REASONABLY FORESEEABLE DEVELOPMENT SCENARIO

FOR OIL AND GAS

FOR THE

GEORGE WASHINGTION NATIONAL FOREST

VIRGINIA AND WEST VIRGINIA

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SUMMARY

A Reasonably Foreseeable Development Scenario (RFDS) for oil and natural gas is developed based on the assumption that all potentially productive areas can be open under standard lease terms and conditions except those areas designated as closed to leasing by law. It covers a time period of 15 years and includes all lands within the boundaries of the George Washington National Forest (GWNF) regardless of mineral estate ownership and adjacent non-forest lands.

Exploration on GWNF lands has been sparse and activity on surrounding lands has been minimal. Thus far, only five wells have been drilled on GWNF lands. All were designed to test a specific horizon and all were dry holes. Two small natural gas fields have been developed adjacent to GWNF lands, but, with the exception of one well, there has been no drilling activity since the 1990's.

Several oil and gas plays have been identified which cover the area of interest. As such, the oil and gas occurrence potential must be considered as high. One of these plays is related to the Marcellus Shale which is present on the surface and in the subsurface under more than half of the GWNF lands. With industry focus currently directed toward the exploration for and exploitation of organic shales and in particular the Marcellus, the oil and gas development potential is also considered as high.

It is foreseen that 20 vertical exploration/evaluation wells will be drilled over the next 15 years which will prove the presence of productive Marcellus Shale in the area of the GWNF. Additionally, 50 vertical and 249 horizontal development wells are forecast to be drilled over the timeframe of the RFDS. The initial gross surface disturbance associated with the exploration, development, and production activity in the GWNF is estimated at 1,515.53 acres. With partial surface reclamation following completion of productive wells, the net disturbance is projected at 953.47 acres. An additional 25 acres of lands are allocated for compression operations, produced water handling, material storage, and other facilities.

INTRODUCTION

The United States Department of Interior, Bureau of Land Management (BLM), Southeastern States Field Office prepared this Reasonably Foreseeable Development Scenario (RFDS) for Oil and Gas for the George Washington National Forest (GWNF). The RFDS is consistent with BLM Handbook 1624-1 and BLM Instructional Memorandum (IM) 2004-89. IM 2004-89 requires that the RFDS project a baseline scenario of activity assuming that all potentially productive areas are open to leasing under standard terms and conditions with the exception of those areas closing to leasing by law.

The RFDS is a reasonable, technical, and scientific estimate of anticipated oil and gas activity based on current information and data available. The baseline scenario presented in the document will be used by the United States Department of Agriculture Forest Service (FS) as the basis for determining the cumulative impacts from oil and gas activity relative to each alternative developed in the planning process.

DESCRIPTION OF GEOLOGY

The George Washington National Forest (GWNF), located in northwestern Virginia and eastern and northeastern West Virginia, is situated within portions of three physiographic provinces. From east to west, these are the Blue Ridge, the Valley and Ridge, and the Appalachian Plateau.

Structure

Blue Ridge Province

The Blue Ridge Province is an area of largely igneous and metamorphic rocks that have been thrust over younger Cambrian and Cambro-Ordovician sedimentary rocks. According to the USGS in the 1995 National Oil and Gas Assessment, “the Province underlies parts of eight States from central Alabama to southern Pennsylvania. Along its western margin, the Blue Ridge is thrust over the folded and faulted margin of the Appalachian basin, so that a broad segment of Paleozoic strata extends eastward for tens of miles, buried beneath these subhorizontal crystalline thrust sheets (Harris and others, 1981). At the surface, the Blue Ridge consists of a mountainous to hilly region, the main component of which are the Blue Ridge Mountains that extend from Georgia to Pennsylvania. Surface rocks consist mainly of a core of moderate-to high-rank crystalline metamorphic or igneous rocks, which, because of their superior resistance to weathering and erosion, commonly rise above the adjacent areas of low-grade metamorphic and sedimentary rock. The province is bounded on the north and west by the Paleozoic strata of the Appalachian Basin Province and on the south by Cretaceous and younger sedimentary rocks of the Gulf Coastal Plain. It is bounded on the east by metamorphic and sedimentary rocks of the Piedmont Province."

