Geosynthetic Institute
475 Kedron Avenue
Folsom, PA 19033-1208 USA
TEL (610) 522-8440
FAX (610) 522-8441

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Geosynthetic Opportunities Associated With Shale Gas Extraction

Robert M. Koerner, Ph.D., P.E., NAE
Director – Geosynthetic Institute
Emeritus Professor – Drexel University
Phone: 610-522-8440
Fax: 610-522-8441
robert.koerner@coe.drexel.edu

George R. Koerner, Ph.D., P.E., CQA
Director Designate
Geosynthetic Institute
Phone: 610-522-8440
Fax: 610-522-8441
gkoerner@dca.net

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Abstract

While natural gas contained within shale rock is geologic by its very nature, the practice of its removal by horizontal drilling coupled with hydrofracing is quite recent. Indeed, these dual technologies are making possible the recovery of huge amounts of natural gas. So much so that one can envision natural gas as an energy source rivaling oil, coal and nuclear, while dwarfing all of the renewables combined. The potential in this regard is awesome particularly since it is worldwide in its availability and opportunities.

This white paper briefly describes shale gas drilling and extraction operations, along with its associated environmental concerns. Using this as a background, the paper then describes and illustrates many geosynthetic materials opportunities that exist in order to make the overall operations more efficient, economical, and environmentally acceptable.

Shale Gas Plays*

Shale is a fine-grained sedimentary rock which is formed by heat and pressure over geologic time. Many formations contain organic materials (they are then called *oil shales)*, which upon decay, generates natural gas within the rock itself. The liberation, capture and transmission of this gas is at the heart of the technology. It should be mentioned that natural gas has traditionally accompanied oil drilling operations and has historically been a nuisance to oil drillers. However, this same gas now takes "center stage" insofar as this white paper is concerned.

Shale gas plays are both nationwide and worldwide in their occurrence, e.g., see Figure 1 in which the data is in units of trillions of cubic meters. In the U.S., there is activity in many states as Figure 2 indicates. Of the locations shown, the Barnett formation in the Fort Worth

*The word "plays" is customarily used when describing the exploration, drilling, hydrofracturing and recovery of natural gas as described herein.

basin is very significant since it was the first large-scale operation using these newer drilling and extraction technologies. By 2004, it had been explored by 15,000 deep wells, over 4000 in 2007 alone, and had produced 1.4 trillion cubic feet; TCF (0.04 trillion cubic meters, TCM) of natural gas in 2008. It appears as though horizontal drilling at great depths coupled with hydraulic fracturing was perfected in the Barnett shale of Texas.

Figure 1 – Worldwide conventional and shale gas reserves (The Economist, August 6, 2011).

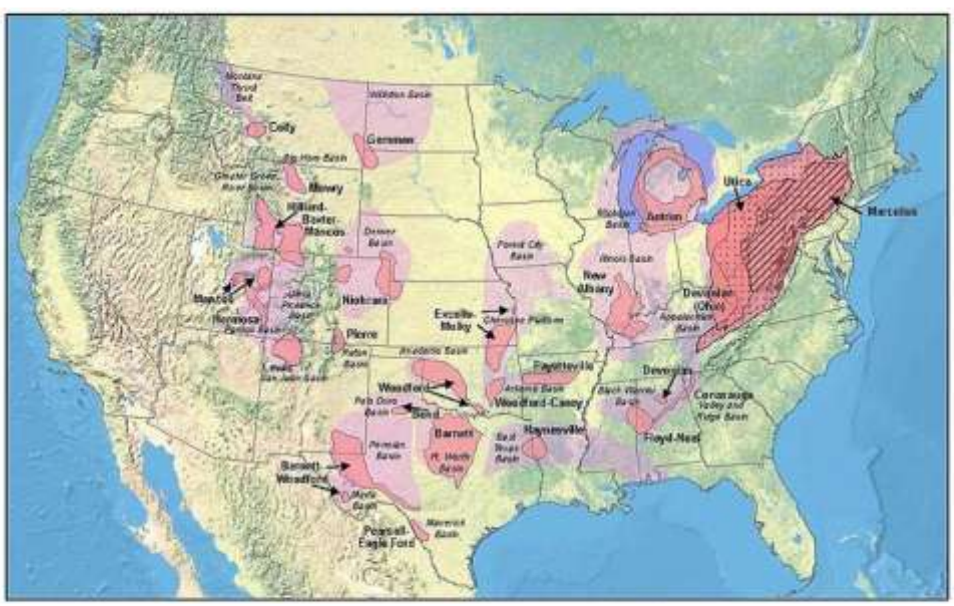


Figure 2 – United States shale gas plays (compl. Wikipedia).

