validity in judgment on possible future actions. Those people can later be brought together to amass their opinions and attempt to form a consensus if indeed one might exist. E&P

Acknowledgment
The authors are pleased to have the permission of RPSEA to cite (i) the frame of reference of RPSEA in using TRLs and (ii) the experience with the specific RPSEA projects referred to in the examples.

TRLs gauge progress on technology, commerciality

This is the second in a two-part series on how the technical readiness level process can be practically used to shorten the time before new technology can be commercialized.

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Investors may invest in the development of new ideas, expecting a high return on their investment by rationalizing that since the risks are high, so must be the rewards. In reality, many new ideas do not work commercially for various reasons that are sometimes not readily apparent when starting on a path to develop new technologies. Moreover, it is through fits and starts, trial and error, and much iteration that some new ideas have historically flourished to become worthwhile advances on the status quo. If, for example, a manufacturer believes his widget is ready for commercialization, he had better be certain that his potential purchasers and end users share his thoughts, quite apart from any consideration of technical readiness levels (TRLs). The oil and gas industry is littered with well-intentioned technologies that have been shelved because end users were not convinced of the products' readiness or value.

That said, TRLs may help as a useful marketing tool to show that widget's readiness. A TRL voting exercise can serve as a reality check by removing much of the subjectivity, not to mention personal enthusiasms, from the equation. It may even result in a complete change in business plan.

Category of votes	Vote		TRL today	TRL in 3 years	Number of voters in panel
Operators	First	Average	**4.3**	**6.1**	9 on Jan. 9, 2013
		Range	3-5	5-7	
	Second	Average	**4.8**	**6.4**	4 at Sept. 5, 2013
		Range	3-6	5-7	
Non operators	First	Average	**5.6**	**6.7**	5 on Jan. 9, 2013
		Range	5-6	6-7	
	Second	Average	**5.0**	**6.5**	4 at Sept. 5, 2013
		Range	4-6	6-7	
Everyone	First	Average	**4.8**	**6.3**	14 on Jan. 9, 2013
		Range	3-6	5-7	
	Second	Average	**5.0**	**6.4**	8 at Sept. 5, 2013
		Range	3-6	5-7	

FIGURE 1. TRLs were used to gauge progress during a RPSEA technology development project, with a projection for TRL three years later. (Source: RPSEA)

Marine technology development

Determination of TRL figures was part of a RPSEA project on deepwater direct offloading systems by Remora's HiLoad DP equipment. Remora A.S. is the Norwegian originator of the technology, working on it since 2001 and patenting the HiLoad DP device as a system to more safely and efficiently transfer crude oil from storage on an FPSO vessel to a shuttle tanker so that the latter vessel could transport the crude to an onshore processing facility.

Although subjected to model tests and field trials, the technology had not yet been fully evaluated for the U.S. Gulf of Mexico's (GoM's) deepwater environment. The project objective was to evaluate the suitability of the technology as a preferable operating and economic alternative for offloading crude in GoM deep waters, determining if it would meet U.S. GoM requirements to enable functioning successfully for both steady-state production situations and in standby roles for emergency situations.

Two TRL votes were conducted: one early in the project Jan. 9, 2013, and the second at the end of the study Sept. 5, 2013. The voting panel was comprised of people from operating companies (end users) and nonoperators, all familiar with offloading operations and fully briefed on this project. All individuals were deemed qualified to vote (generally 15 to 35 years industry experience), with a composition as follows:

No. of Voters	FIRST VOTE	SECOND VOTE
Operators:	9	4
Nonoperators:	5	4
Everyone:	14	8

The same individuals were polled in the second votes, but only eight voted. Each voter was asked for an assessment of TRL based on the RPSEA TRL scale. The development of marine technologies such as offloading is known to be historically slow, so voters also were asked to give their assessment of TRL at some point three

FIGURE 2. These examples show how TRLs have been used with technologies in the offshore petroleum industry. (Source: RPSEA)

Example	Technology	Typical System CAPEX,$ million	Study length, months	Study Cost, $ million	TRL at start	TRL at end	RPSEA Project Number (a)	Applicable Business Sectors	Is it commercial in 2014? (b)
1	Deepwater direct offloading systems	132.0	15	1.073	**4.8**	**5.0**	10121-4407-01	FPSO units & shuttle tankers	No
2	Intelligent Production System for Ultra-deepwater Short Hop Wireless Power and Wireless Data Transfer for Lateral Production Control and Optimization	0.5	14	1.424	**2.0**	**5.0**	09121-3500-01	Subsea production	Yes
3	Autonomous inspection of subsea facilities	1.4	18	2.718	**2.5**	**5.5**	09121-3500-05	Subsea production Offshore pipelines	Probable

(a) RPSEA publishes a final report for work on each of these technologies, which will become public domain and can be tracked using this project number.
(b) While TRL can be a good signal for commerciality, the marketplace still rules and a high TRL is thus no guarantee of commerciality.
(c) Final field trials are in progress. Plans are to commercialize before year-end.

years in the future, assuming all goes well in the operation of a HiLoad DP.