In a Description of the Geology of Virginia (James Madison University), the Blue Ridge is characterized structurally "as a large, eroded anticline overturned to the west. The core of the anticline is composed of igneous and metamorphic rocks collectively known as the Grenville, although there are also late Proterozoic intrusives and sediments present too. They are the oldest rocks in the state at 1.1 billion back to 1.8 billion years. The east and west flanks of the anticline are much younger volcanics and clastic sediments. Stratigraphic thicknesses range from about 3000 meters to 7000 meters. The final filling of the graben and creation of a divergent continental margin is preserved in the metamorphosed lava flows (Catoctin) and sedimentary rocks (Chilhowee Group and Evington formation) about 570-600 million years old."

Valley and Ridge

The majority of the GWNF lies within the Valley and Ridge Province. The Valley and Ridge represents a physiographic province of the larger Appalachian division which extends from southeastern New York, northwestern New Jersey, northeastern and central Pennsylvania, western Maryland, eastern West Virginia, northwestern and southwestern Virginia, and into Tennessee, Georgia, and Alabama. The Valley and Ridge forms an arc between the Blue Ridge Mountains on the east and the Appalachian Plateau on the west.

The province includes the Great Valley which is an expansive, flat region composed of complexly folded and faulted Cambrian and Ordovician carbonates and the Ordovician aged Martinsburg Shale. The Great Valley extends west to east from North Mountain to the Blue Ridge and is some 20 miles wide.

From North Mountain westward to the Allegheny Front, a distance of about 50 miles, are a series of northeast-trending mountains and valleys from which the Valley and Ridge Province is named. The ridges are comprised of resistant beds of sandstones, conglomerates, or quartzites and the valleys of less resistant carbonates and shales. Formations in the Valley and Ridge are thrust faulted and folded into anticlines and synclines and range in age from Cambrian to Lower Mississippian. The Valley and Ridge province is divided into several sharply defined anticlinal complexes separated by much broader synclinal zones. The most persistent of these synclinoria, the westernmost, extends 250 mi from central Pennsylvania to southern Virginia and averages 10-20 mi in width.

The majority of the GWNF lies within the Valley and Ridge Province between the Little North Mountain Fault and the Allegheny Plateau. This area is part of the Broadtop Synclinorium. Jacobeen and Kanes (1974) state, "Component structures of the Broadtop synclinorium include: Broadtop syncline (Broadtop coal basin) of Pennsylvania; Town Hill syncline, Whip Cove West anticline, Whip Cove syncline, Whip Cove East anticline, Spring Gap syncline, Sideling Hill syncline of Maryland and West Virginia (Tilton et al., 1927); and the Bergton-Crab Run anticline of Virginia (Brent, 1960). In this synclinorium, surface outcrop consists of predominantly Carboniferous and Devonian strata. Ordovician to Lower Devonian rocks comprise the cores of bounding anticlinoria."

Allegheny Plateau

The Allegheny Structural Front is the transition zone between the highly folded and faulted formations of the Valley and Ridge and the relatively flat lying rocks of the Allegheny (Appalachian) Plateau. Formations exposed on the Allegheny Front range in age from Middle Devonian to Lower Mississippian. Only a small portion of the GWNF, that located in Highland County, Virginia, lies within the Allegheny Plateau Province.

STRATIGRAPHY

The following formations crop out in the GWNF.

- Pocono Formation – Massive gray sandstone with some dark shale
- Hampshire Formation – Chiefly red sandstone; some flagstones, shales, and mudrock.

