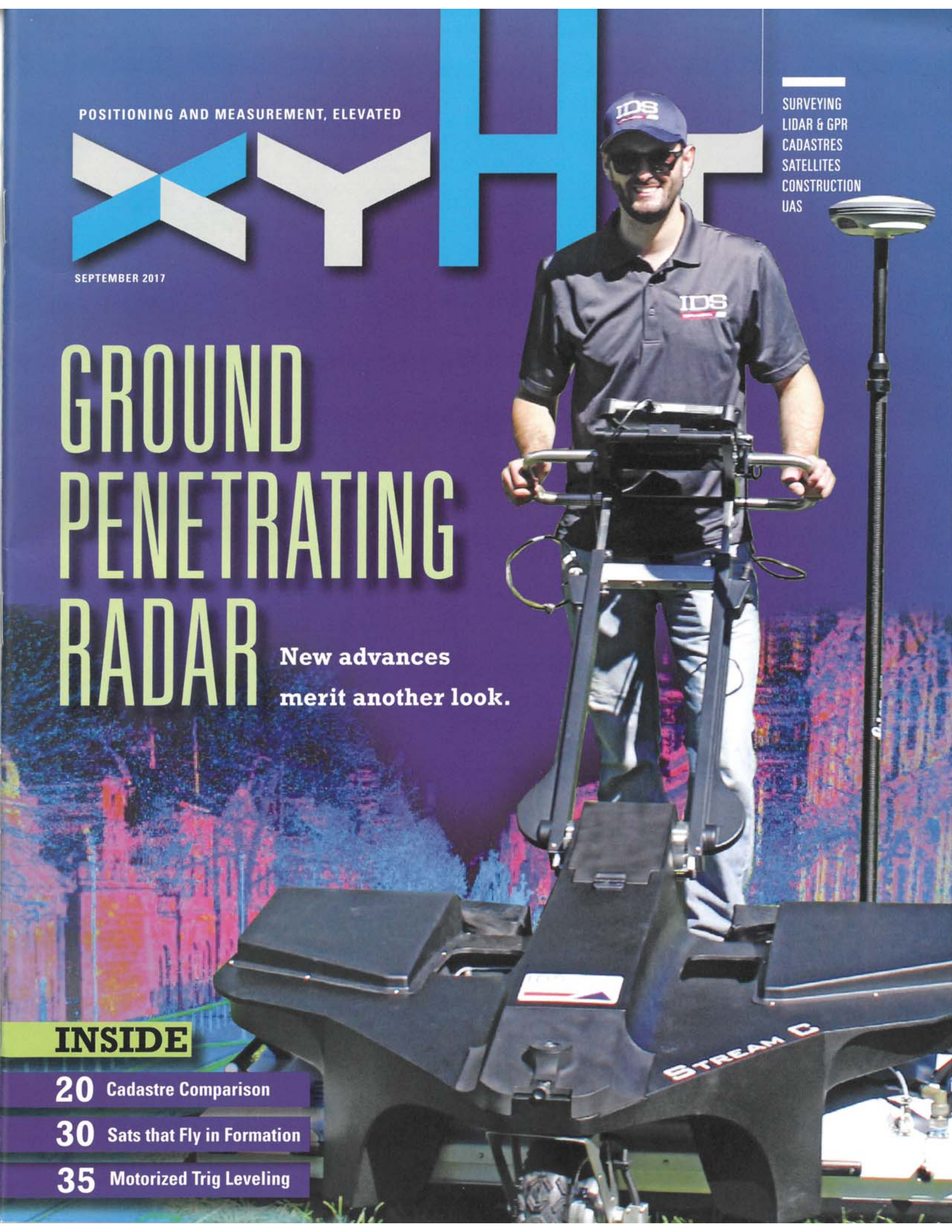

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A STREAM C is demonstrated in Golden, CO; credit: IDS NA. Background: a scan of London created by a Leica Pegasus and a STREAM EM. Credit: Leica Geosystems (part of Hexagon).

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Contributors



LEFT: Melody Cao, Kevin P. Corbley, Geoff Jacobs

BELOW: Matteo Luccio, John Stenmark, Alexandre Novo
Francisco Rojas, Gavin Schrock, Jeff Salmon






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Melody *(Berlin, page 56)* is a freelance map designer. After graduating from Brown University and the Rhode Island School of Design, she moved to San Francisco, CA in pursuit of reasonably priced avocados and an excuse to gorge ice cream year-round.