The most recent major gas play is in the Marcellus formation underlying major parts of Pennsylvania, New York, Ohio and West Virginia. Figure 3 shows the extent and depth of this formation, in which it is seen to be near surface in Ohio, but 7000 ft (2100 m) deep in Pennsylvania and New York. The Marcellus formation is about 800 ft. (40 m) thick in these two states and only 50 feet (15 m) thick in Ohio. Pennsylvania is currently in full production of natural gas with 2815 producing wells and 3300 permits granted in 2010 (up from 117 in 2007). Meanwhile, New York has a temporary moratorium on gas drilling pending legislative action expected in the near future.

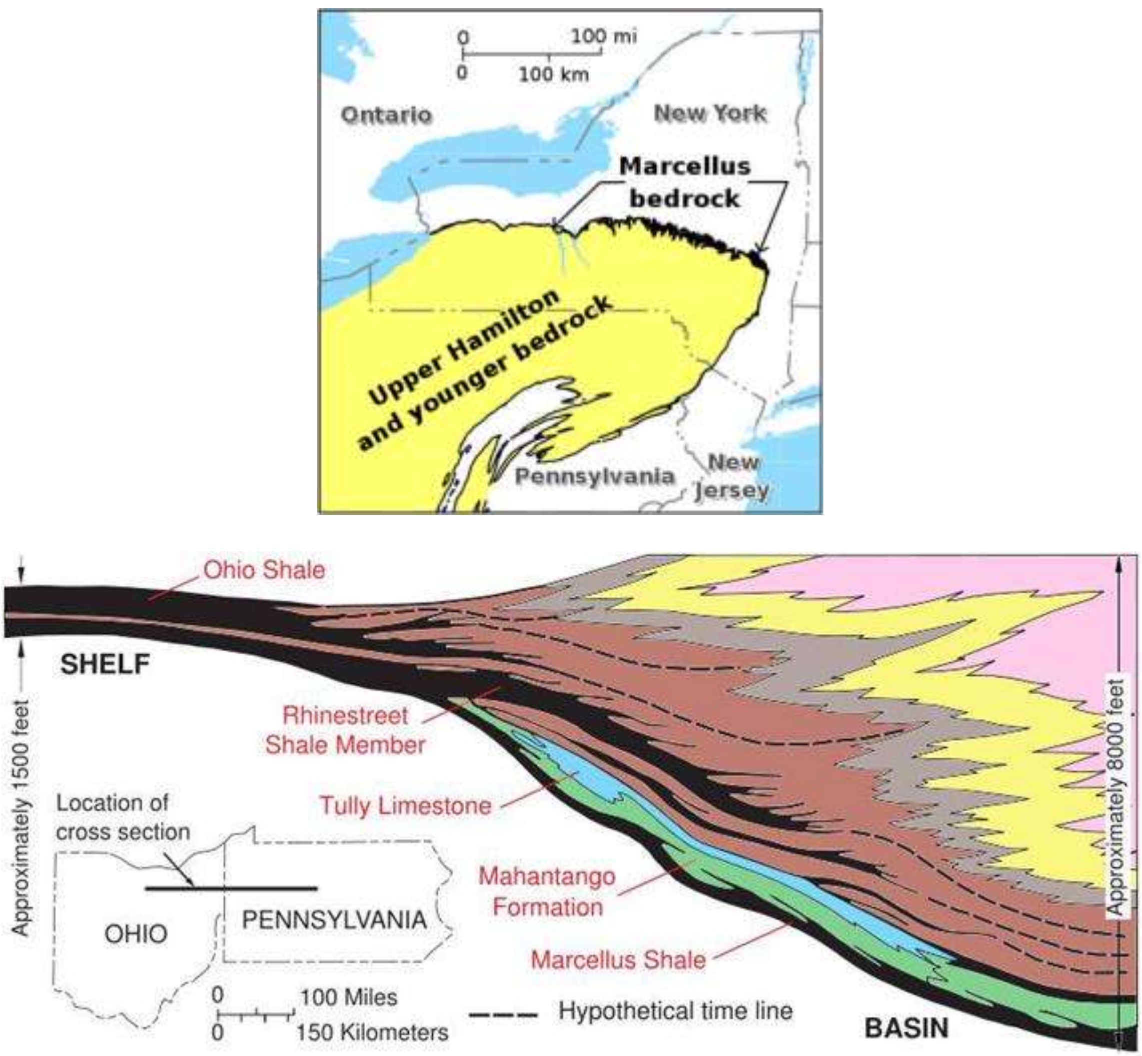


Figure 3 – Plan and elevation views of Marcellus Shale (compl. Wikipedia).

The Marcellus formation is a 400 M year old marine sedimentary rock named for an outcrop near Marcellus, New York. The bedding is well developed and it is relatively easy to fracture. That said, at these depths it requires approximately 15,000 lb/sq. in. (103 MPa) to accomplish the fracturing. The in-situ and surface exposed features are apparent in Figure 4. Its organic content varies from 1 to 10% and it sometimes contains enough carbon to support combustion. The Marcellus is underlain by the Utica formation which is a much more extensive formation covering all of New York State and continues into Canada. To our knowledge the Utica formation is not being developed at this time nor are the overlying formations, the Upper Devonian shales. However, both of these formations are thought to have large potential gas plays.

Figure 4 – In situ and fractured Marcellus shale (compl. Wikipedia).

The U. S. Department of Energy estimates that the Marcellus contains 262 trillion cubic feet, or TCF (7.4 trillion cubic meters, or TCM) of natural gas. Conversely, Professor Terry Engelder of Penn State University estimates are much higher, i.e., 4,360 TCF (123 TCM) total of which 1,310 TCF (37 TCM) are recoverable. At a market price of $0.02/ft^3 ($0.71/m^3) the U.S.