- Foreknobs Formation (formerly Chemung) - Green and greenish-gray, thin- to thick-bedded, fossiliferous (most notably large crinoid stems) quartz sandstone and shale and minor quartz-pebble conglomerate.
- Brallier Formation - Olive-gray, thin-bedded, micaceous, sparsely fossiliferous siltstone, shale, and thin lithic sandstone. Thickness: 1500 to 2200 feet.
- Millboro Shale (Marcellus) and Needmore Formation **-** Millboro Shale: black, fissile shale, with thin bentonite beds. Near the base is an interval of dark-gray, aphanic, thinbedded limestone (Purcell Member?). Needmore Formation: olive-gray, weathered, fossiliferous shale, with thin bentonite beds. Composite thickness 800 to 1200 feet.
- Ridgeley Sandstone, Helderburg, and Cayugan Groups – Calcareous sandstone; limestone, cherty in part; and calcareous shale; fossiliferous.
- Keefer, Rose Hill, and Tuscarora Formations – Quartzarenite, dusky-red shale, and sandstone.
- Massanutten Sandstone – Quartzarenite with lenses of conglomerate.
- Juniata, Reedsville, Trenton, and Eggleston Formations – Dusky-red shale, mudstone, and sandstone; shale and limestone
- Martinsburg Formation – Gray shale, sandstone, and siltstone; gray argillaceous limestone.

PAST AND PRESENT OIL AND GAS EXPLORATION ACTIVITY

Regional seismic exploration was conducted in the late 1960’s and early 1970’s from the Blue Ridge, through the Valley and Ridge, and into the Appalachian Plateau Province utilizing Vibroseis on existing major east-west roads. Several of these lines crossed through the area of the GWNF. Additional seismic exploration was conducted in the general area in the late 1970’s and early 1980’s in response to industry interest in the Eastern Overthrust Belt in which most of the GWNF is situated. Five wells in Virginia and two wells in West Virginia were drilled in the overthrust belt in response to these efforts. The primary objective was the middle Devonian Oriskany Sandstone. None of the wells were productive.

There are five wells drilled on GWNF lands – four exploratory and one development. All were dry holes. There are other exploratory wells drilled on private lands between or within the GWNF, but only one discovery was made, that in the Bergton area of Rockingham County.

The only recent exploration activity in the area of the GWNF has been the Hardy County, West Virginia well drilled by Carrizo Marcellus, LLC in March 2010.

PAST AND PRESENT OIL AND GAS DEVELOPMENT ACTIVITY

The discovery of natural gas in the Devonian Oriskany Sandstone at Bergton Field located in Rockingham County, Virginia led to the drilling of 18 development wells. 7 were initially productive, but all are now plugged and abandoned.

There has been a well drilled in Hardy County, West Virginia on the Bergton structure. The well specifically targeted the Marcellus Shale. The same company that drilled the Hardy County well has applied for a permit to drill a Marcellus test on the Bergton structure in Rockingham County, Virginia.

The only other field of consequence near the GWNF is the Thornwood-Horton Field located in Pocahontas County, West Virginia. The field, which is immediately adjacent to GWNF lands in northwestern Highland County, Virginia, produces from the Oriskany Sandstone. One of the wells in that field communitized GWNF lands into the production unit for the well.

Other than the new Hardy County, West Virginia well and the proposed Rockingham County, Virginia well, activity in the area in and surrounding the GWNF has been nonexistent since the late 1990's.

OIL AND GAS OCCURRENCE POTENTIAL

The BLM RFDS Handbook, H-1624-1, recommends that all areas within USGS or other defined plays should be given a high potential rating for oil and gas occurrence potential. In the Appalachian Basin Province evaluation of the USGS 1995 National Oil and Gas Assessment, R. T. Ryder defined some 34 real and hypothetical conventional and continuous (unconventional) plays. Four of these plays directly relate to the part of the Appalachian Basin Province where the GWNF is located. These are:

6702 Upper Cambrian, Ordovician, and Lower/Middle Silurian Thrust Belt

6716 Upper Silurian Sandstone Gas

6718 Silurian and Devonian Carbonate Thrust Belt

6720 Oriskany Sandstone Gas/Faulted Anticlines

In response to markedly higher natural gas prices in the 1990's, the Barnett Shale in Texas became a target for exploration and development activities. The play was only marginal from an economic stand point until new drilling and completion techniques were applied, thus demonstrating the viability of continuous resource plays. Since that time, development of continuous resource plays, including the Marcellus Shale, has been at the forefront of industry activity in the United States. Trillions of cubic feet of natural gas reserves have been added as a result of this activity.