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Geoff Jacobs

Geoff *(Efficiency Snapshot, page 43)* is a 27-year, former marketing executive with Leica Geosystems (3D Scanning/HDS) and Trimble (GPS), deeply involved at the early stages of these technologies. He's authored 40+ articles on 3D scanning alone. "I've found that professionals who are keeping an eye on certain new technologies that they don't yet have (like scanning) value practical field and office productivity examples that compare the use of the new technology to traditional methods."

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Matteo Luccio

Matteo *(Recording, Registration, and Cadastres, page 20)* has been covering geospatial technologies and professions for nearly 17 years. "A country as large and diverse as the United States may never be able to achieve as unified a cadastral system as that of a small, more homogeneous one, but the Dutch example is definitely worth studying."

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John *(Motorized Trig Leveling, page 35)* is a writer and consultant, with more than 25 years of experience in applying advanced technology to surveying and related disciplines. "Motorized trig leveling might be surveying's redheaded stepchild. Robotic measurement improves efficiency and can give this under-utilized technique a place at the table."

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WE'RE LOOKING
for ideas and articles
from people in the positioning
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Gavin *(GPR Revisited, page 14)* is a land surveyor, technology writer, and *xyHt* editor. "Like many surveyors, I found legacy GPR as being difficult to interpret and use, so I was pleased to look at some of the latest offerings—and was not disappointed."

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Jeff Salmon

Jeff *(Drone Coding for Surveying's Next Gen, page 47)* is the editor for *xyHt's* Located section and *Pangaea* newsletter. As a tech writer, he enjoys covering unmanned systems, "new space," and other geospatial topics. "Kids, drones, STEM, and coding are a great combination and give youngsters an insight into important geospatial tools, plus they draw attention to possible surveying careers."

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GPR REVISITED

Arrays of multiple sensors and advances in processing breathe new life into the field of ground penetrating radar.

By Alexandre Novo, PhD;
Gavin Schrock, PLS; Jose Bohorquez;
and Francisco Rojas

We continue to struggle with the opaque elements of our world. To be able to penetrate the opaqueness of night, fog, clouds, and the ocean's depths is a relative snap compared to the challenges of seeing downward into terra firma. Civil engineering, utility engineering, resource exploration, archaeology, forensics all seek to define what lies beneath, by many technological means. Yet the only sure-fire answer comes from potholing: digging a hole. Maybe this is not such a hard rule anymore.

Ground penetrating radar has been used since the late 1920s, beginning not long after the first patents for radar. While GPR has truly been commercially available since the 1980s, its growth in use has been steady. But the sad reality is that, while many people who have tried GPR in past decades have been impressed, just as many may have been disappointed. Such disappointment might stem from a combination of unrealistic expectations; misunderstanding of the underlying science; or a belief that legacy solutions are hard to interpret, requiring specialized skills.

Above: A demonstration scan of a London street; mobile lidar for above ground and GPR for below ground. Credit: Leica Geosystems (part of Hexagon).

Left: The STREAM C, a multi-array with 34 sensors and real-time pipe detection and mapping. Credit: BTL.

It was inevitable that a technology as promising as GPR would improve; numerous advances have been developed by multiple parties. I stand among those previously disappointed by GPR, but no more. The latest wave of solutions is impressive. For those who have deeply adopted GPR, much of the following may not come as a surprise, but we hope more of the previously disappointed might give GPR a second look.

Above: the STREAM C demonstrated by IDS-NA targets underground utilities for base mapping. Credit: IDS.

Left: The STREAM EM as a towed array, pictured with GNSS for precise mapping. Credit: BTL.

LEGACY GPR

The principle is quite simple, as the word "radar" in the term implies. Emitted signals bounce off obstructions or changes in the electromagnetic properties of objects or strata below. GPR operates typically in microwave bands, from 10MHz to 2GHz. There are signal power limitations (due to strict rules from the Federal Communications Commission), but even within the allowed power limits there is still a lot you can do with GPR.

The general trade-off is that lower frequencies are typically better at depth penetration, but higher frequencies can provide better definition at shallow depths. So, you may wish to use low frequencies to look for, say, deep underground sewer and drainage structures, mid-range when you look for many other utilities that are typically not buried below 2m, and the highest frequencies to examine pavement conditions.