DOE estimated value is \$5.2T, while Engelder's is \$26.2T. Whatever estimate holds true, the financial incentives are enormous. For example, Professor Timothy Considine of the University of Wyoming estimates that a *typical Marcellus well* generates \$2.8 M in direct economic benefits, another \$1.5 M from workers and landowners, and \$2.0 M in federal, state and local taxes. This type of financial incentive is, of course, reflected in the present activity associated with shale gas extraction, transportation and eventual usage as an energy source.

<u>Regulations and Environmental Concerns</u>

The U.S. Energy Policy Act of 2005 was, and is, the foremost federal regulatory act governing shale gas plays of the type described in this white paper. Two aspects of this legislation have attracted considerable scrutiny;

(i) hydrofracking was exempted from the Safe Drinking Water Act, and

(ii) chemical additives to the water used for fracing were exempted from disclosure.

To gain some perspective in this regard a chemical analysis of the flowback fracwater (at a specific site) is of interest, see Table 1. Note should be made of the highlighted alkaline minerals which results in an extremely brackish liquid about five-times the salinity of sea water. Also to be noted is the number of heavy metals, although the quantities are felt to be relatively low.

Table 1 –Chemical Analysis of Flowback Water at a site near Williamsport, Pennsylvania (compl. CETCO)

Na, mg/Kg	25,930	Mg, mg/Kg	725	Ag, mg/Kg	12
K, mg/Kg	137	CL, mg/Kg	60,769	Au, mg/Kg	23
Ca, mg/Kg	6,896	HCO_3, mg/Kg	275	Ba, mg/Kg	5,145
Fe, mg/Kg	39	Hg, mg/L	<0.001	Cd, mg/Kg	0.12
Cr, mg/Kg	0.28	Pb, mg/Kg	0.80	Se, mg/Kg	1.4
Zn, mg/Kg	33	Cu, mg/Kg	1.6	TSS, mg/L	1.1

It should be noted that pending federal legislation, the so-called Frac Act of 2009, will require disclosure of fracing chemicals and place the entire process under U.S. Environmental Protection Agency regulations.