In a 2002 assessment of undiscovered oil and gas potential of the Appalachian Basin Province, Milici and others outlined various conventional and continuous (unconventional) oil and gas resources. In this report, the Marcellus Shale Assessment Unit of the Devonian Shale-Middle and Upper Paleozoic Total Petroleum System was estimated to contain a mean value of potential resources of 1.9 TCF, with a range of 822 BCF to 3.67 TCF. Since that time, the Marcellus and other black organic shales in the Appalachian Basin have become the focus of intense exploration and development efforts. In response to these efforts, potential recoverable reserve estimates for the Marcellus Shale have now been projected by industry to as high as 50 TCF (Engelder 2008).

Patchen and Avary (2008) state, "The Middle Devonian Marcellus Shale is the oldest, thickest and most widespread of four formations in the Hamilton Group of central and eastern New York. This black shale unit extends from New York southward to Virginia and West Virginia, and westward into eastern Ohio where it pinches out beneath the Middle Devonian unconformity. In Ohio, the Marcellus Shale generally is not separated from younger rocks in the lower Olentangy Formation; in Virginia, the Marcellus usually is included in the basal portion of the thick Millboro Shale. Throughout the basin, the Marcellus Shale overlies the Onondaga Limestone or eastern facies equivalents, the Huntersville Chert or Needmore Shale." Enomoto (2009) states, "In the Virginia portion of the Appalachian Basin, the Devonian Mahantango Formation and the Marcellus Shale are mapped collectively as one unit that is named the Millboro Shale. This unit in Virginia consists of black, fissile shale units, with interbeds of dark gray argillaceous limestone or calcareous shale. Thin, dark gray, aphanitic limestone beds occur near the base. Geophysical logs from wells drilled in Highland and Rockingham counties, Virginia, indicate that the thickness of the Millboro Shale ranges from 368 to 570 feet thick in this region."

The Marcellus Shale underlies more than 50 percent of the area of the GWNF. When coupled with previously defined plays, the oil and gas occurrence potential of the GWNF is considered as high.

OIL AND GAS DEVELOPMENT POTENTIAL

Well log data from wells drilled in the area indicate that the Marcellus Shale is present in the subsurface. Data evaluated from the cuttings from several of these wells and from samples taken from outcrop, show that the Marcellus Shale in the area of the GWNF has sufficient organic content and thermal maturity to be productive of natural gas (Enomoto, 2010). Patchen and Avary (2008) state, "the thickest accumulation of this organic-rich black shale occurs along the eastern side of the basin from New York to Virginia where thermal maturity is the highest. This combination of thick, thermally mature (dry gas window) black shales with well-developed regional fracture sets makes the Marcellus Shale an attractive play along the eastern side of the basin far from historical shale play areas as well as in the center of the basin," including the Valley and Ridge of Virginia and West Virginia.

There is some general interest in the area as a well targeting the Marcellus Shale has been drilled in Hardy County, West Virginia and another is being permitted by the same company across the state line in the Bergton area of Rockingham County, Virginia. One reason for the interest this area is the proximity of natural gas pipelines. The results of natural gas production from these wells and other new wells if drilled, coupled with evaluations of the log data from previous exploratory wells both within and adjacent to the GWNF, should serve as the basis for the leasing and future development of the Marcellus Shale resource in the GWNF.

TYPICAL DRILLING AND COMPLETION SCENARIO

Drilling

Both vertical and horizontal wells will be utilized for the exploration and development of the Marcellus Shale resource in the GWNF. The true vertical depth (TVD) of these wells will range between 1000' and 8000'. Actual measured depths (MD) should range between 4000' and 12,000'.

In the GWNF, the likely drilling medium for vertical wells will be air or air-mist. For horizontal wells, air or air-mist will be used to the kickoff point, then either water or oil based drilling mud will be used for the radius turn and horizontal lateral portion of the hole.

Vertical wells are drilled from the surface to a point in the subsurface directly below the surface location. Horizontal wells are drilled from the surface to a point in the subsurface some hundreds or thousands of feet from the surface location. In each instance, conductor casing is run to a depth of 30, 60, or 90 feet. Drilling then continues to a point below the level of any aquifers or other zones that contain fresh water and a string of protective casing is run to that depth and cemented to surface. The setting of the surface casing isolates and protects fresh water and other important zones from contamination by connate waters, drilling mud, and hydraulic fracture fluids.

