Advancements throughout the past 10 years have made horizontal drilling more available, reliable and cost-effective. This technique along with multistage fracturing designs has played a major role in the development of many unconventional oil and gas fields globally, particularly the “shale revolution” in North America. These horizontal well designs include long lateral sections intersecting the target formation with many closely spaced perforation clusters grouped in planned stages. Placing the laterals perpendicular to the formation’s least principle stresses allows an effective fracture system and drainage architecture to be created in the reservoir. The large drainage area covered by each wellbore leads to efficient, economical drainage of large sections of reservoir but also leaves the possibility of stranding reserves either during the primary completion or later in the well’s life. The development of a groundbreaking diversion technology is providing a viable solution to rescue stranded assets in an array of applications from the most complex well rescues, remedial treatments and refracturing operations.

Well rescues
A flexible new diversion technology is proving to be up to the challenge of rescuing these problem wells through an interventionless process where increased lengths of lateral and numbers of clusters can be effectively fracture-stimulated. This new diversion technique does not use conventional wellbore interventions such as isolation plugs to help ensure zonal isolation but rather uses a new generation of diverting technology. Along with improved design and delivery methods, advanced diverting agents used in Halliburton’s AccessFrac service are providing higher competent diversion efficiency and offer many advantages compared to earlier materials used in oil and gas wells for temporary fluid diversion. The new engineered diversion spacers used during well rescue operations consist of the new diverting agent, which contains a multimodal particle distribution with self-assembling properties that make it useful for packing off the near-wellbore region of the formation. The new chemical diverter is environmentally benign and self-degrades in any aqueous fluid, leaving behind products that are nontoxic and that do not interfere with recycling or disposal of the recovered water.

FIGURE 1. Average daily gas production rate for the rescue well that used the AccessFrac RF to execute a ‘perf-n-plug’ technique is compared to neighboring offsets. (Source: Halliburton)
**Stimulation technique used in Marcellus**

A horizontal well in Lycoming County, Pa., was drilled to access the Marcellus Formation. After completing the first stage of hydraulic fracturing in August 2012, the operator discovered a failure in the heel of the production casing and elected to run a casing patch to remedy the situation. The inside diameter of the casing patch was too small for standard isolation plugs to pass through it. Without a new approach it was unlikely that effective stimulation coverage of the lateral could be achieved, and the operator faced the possibility of an uneconomical well. The challenge was to provide effective zonal isolation along an entire lateral without the use of mechanical plugs so fluid and proppant could be distributed evenly across all of the planned perforation clusters.

**‘Perf-n-plug’ process**

Halliburton’s solution was to apply a novel stimulation technique enabled by advancements in diversion technology. The technique is sometimes dubbed “perf-n-plug”—not to be confused with plug and perf (PNP), which uses a bridge plug to isolate each fracturing stage. In the perf-n-plug technique, after a fracturing stage, only the perforation guns are pumped down for the next stage and no plug is set. Instead of relying on a mechanical isolation plug to separate each stage, a newly engineered diversion process is executed on the front end of the following fracturing stage to plug the stimulated clusters from the previous stage. This provides isolation for the new zone, and the next stage is then pumped as designed through the newly shot perfs. This process is repeated for as many zones for length of lateral as desired.

The new technique was used in early 2013 to complete the remaining length of lateral in the Lycoming County well. Nine stages were successfully pumped, each placing roughly 300,000 pounds-mass (lbm) of proppant in 4,500 bbl of fluid. This technique can be employed any time a reduction or elimination of fracturing plugs is desired.

Strong pressure responses along with effective formation breakdowns on each of the new stages were seen. After the well was successfully completed using the new service, another benefit became apparent: no plugs to drill out. The new well rescue technique saved completion and drill-out time and provided superior well performance compared to conventional PNP offsets (Figure 1).