At the state-level in Pennsylvania, shale gas operations are regulated under various departments, for example;

- drilling via the state Oil & Gas Division,
- fracing water via the state Field & Stream Division, and
- waste disposal via the state Solid Waste Division.

In keeping with an emotionally-charged technology, such as natural gas plays, there are many environmental issues that have been raised by various concerned organizations, such as, federal, state and local regulatory groups, local water authorities, various industry groups, concerned citizens groups, etc. Some (but clearly not all) are mentioned below and have been selected because of the positive potential of using geosynthetic materials to solve, or at least mitigate, the issues listed:

- Containment and storage of large quantities of surface water for drilling and fracturing purposes.
- Storage and reuse of flow-back water from the hydrofracing process.
- Proper disposal of the "cuttings" from drilling operations (ca. 1000 tons per well).
- Drill pad site contamination (each being typically 3-5 acres in size).
- Frac-tank and storage area contamination.
- Access roads, parking and staging areas, and maintenance thereof.
- Minimizing site disturbance and providing level staging and working areas.
- Soil erosion and temporary containment so as to avoid stream and property contamination.

In order to appreciate some of these environmental issues it is helpful to view a composite drilling operation as well as the enormity of the drilling wells themselves, see Figures 5a and 5b.

Furthermore, some knowledge of the actual drilling operations are significant insofar as site development and maintenance. For example, a typical well site usually contains a number of vertical wells (3 to 6) which have horizontal branches going in different directions. Also, each well is generally hydraulically fractured several times. This iterative process depends upon the diminishing gas yield over time. Lastly, it is anticipated that a well pad should have a usable lifetime of approximately 20 to 30 years.

Furthermore, the following generalized goals with these shale gas extraction plays are interesting to keep in mind as we now go into geosynthetic opportunities and solutions;

- the drilling operations are large construction projects with considerable public and regulatory scrutiny,
- once permitted, fast mobilization and deployment is necessary,
- a “low profile” is advantageous particularly with minimization of truck traffic, and
- benefit/cost is always important but maximum benefit often outweighs minimum cost.

(a) Typical gas extraction operation in Marcellus Shale in Pennsylvania

(b) Several large gas well drill rigs

Figure 5 –Site operations at natural gas plays (compl. Wikipedia).

Geosynthetic Opportunities

This section of the White Paper describes some of the many geosynthetic solutions that can be applied to shale gas plays. The section is subdivided according to (i) the drilling operations themselves, (ii) opportunities at permanent locations, and (iii) opportunities at temporary locations.

Geosynthetics Associated with Drilling Operations

The first, and quite obvious, opportunity is the use of geomembranes for fresh water containment and subsequent use in the well drilling operations. The design stages are well known and consist of the following sequential steps:

- geometry (length, width, depth)
- cross section materials
- geomembrane type
- geomembrane thickness
- subgrade soil stability
- cover soil stability
- runout and anchor trench details

Perhaps the most overlooked design detail is the requirement of providing an underdrain system beneath the geomembrane. Shown in Figure 6 are the all-to-common “whales” lifting up the geomembrane via rising gases within the underlying soil subgrade. Various underdrain solutions that should be considered are the following:

- thick needlepunched nonwoven geotextiles
- drainage geocomposites (complete or strips)
- interconnected perforated pipe system
- geotextiles with small perforated pipes
- sand bedding layer (with pipe network)

Figure 6 – Some very recent whales (2009) in a potable water reservoir (compl. GSI).

The second, and also obvious, opportunity is the containment and re-use of the flow back water which was characterized in Table 1 and is seen to be quite contaminated. Presently, this water is generally being held in mobile holding tanks (see Figure 7) but geomembrane lined ponds or even underground storage systems offer attractive alternatives. Figure 8 is a double lined contaminated surface impoundment in Virginia (the cross-section is soil subgrade, geotextile, geomembrane, geonet, geomembrane from bottom to top) and Figure 9 is an underground storage system that is typically used for storm water runoff from industrial and private development sites. Both strategies should be considered in contrast to hundreds of holding tanks interconnected to one another as shown in Figure 7.