Systems are produced for specific applications, such as handheld, cart, and trailer systems for shallow subsurface utilities and dedicated pavement scanners (suspended on vehicle-mounted booms that can scan at normal traffic speeds).

Since the 1980s, the simple one- or two-frequency "lawn mower" style commercial GPR units have been widely used, but often only as a first peek. The GPR may serve simply to inform subsequent potholing or for further use of detector systems.

What GPR returns to the operator can be difficult for the untrained eye to interpret. First-time operators often report that they feel it would be easier to determine the sex of a baby in an ultrasonography image than to interpret GPR. Varied strata look like waves, and hard objects such as pipes appear as parabolas (which are actually hyperbolas, as that is the common term used in GPR verbiage). GPR of this type gets characterized as 2D GPR but can be used as "two and a half D."

A skilled operator or technician can look at a series of images and essentially "connect the dots" between hyperbolas to try to trace the paths of pipes or other complex structures. The image also gives a depth for the top of the (possible) pipe. A technician may be able to make logical assumptions and draft objects in 3D, but this is time-consuming and highly skilled work. An excellent white paper on the subject is "Utility Mapping Using Multichannel 3D GPR Array Technology" (M. Celaya, A. Novo, M. Sray, K. Tabrizi, and E. Boi — goo.gl/XMs24V).

Spatial inaccuracy of objects identified in separate images, relative to each other, provides a further challenge in this exercise of connecting the dots. Many legacy GPR units have typically relied on wheel encoders and measurement tapes solely; the addition of high-precision GNSS, especially RTK or network RTK (RTN), has helped greatly.

GPR ARRAYS

The application of GPR is still expanding. In addition to utility locating, GPR can be used for archeology, mapping landfills, detecting sinkholes, mapping rebars, concrete scanning, bridge-deck assessment, monitoring bridge scour, highway-related problems, stratigraphic analysis, and many more. It stands as one of the fundamental principles in surveying, photogrammetry, and remote sensing that observations from multiple vantage points can yield 3D positions; of course this would have to be also true of GPR.

From the white paper noted earlier: "An alternative solution to this is creating high-resolution

A GPR deliverable from Bess Testlab; for a roadway improvement project, their client needed to know the precise location of concrete remnants from an older concrete road below.

plane view GPR images capable of showing utilities as linear features across the survey area so that a non GPR trained human brain can quickly interpret them. With a transmitter/receiver spacing approaching a 1/4 wavelength of the transmitted microwaves into the ground, modular multichannel 3D GPR array systems have greatly improved the speed and areal coverage of the ground together with precise images of the subsurface targets."

Scientists within IDS GeoRadar (several are co-authors of the paper cited here) capitalized on this very idea of arrays of GPR sensors working in concert. IDS produces GPR array systems consisting of many closely spaced antennas which can be seamlessly integrated with cm-grade positioning devices (GNSS, total stations).

Alexandre Novo, Ph.D., a GPR scientist and geosystems business unit director at IDS-NA (IDS North America) further explained: "The STREAM (Subsurface Tomographic Radar Equipment for Assets Mapping) systems were specifically developed for large-scale utility mapping using high-resolution underground imaging. The STREAM systems are composed of modular arrays of a variable number of antennas and frequencies depending on the application and needs.

"The system is scalable because it can drive one to four antenna arrays at the same time. Additionally, the array can be mounted with single or dual polarization. Dual polarization is often useful for mapping utilities buried in two orthogonal directions acquiring data in just one single direction and therefore saving time."

IDS produce lawn-mower-sized systems like the Opera Duo (dual frequency), and these are suited for simple detection or cursory small-area GPR surveys. Then come their multiple array systems, like the STREAM C: a cart that can be pushed by hand or run on its motorized rear-drive wheels or towed behind a vehicle.

The multiple sensors, 34 on the STREAM C, work in two polarizations to enable 3D definitions. You operate the unit with a ruggedized tablet with the One Vision software. This drives a multi-view screen with GPR radar maps (B-scan and T-scan), radar tomography (C scan), and cartography survey tools. A pipe-detection module automatically identifies individual returns, like on pipes, and connects the dots.

Now, the user can do a survey of a wide area quickly and see a map of candidate pipes, in the field in real-time. Through additional post-processing you can better define the pipes or other features and export those as 3D objects for CAD.