**Unconventional refracturing**

In recent years, advancements have led to dramatic progress along the learning curve in designing wells and fracturing treatments for the most efficient reservoir drainage. This has left many wells that were completed early in a play’s development understimulated when compared to the more recent progressive strategies. The recent aim of most operators has been to increase reservoir contact area with an optimal number of conductive transverse fractures or access points that intersect the wellbore. Trends to better accomplish this have been to reduce cluster spacing (RCS), shorten stage lengths and increase proppant pumped per foot of lateral. In addition to a desire to “catch up” to present-day progressive designs, some wells observed low cluster efficiency in primary completions; this often leaves areas of the reservoir ineffectively stimulated. Most diagnostic studies have shown that on average only 60% of the clusters are significantly contributing to production. This means that thousands of existing wellbores in most unconventional plays have vast stranded hydrocarbon reserves in existing perforation clusters that did not receive effective stimulation initially.

A successful refracturing program can have big economic and asset implications for field development and thus is economically and environmentally appealing because treatments involve reusing the existing wellbore. Additionally, permitting issues, pad construction, rig moves, pipelines and several other operational issues can be eliminated when production can be enhanced using an existing wellbore.

Due to their unique attributes, it appears that most unconventional multistage horizontal wells are going to be potential restimulation candidates at some point in their life, particularly those completed early in a play’s development that are deemed to have been understimulated or are underperforming.

Refracturing also provides the ability to go back in time and apply the current optimized methods to the old wellbore. This means a well remediation opportunity to clean out the wellbore, diagnose any scaling issues and optimize drainage volume with new formation fluid mobility modifiers to alter wettability and optimize interfacial chemistry as part of the refracturing program.

**Marcellus refracturing**

CONSOL Energy’s GH-15 is a horizontal well drilled in Greene County, Pa., with a 556-m (1,825-ft) lateral targeting the Marcellus Shale Formation. During the original completion in September 2009, the rig encountered casing-to-bottom issues, leaving a roughly 396-m (1,300-ft) openhole section past the toe of the production casing. The original completion included typical slickwater
fracturing treatments through three sliding sleeve ports spaced roughly 137 m (450 ft) apart. Due to the completion complication scenario encountered and the current fracture spacing, the well was deemed understimulated compared to current evolved stimulation designs and techniques. It was clear that refracturing potential existed. The challenge would be to effectively stimulate the openhole section as well as add newly optimized perforated zones within the cased section and initiate dominate fracture geometry at each one.

In October 2013, an AccessFrac RF treatment was performed. To start out on the refracturing, the two upper sleeves were closed, 72 perforations were added at the toe of the casing and six discrete proppant treatments separated by diversion spacers were pumped through the new perfs and the deepest sleeve out of the bottom of the casing into the openhole section. The second phase of the refracturing treatment included setting a plug with coiled tubing (CT) toward the toe of the production casing and adding new perforations with a RCS scheme between the existing ports. This phase was done in two parts that were separated by a bridge plug. The first large perforating run added 11 clusters and 88 perfs, which were stimulated using three proppant treatments. The second CT-conveyed perforating run added 10 clusters with 80 perfs and was again fracture-stimulated through three proppant treatments. A continuous pumping operation was used to stimulate the first phase in the openhole section and then in each of the two new large sets of perforations. To separate each proppant treatment, a specialized diversion spacer was pumped. A total of 12 treatments were pumped placing 1,091,881 lbm of proppant.

The post-refracturing production was in line with the original and has held a slightly shallower decline profile (Figure 2). The production potential also was increased through the refracturing, adding 59.5 MMcm (2.1 Bcf) results, CONSOL has recently applied the service technology to several subsequent wells and has identified more than 200 potential wells to recomplette.

![Gas Production](image)

**FIGURE 2.** Daily production of the CONSOL Energy GH-15 well is seen. An AccessFrac RF treatment was performed after just under four years of being online. The refracturing uplifted production in line with the original completion and added 59.5 MMcm in incremental EUR. *(Source: Halliburton)*