Figure 7 – Mobile holding tanks for frac-water (compl. Wikipedia).

Figure 8 – Double-lined surface impoundment for contaminated water (compl. GSI).

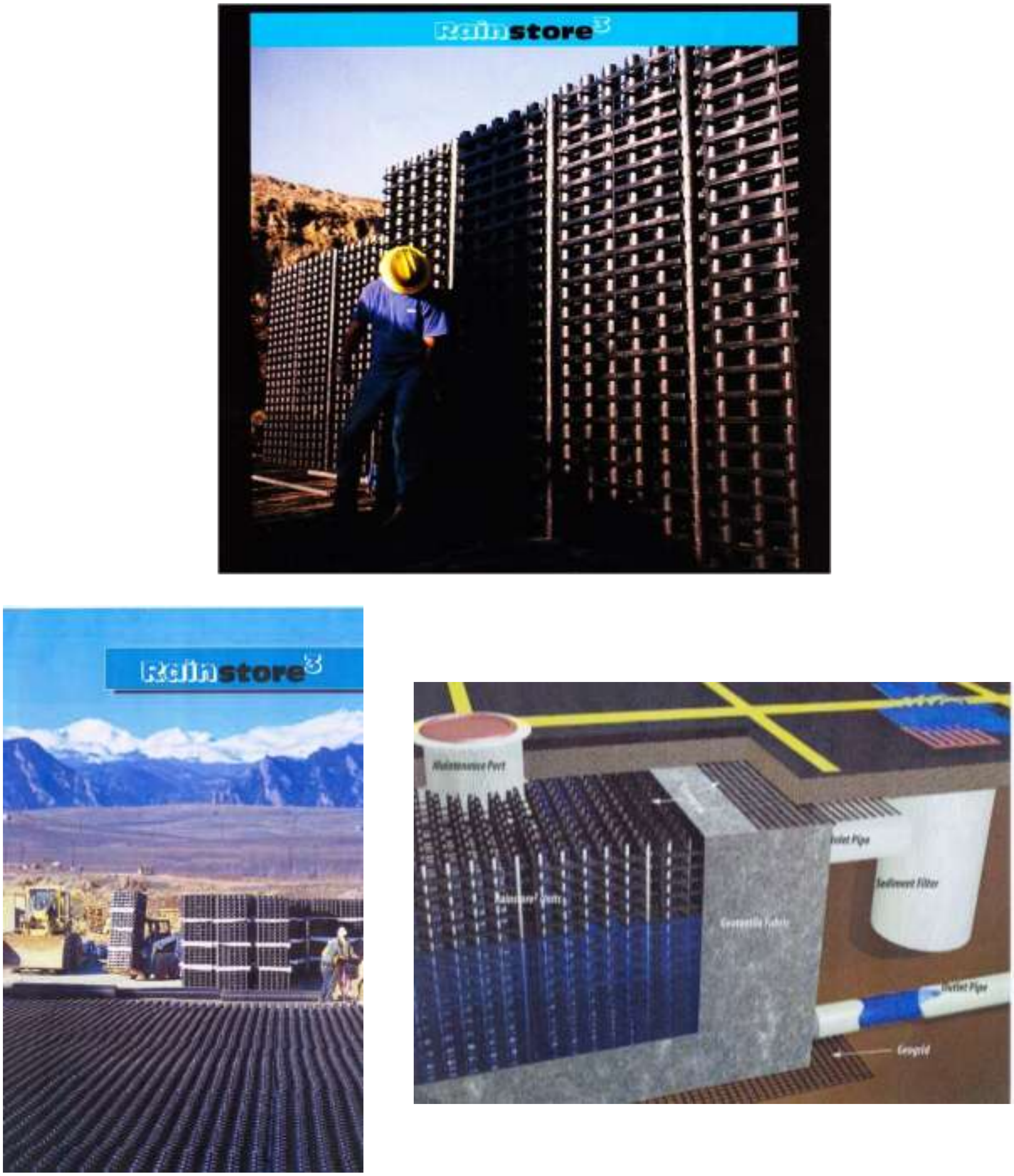


Figure 9 – Various underground storm water storage systems (compl. Rainstore®).