Below the surface casing, vertical wells are drilled through the objective horizon. Once total depth is reached, a string of production casing is run and cemented in place with the level of cement sufficient for isolation of the productive interval. Horizontal wells are drilled to a point below the surface casing to the kickoff point where the well is steered from the vertical to the horizontal utilizing a medium or long radius turn. The well is designed for the borehole to enter the objective horizontally and then drill the lateral within the objective formation. Measure While Drilling (MWD) equipment and Geosteering software allow for the drilling of the borehole in a determined direction and attitude. Once Total Depth (TD) is reached, production casing is run to or near the total drilled depth and cemented in place with the level of cement sufficient for isolation of the productive interval. Horizontal lateral length will average 4000'.

By law in Virginia, vertical wells must be drilled at least 2500 feet apart. At a minimum, the vertical well spacing unit is 112.69 acres – a circle with a 1250' radius. For horizontal wells, the unit size is 320 acres – a rectangle with dimensions of 2640' X 5280'. Horizontal laterals will be drilled parallel to the long side and are required to have 600' of separation. There is also a 300' offset from the unit boundary requirement thus limiting maximum lateral length to 4680'. As a result, a maximum of 3 laterals can be drilled in each horizontal well unit.

Over the 15 year time frame of the RFDS, the average cost for a completed vertical well is estimated to average $2,500,000. For horizontal wells, the estimate is between $6,000,000. and $9,000,000. per well. Although the well cost for a horizontal well is 2 to 4 times higher than that for a vertical well, the potentially productive formation exposed in the horizontal borehole is 10 or more times greater. Recoverable reserves in horizontal wells are normally higher also. Recoverable reserves are estimated at 1,000,000 MCF/well for vertical wells and 3,000,000 MCF/well for the horizontal ones.

Based on the above averages, the drilling, completion, and production costs of the wells projected to be drilled in the GWNF is $2,042,000,000. The estimated ultimate recoverable reserves (EUR) developed from the drilling of these forecast wells is 817,000,000 MCF.

Completion

The higher cost for a horizontal well is the result of the increase in measured depth due to the length of the lateral and also the added stimulation cost. The typical vertical shale well is usually perforated over the potentially productive interval and stimulated by one hydraulic fracture treatment. The typical horizontal well, on the other hand, often undergoes 10 or more staged fracture treatments each the same size as that for a vertical well. This again relates to the demonstrably increased productiveness inherent to horizontal drilling.

Hydraulic fracture stimulation is utilized in many wells, but is a necessary process for wells drilled in low permeability reservoirs like shales. An estimated 90% of the natural gas wells in the US use hydraulic fracturing to produce gas at economic rates.

The hydraulic fracturing of horizontal wells requires large volumes of water. Each stage of the stimulation uses 10,000 to 12,000 barrels of water (420,000 to 504,000 gallons). Usually 10 or more treatments are necessary in order to stimulate the entire productive horizon requiring 100,000 to 120,000 barrels of water (4.2 to 5.0 million gallons). During initial post treatment flowback, only 20 percent or less of the fracture fluid is recovered. The rest of the fluid is produced over time. The returning fracture fluid can be treated and reused, treated and disposed of at the surface, or disposed of by underground injection. Both state and federal agencies have oversight of surface disposal. The EPA or EPA-delegated state program have oversight of underground injection.

RFD BASELINE SCENARIO ASSUMPTIONS AND DISCUSSION

The initial assumption is that all potentially productive areas can be open under standard lease terms and conditions except those areas designated as closed to leasing by law. It covers a time period of 15 years and includes all lands within the boundaries of the George Washington National Forest regardless of mineral estate ownership and adjacent non-forest lands where oil and gas activity may impact Forest lands.