The results of the voting are shown in Figure 1. The operators were more conservative than the nonoperators, giving TRLs that were lower. In the second vote that trend reversed a little:

	FIRST VOTE		SECOND VOTE	
	TRL today	In 3 years	TRL today	In 3 years
Operators:	4.3	6.1	4.8	6.4
Nonoperators:	5.6	6.7	5.0	6.5
Everyone:	4.8	6.3	5.0	6.4

After nine months of thinking about it and reviewing further engineering design, operations, economics and environmental work, the operators had increased their TRL assessment by half a TRL level and the nonoperators by about a fifth of a TRL level. It did seem to be a perceptible increase but, as these studies went at RPSEA, it was not very much considering the expectation had been to increase TRL by one or more levels as a result of the RPSEA process and funding.

Looking into the future for three years, it was interesting to see how the consensus was that even after three years of successful operation, an offloading technology would still be a half level from being fully accepted and proven (i.e., TRL of 6.4 instead of 7), which gave an insight as to how slow-moving and conservative the marine business can be. If that had been a downhole device for drilling operations, one doubts there would be any question at the end of three years of successful operation that the device would be fully proven and a TRL 7.

Example 1 shows: (a) how this particular study effort was not very effective in advancing TRL and (b) the use of TRLs on a technology that involves large capex, estimated at $132 million for a typical U.S.-built unit for a GoM application.

Subsea downhole production technology

"Intelligent Production System for Ultra-Deepwater Short Hop Wireless Power and Wireless Data Transfer for Lateral Production Control and Optimization" is the name given to a novel system for providing controls and power to downhole subsea production systems in a radically simpler and more economical way than current hardwired systems. While the capex required is much less than in Example 1, the potential payoffs are a high multiple.

This technology is attractive to the offshore production community as it may simplify subsea operations and offer substantial overall economies well beyond the capex of an embodiment of this technology.

TRLs for examples 2 and 3 were established by RPSEA staffers and not an independent voting panel as in Example 1. In Example 2, the technology was shown to work in other oilfield and industry experience but was not proven in subsea or deepwater, which together posed serious new challenges. This RPSEA project succeeded in proving downhole live operations in onshore wells. At this point the TRL was deemed to start at a 2, and afterward the project reached a TRL of 5. Subsequently, the product has been tested by an unnamed operator, commercialized and is now being used in several wells. It also is being developed for higher temperature applications, implying some increase in TRL.

It was developed by Tubel Energy, a small Texas company, with support from the University of Houston.

Subsea inspection technology

The "Autonomous Inspection of Subsea Facilities" in this example responds to the growing need for subsea inspection of wellheads, subsea flowlines and seabed pipelines. In contrast to Example 2, it was developed by a very large corporation (Lockheed Martin), with the RPSEA study effort providing needed petroleum industry inputs in addition to the objective of advancing the TRL.

The value of using an AUV was first seen in the U.S. Navy and then in oceanographic communities, which encouraged the adaptation for petroleum industry requirements.

Once again the progress with TRL was dramatic, going from the initial stage of between TRL 2 and 3 to a test system operated in a live production situation in 76.2 m (250 ft) of water in the GoM inside 18 months. The final test arrangement was judged to correspond to a TRL between 5 and 6, implying once again that a shift of three TRL levels was achieved, going from 2.5 to 5.5. Within a matter of months the production version of the AUV was routinely operating at depths of up to 305 m (1,000 ft), and newer versions are expected to extend it to 2,438 m (8,000 ft) in the near future.

The capex in a production environment would be about $0.7 million.

Comments on results

Funding for example 1 did not do much to advance TRLs, but for examples 2 and 3, the funding appears to have had a dramatic effect. That "moving the needle" may be of value in determining what additional investment should be made before the technology is widely applied in the field as well as represent a signal to operators how far the technology may be from actual trials and use.

That downhole device or survey tool might cost less than $1 million to buy but may ultimately be supplied and put in service hundreds of times and might become an enabler for many further savings in field developments. For example, the TRL may be a valued signal for commercializing an attractive technology.

Alternatively, with the quantitative indication from TRLs, the payoff may be judged not an attractive enough proposition to make the technology funding investment.

Historically, while TRL ratings may not have been explicitly used in the petroleum industry for making investment decisions, the judgment of seasoned industry experts was first employed and then calibrated by operating company feedback and comments to arrive at as careful an assessment as possible of the technology to fit market needs. That process has often been one of selection with best available judgments in the absence of the new logic of the quantification technique that TRLs can offer. E&P

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TRL conclusions

- TRLs are a frame of reference giving a useful quantitative assessment, better than a focus group or market research but not a perfect or absolute number;
- If used consistently, TRLs can be useful in gauging development progress and appear particularly useful when applied in small capex projects that may be of fairly complex technology;
- While employed as a known tool by technology developers, TRLs have broader practical value for business and management decisions;
- TRLs can act as a metric to differentiate among various options, to decide where and how much one should spend on related new technologies and assist technology developers in determining areas of weakness or needed improvements;
- In the world of the big crew change, TRLs may offer a way to codify available judgment to a similar end result, offering a metric that can be understood readily across different types of technologies and across different funding entities; and
- Since TRLs appear to gain importance as a function of larger capex and when safety is imperative, perhaps the onshore oil and gas industry should consider using TRLs since its associated costs and safety issues are on the rise while at the same time new and more complex products are being developed and marketed.

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