A <u>third</u> opportunity for geosynthetics is the containment of cuttings from the drilling operation itself insofar as proper safe and secure disposal is concerned. In this regard, it should be mentioned that each well produces about 1000 tons ($\underline{\sim}$ 75 truckloads) of contaminated cuttings of the type shown in Figure 10.

Figure 10 – Contaminated cuttings from well drilling (compl. Wikipedia).

These cuttings can, of course, go to a licensed public or private landfill but alternatively can be placed in geotextile tubes at the site (or within a landfill as seen in Figure 11) and can even have a decontaminant added such that the treated effluent can be released to the environment. The addition of charcoal, activated carbon, phosphoric rock, or organoclays is necessary and all are within decontamination technology that is associated with geotextile tubes.

Figure 11 – Geotextile tubes located within a landfill as they are being filled whereby the effluent is automatically captured (compl. GSI).

Opportunities at Permanent Locations

Of first priority in this category are the roadways into and out of the drilling site which are necessary for the 20 to 30 years lifetime of the operations. Geotextiles and geogrids have been shown to save from 10 to 50% of the crushed stone thickness of base courses placed on soil subgrades[*]. The functions of separation, stabilization and/or replacement are clearly indicated in the literature since this application has been ongoing for about 30-years; see Figure 12. Not only is there a savings in stone base material, the distance from the quarry is significant in the total cost of the application.

A second way of reducing crushed stone thickness there is considerable economy offered by using geocells as shown in Figure 13. They are filled with gravel, sand or locally available soil and their design (which uses a geotextile beneath them) is well established. Thicknesses saved are from 50 to 100% over the use of gravel by itself.

[*]The old adage that "Ten pounds of soil and ten pounds of water make twenty pounds of mud" is seen at many drill sites particularly in the spring of the year.

Figure 12 – Use of a geotextile (or geogrid) in an unpaved road applications (compl. IFAI/GMA).

Figure 13 – Thick (~ 8.0 in or 200 mm) geocells (compl. PRS Med. Ltd.).

Thirdly, these same geocells in a less-thick format are ideal for parking and staging areas located adjacent to the drill pad, see Figure 14.

Fourth, locally available soils (even silts and clays) can be meaningfully strengthened by the addition of discrete fibers or microgrids, see Figure 15. Both types lead to major increases in shear strength in the upper 4 to 12 inches (100 to 300 mm) of surface. The technology is well advanced and mature at this point in time.

Figure 14 – Less thick ($\underline{\sim}$ 4 in or 100 mm) geocells (compl. CETCO Cont. Services).

Figure 15 – Examples of discrete fibers and microgrids (compl. Propex and Tensar).

Fifth, the drill pad site along with adjacent parking and staging areas must be level. To accomplish this in hilly terrain (as is typical in the Marcellus shale area) one needs to create stable soil slopes or even vertical walls. The concept of mechanically stabilized earth (MSE) slopes and walls using geogrid or geotxtile reinforcement is ideal in this regard. Not only are these situations the least expensive of all types of retaining structures (GRI Report #20), they are straightforward to construct, have no limitations as to curvature, height, or orientation, and have proven stable insofar as extreme surcharge loads are concerned; see Figure 16.

Figure 16 – Vegetated MSE wall in Pennsylvania (compl. Waste Management, Inc.)