Additional assumptions include:

- Initial and primary activities will be directed toward exploration and development of the resources of the Marcellus Shale.
- The Marcellus Shale underlies 569,763 acres of the 1,065,499 acre GWNF. Of this total, 484,299 acres are projected to be capable of natural gas production from the Marcellus Shale.
- Seismic exploration will utilize existing roads for Vibroseis and not result in any appreciable surface disturbance.
- Minimum well spacing and unit size will be governed by rules and regulations the various state authorities designated for oversight of oil and gas operations.
- Access roads construction disturbance is based on a 30’ wide ROW. The actual travel surface and buffer area, however, is anticipated to be less than 30’.
- Well pad and pit size will vary between 2.07 acres for vertical wells to 5.74 acres for multi-well locations.

- For productive wells, those portions of the well site not necessary for production facilities and well operations will be reclaimed. For non productive wells, the entire area will be restored.
- For productive wells, all production facilities will be located on the initial well pad.
- Well gathering and other pipelines will utilize existing access and other road right of ways. Utility lines will also be constructed within existing access roads right of ways.
- Wells drilled to test other, deeper horizons that may become of interest can be drilled from facilities constructed for the exploitation of the Marcellus Shale, either concurrent with or after development.
- Compression, processing, produced water, and material storage facilities will most likely be constructed on private lands, but could be constructed on GWNF lands. 25 acres of land is allocated for the construction of these facilities.

SURFACE DISTURBANCE DUE TO OIL AND GAS ACTIVITY

Access Roads and Well Pads

The two primary sources of surface disturbance from oil and gas exploration and development activity are well (drill) pad construction and the building of access roads to the well site. In situations where production is not established, the well site and the access road are reclaimed. In situations where production is established, a portion of the well site is reclaimed and the access road is upgraded for long term use.

New well roads would be necessary to access drill sites from the existing GWNF road system or from other highways. Access roads are generally constructed for temporary use during the drilling phase of operations. After production is established, access roads are upgraded with a single lane or wider all weather travel surface for long term use. For purposes of the GWNF RFDS, disturbance estimates were based on access roads having a consistent 30’ construction limit width. All access roads would be constructed under established GWNF guidelines.

Well pads vary in size depending on the type of well to be drilled, well depth, the number of wells to be located on the same pad, and local topography. Well pad size can also be proportional to the type and amount of equipment and material needed to complete the well once drilling has ended. Well pad size in the area of the GWNF is projected to vary between 2.07 for a single vertical well location to 5.24 acres for typical 3 well directional or horizontal well sites.

Each drilling rig can on average drill and complete approximately 1 horizontal well in this area every 3-4 weeks (12-17 wells/year) or 1 vertical well every 10-14 days (26-35 wells/year). To fully develop the resource in the GWNF would require some 20 rigs, each drilling 15 horizontal wells per year over the 15 year life of the plan. Given the number of wells and rigs required, a projected increasing natural gas supply in the U.S., the need for projected steady gas pricing through the year 2025, and simply that there are better areas for Marcellus Shale exploitation, full development of the resource in the GWNF is not a likely scenario within the operative time frame of the plan.

Forecast Development and Disturbance

The development of the Marcellus Shale resource within the GWNF is anticipated as follows:

- Seismic Exploration (Vibroseis): 163 miles on existing roads (casual use minimal disturbance)
- Exploration/Evaluation Wells - Vertical (20 drilled from a single 2.07 acre pad): 41.32 acres
- Exploratory/Evaluation Wells Access Roads (1.5 miles/well): 109.09 acres
- Development Wells-Vertical (50 drilled from single 2.07 acre pad): 103.31 acres
- Development Wells-Vertical Access Roads (1.0 miles/well): 181.82 acres
- Development Wells-Horizontal (249 drilled from a 5.74 acre 3 well pad): 476.35 acres
- Development Wells-Horizontal Access Roads (83 X 2.0 miles/pad): 603.64 acres
- Total Initial Disturbance from exploration and development: 1515.53 acres
- Total Area Reclaimed Following Well Completion: 562.06 acres
- Total Net Disturbance from exploration and development: 953.47
- Area allocated for Compression operations, gas processing, produced water handling, and material storage facilities: 25 acres
- Percentage of Leasable Forest Acres disturbed by oil and gas operations is less than two-tenths of one percent.

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