INTEGRATED MAPPING

A step up from the STREAM C is IDS's STREAM EM. This larger array of 40 sensors in two polarizations is built on a trailer that can be towed at speeds of up to 15km per hour, covering nearly a whole traffic lane in each pass. Real-time high-precision GNSS is typically added to the trailer or prism for tracking with a total station in sky-view challenged areas.

Hexagon (the parent company of Leica Geosystems) purchased the GeoRadar division of IDS in June 2016 and has added other mobile-mapping capabilities to the EM in the form of the Pegasus: Stream. A full Pegasus mobile-mapping system is mounted on the trailer, providing high-speed laser scanning and 360 imaging. The system includes integrated GNNS and inertial positioning. Users can perform 3D above-and-below mapping over wide areas, even whole areas of a city, rapidly, and in a cost-effective manner.

You can survey a wide area quickly and see a map of candidate pipes, in the field in real-time.

FIELD APPLICATIONS

An early adopter of IDS's multi-array systems is Bess Testlab, Inc. (BTL), a large and established California firm providing a wide array of detection, inspection, and assessment services.

Says Jose Bohorquez, president of BTL, "Our clients are utility companies, cities, counties, municipalities and military installations, contractors, consulting and engineering firms."

BTL applies multiple technologies to reduce or eliminate uncertainty. Among these are IDS STREAM C, STREAM EM, Opera Duo, and a variety of other detection and potholing systems and surveying and mapping solutions, including UAV. Adds Bohorquez, "We will not leave you with a "wonder."

Bohorquez, originally from Peru, holds a degree in metallurgical engineering. In 1995, he formed Bess Testlab from an existing lab which he had been a customer of. BTL was born. The company started as a non-destructive testing (NDT) lab: soil borings, concrete cores, sonic technologies, x-rays for testing metal welds and castings. Bohorquez added more metallurgical testing capabilities.

Moving into GPR was a logical progression. Bohorquez said, "We already did x-rays of concrete walls and floors. We knew about GPR and got our first [one] in 1996 and tried it out for a year. We found it was good for deeper in the ground and got a 400MHz antenna so we could do blind search for sewer and storm [pipes]."

"There is a road improvement project [in a city just north of San Francisco] where the client wanted to see how much concrete was under the existing pavement, remnants from an older concrete road," said Francisco Rojas, project manager at BTL.

"We pulled the STREAM EM behind an ATV—at street safety speeds of 7 mph—with a [GNSS rover] attached. We did three passes on each lane, with about 10%-20% overlap. Work started about 4:00 a.m. to avoid traffic."

Rojas explains the tradeoffs between object size, depth, and choice of GPR antenna: "Resolution is basically the smallest target that the GPR can detect. A rule of thumb is that the GPR can detect a target if it is larger than 10% of the wavelength associated with the radar.

"It is not only the size of the target that makes it visible to the radar, but also its depth. The higher-frequency antennas can see shallower depth but with a higher resolution. Lower frequencies can penetrate deeper, but the target size must be at least about 10% of the wavelength of the radar."

Because some potholing was also performed, this provided BTL with an opportunity to compare the GPR to the results. In all but a few instances, the results for observed utilities matched very well.

Results clearly defined the chunks of concrete remnants. The difference between the concrete and surrounding strata is quite pronounced; GPR keys on the dielectric properties of the mediums, the differences in density. BTL understands that there are some limitations, such as observing in soil with a high clay content or in saturated soil, but still it is rare that they will not find a solution from their extensive toolbox.

I asked Rojas about situations where the sky view for a GPR project is obscured, like tree-lined road rights of way. "We can usually get a [GNSS] fix. But even if we get a bad fix, we can map, like with a [UAV], and align with the map."

In another project for a major power utility, a two-mile stretch of road needed complete as-built above and below ground. The STREAM EM was towed down the roadway, and the STREAM C was towed along the shoulders and adjacent dirt area. The corridor was then driven with their mobile mapping system.

The above examples highlight the key challenge in dealing with the opaque world of underground infrastructure; we really do not know what is down there. Decades (and in some cases, centuries) of poor documentation of as-built conditions exacerbate the uncertainty.

With multi-sensor GPR, Bohorquez says, "We go from detection to mapping." Fortunately, for outfits like BTL and the rest of us there are many great options available.

Is it time to give GPR another look? ■