Sixth, the drill pad itself should be lined so as to avoid contamination from spilled fracwater, hydrocarbons or other potential ground contaminates. This calls for a geomembrane, a geosynthetic clay liner, or both, as a composite liner. There are many choices in this regard and a designer should consider the generation of a benefit/cost ratio to select the appropriate liner material. See Table 2 for a hypothetical example situation. In it, the procedural steps are as follows:

(a) select relevant site-specific properties as per application

(b) weight properties from 10 (high) to 1 (low)

(c) select candidate geomembrane types

(d) grade types from 5 (high) and 1 (low)

(e) multiply weight by grade

(f) add resulting numbers

(g) divide by estimated unit costs

(h) select the geomembrane type with highest benefit/cost ratio

Upon geomembrane selection, the engineer must now specify the properties. For the past several years there have been generic specifications available for common liner materials. Those that are currently available are the following:

- GRI-GM13 for high density polyethylene (HDPE)
- GRI-GM17 for linear low density polyethylene (LLDPE)
- GRI-GM18 for flexible polypropylene(fPP and fPP-R)
- GRI-GM21 for ethylene propylene diene terpolymer (EPDM and EPDM-R)
- GRI-GM25 for reinforced linear low density polyethylene (LLDPE-R)
- GRI-GCL3 for geosynthetic clay liners (GCL)
- ASTM-D7176 for polyvinyl chloride (PVC)

Hypothetical Example Only

Table 2 – Example B/C Matrix for Drill Pond Liner Geomembrane

Property	Weighting	HDPE		LLDPE		fPP-R		PVC		CSPE-R		EPDM-R	
chem. resist.	3	5	15	3	9	4	12	2	6	5	15	5	15
durability	10	5	50	3	30	4	40	2	20	5	50	5	50
UV stab.	8	5	40	3	24	4	32	2	16	5	40	5	40
shear strength	7	4	28	4	28	3	21	3	21	3	21	3	21
stress. crack	7	2	14	5	35	5	35	5	35	5	35	5	35
seamability	9	4	36	3	27	3	27	4	36	3	27	2	18
seam behavior	9	4	36	4	36	3	27	4	36	3	27	3	27
strength	5	4	20	3	15	5	25	3	15	5	25	5	25
elongation	5	4	20	5	25	2	10	5	25	2	10	2	10
tear	6	3	18	2	12	5	30	2	12	5	30	5	30
puncture	6	4	24	3	18	5	30	3	18	5	30	5	30
impact	6	4	24	3	18	4	24	3	18	4	24	4	24
exp./cont.	4	2	8	3	12	4	16	3	12	4	16	4	16
constructability	10	3	30	4	40	4	40	5	50	4	40	4	40
benefit	n/a	-	363	-	329	-	369	-	320	-	390	-	381
cost/m^2	n/a	-	10.00	-	10.50	-	11.25	-	9.00	-	12.50	-	13.00
B/C ratio	n/a	-	36.3	-	31.3	-	32.8	-	35.5	-	31.2	-	29.3

Seventh, natural gas plays are replete with plastic pipe. Such pipe as shown in Figure 17 is used for many purposes such as;

- fresh water transmission
- frac water transmission
- gas transmission
- surface water drainage

Figure 17 – HDPE solid wall, PVC solid wall, and HPDE corrugated pipe (various sources).

The pipe is generally HDPE or PVC and can be solid wall (for transmission) or corrugated with slots or holes (for drainage). Whatever the case, natural gas plays require the use of plastic pipe in a major way.

<u>Opportunities at Temporary Locations</u>

<u>First</u> of all, temporary roadways of weeks or months are necessary in connection with setup and eventual demobilization at natural gas plays. The geosynthetics industry has the capability of providing wearing surfaces placed directly on the ground. Shown in Figure 18 are light and heavy roadway systems developed by the Dutch Military for rapid deployment of heavy vehicles and equipment. They are typically 60 ft. long and 10 ft. wide and the weight varies with type. Obviously, they can be redeployed as often as necessary.

<u>Secondly</u>, temporary dams may be used for surface water control or for accidental spills associated with the drilling or containment operations. Figure 19 shows that geomembranes can readily provide such temporary containment and be adaptable to myriad applications.

<u>Third</u>, on sloping surfaces soil erosion is a concern and must be avoided so as to prevent silting of off-site areas and local streams and rivers. Geotextile silt fences have played an economical role in this regard for decades. Figure 20 shows such a silt fence being installed and properly functioning.

<u>Fourth</u>, rather than containing the site's erosion after it occurs it is better to control and stabilize it before it starts. This has been traditionally provided by geosynthetic-erosion control materials of which there are a great variety. The two major categories are shown in Figure 21 for slopes and channels/ditches, respectively. Designs are well advanced in both cases.

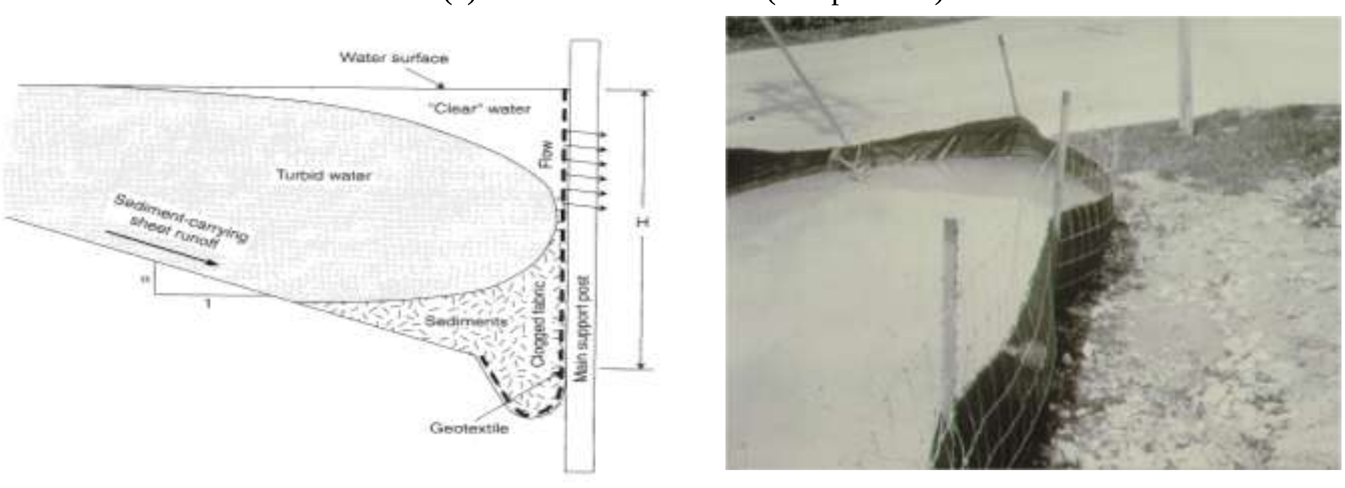
(a) Light trackway type

(b) Heavy trackway type

Figure 18- Temporary roadways developed by the Dutch military.

Figure 19 – Temporary containment systems (compl. Portadam®).

(a) Silt fence installation (compl. IFAI)



(b) Properly perofrming silt fence (compl. GSI)

Figure 20 – Silt fence for erosion control.

(a) Slope erosion control (compl. TenCate)

(b) Channel/ditch erosion control (compl. Colbond)

Figure 21 – Erosion control and revegetation systems.

Closing Comments

Natural gas plays (including actual drilling, the well pad, staging and parking areas, permanent and temporary roadways and access areas) are extremely large construction projects with enormous natural gas energy potential. They also have attracted considerable public and regulatory scrutiny. That said, once permits are obtained, fast mobilization, deployment and operations are necessary. Within the entire activity a low profile and exposure is always an advantage. All of these aspects can capitalize on geosynthetics in a major way. This White Paper has described many of these opportunities.

Of course, and within acceptable environmental criteria, benefit/cost analyses are always required for alternative and competing systems. We feel that in so doing, geosynthetic materials will invariably be the obvious choice for many of these applications.

For general information on geosynthetics see the following websites or contact the authors of this White Paper.

- Geosynthetic Institute www.geosynthetic-institute.org
- Geosynthetic Materials Association www.ifai.com
- GMA Techline at gmatechline@ifai.com
- Geosynthetics Magazine www.geosyntheticsmagazine.com
- Geosynthetica www.geosynthetica.net
- International Geosynthetics Society www.geosyntheticssociety.org
- North American Geosynthetics Society www.nagsigs.org