INTRODUCTION

Rockies Gas Production Challenge: The U.S. Energy Information Agency (EIA) indicated in its Annual Energy Outlook that Rocky Mountain region annual gas production would need to grow by 1.3 TCF or 162.5 BCF per year, based on the eight years from 2003 through 2010, to meet its 2010 gas production forecast. At least 75 percent of this production growth would come from unconventional reservoirs with tight sands contributing 859 BCF or almost two-thirds of the total forecast. Annual Rocky Mountain gas production [Fig.1] has grown from about 2.1 TCF in 1990 to 4.4 TCF in 2003. This represents an average annual growth of 169 BCF per year. Since 2000, however, the average annual production has increased by only 138 BCF per year. Future Rockies production growth rates must increase by some 18 percent in order to reach the EIA target.

Unless the current mix of well productivity improves, the only way to meet the growth target is to increase gas drilling. According to IHS Energy’s vintage gas produc-
tion assessment, end 2003 annual base Rockies gas production declined by 283.6 BCF or 6.8 percent during 2004. Therefore, annual new drilling must replace this amount of production and an additional 162.5 BCF of production to meet the EIA’s annual growth target. To do so, the industry must complete at least 6,500 gas wells per year, some 15 percent more than the 5,649 gas wells reported during 2003. Maximizing production from unconventional reservoirs will be a key factor in meeting the EIA projection.

Constraints: The industry must overcome significant constraints to hit the EIA’s projected gas production growth target. Important issues include:

- Periodic pipeline bottlenecks
- Periodic large gas price basis differentials which have caused some operators to shut-in production
- Restricted access to resources on public lands
- Delays during permitting and regulatory processes
- Repeated legal challenges and injunctions from anti-business interests

Location of Rockies gas plays: The map of 2003 well completions in the Rocky Mountain region was used to identify the key unconventional gas reservoirs that were analyzed in this study. The selected reservoirs include:

- Coalbed Methane: With the exception of the Eocene Big George CBM wells in the Powder River Basin, CBM wells and associated formation codes on this map are shown in dark red.
- Powder River Basin CBM production is outlined by the yellow oval on Figure 2. Eocene Big George (BGGG) wells are highlighted in yellow and shallower Wyodak–Anderson CBM completions are dark red.
- Upper Cretaceous Fruitland Coal (FRLD) in the San Juan Basin, Upper Cretaceous Ferron coals (FRRN) in the Uintah Basin, and Cretaceous Vermejo coals (VMRJ) in the Raton Basin (or Las Vegas–Raton Basin) are the other prime historic CBM targets. Emerging Mesaverde coal (MVRD) plays in the Green River and Piceance basins were reviewed but it is not yet clear what impact these resources will have on Rockies gas production.

Figure 1. Rockies annual production from 1990 through 2004 is shown with CBM volumes in violet, other gas-well gas in red and associated gas in orange.
Tight sands reservoirs:

- Upper Cretaceous, primarily Mesaverde (MVRD) and equivalent (Almond – ALMD; Eagle – EGLE; Cameo – CMEO; Williams Fork – WMFK; Lance - LNCE) tight sand gas completions are highlighted in yellow with formation codes in black. Productivity of Upper Cretaceous tight sands in the Green River, Piceance, Uinta and San Juan basins was analyzed.

- Niobrara (NBRR), Codell (CDLL) and Dakota (DKOT) in the Denver Julesburg basin; Fort Union (FRUN) in the deep Wind River Basin; Frontier (FRNR) in the western Green River Basin and Dakota (DKOT) in the San Juan Basin.

- Analyses of interesting new Jurassic Entrada and Triassic Wingate (WNGT) production in the Uinta Basin and of Ft. Union (FRUN) production in the Wind River Basin are included.

Other gas plays are identified on the map with bright red well symbols and formation code annotations. The plays include:

- Nibrara (NBRR), Codell (CDLL) and Dakota (DKOT) in the Denver Julesburg basin; Fort Union (FRUN) in the deep Wind River Basin; Frontier (FRNR) in the western Green River Basin and Dakota (DKOT) in the San Juan Basin.

Methodology: The objective of this study was to assess and compare gas productivity trends for key Rockies CBM.
and tight sands reservoirs. It was determined that “vintaged” gas production analyses provide the most comprehensive and easy-to-use results to compare and contrast production performance parameters between multiple plays with large well populations. The vintaging process combines monthly production streams for all wells completed in each calendar year for any unit of production – reservoir, field, basin or region – that is analyzed. Basic output consists of the monthly production volumes and associated producing well counts for the wells that are completed in each calendar year. The vintaged monthly production data were used in this study to determine average peak well production, cumulative production during the first 24 months, average per well reserves, total annual reserve additions, well drilling and abandonment rates, and to project future drilling rates that will be required to sustain or grow future gas production. All of the analyses and conclusions presented in this paper were derived from IHS Energy’s production databases and vintaged gas analysis software tools.

Gas production histories for 37,845 wells were analyzed for this study. Specific project well counts included:

<table>
<thead>
<tr>
<th>Coalbed Methane</th>
<th>17,335 wells</th>
</tr>
</thead>
<tbody>
<tr>
<td>Powder River Basin</td>
<td>10,810 wells</td>
</tr>
<tr>
<td>San Juan Basin</td>
<td>4,375 wells</td>
</tr>
<tr>
<td>Raton Basin</td>
<td>1,387 wells</td>
</tr>
<tr>
<td>Uinta Basin</td>
<td>763 wells</td>
</tr>
<tr>
<td>Total Tight sands</td>
<td>20,510 wells</td>
</tr>
<tr>
<td>Green River Basin</td>
<td>6,523 wells</td>
</tr>
<tr>
<td>–Upper Cretaceous Lance</td>
<td>540 wells</td>
</tr>
<tr>
<td>–Upper Cretaceous Mesaverde</td>
<td>2,153 wells</td>
</tr>
<tr>
<td>Piceance Basin, U. Cretaceous Mesaverde</td>
<td>3,122 wells</td>
</tr>
<tr>
<td>Uinta Basin</td>
<td>4,799 wells</td>
</tr>
<tr>
<td>–U. Cretaceous Mesaverde</td>
<td>851 wells</td>
</tr>
<tr>
<td>–Jurassic-Triassic</td>
<td>43 wells</td>
</tr>
<tr>
<td>Wind River Basin</td>
<td>2,184 wells</td>
</tr>
<tr>
<td>–Tertiary Ft. Union</td>
<td>295 wells</td>
</tr>
</tbody>
</table>

**COALBED METHANE**

Coalbed methane wells contributed 1,537 BCF or 34 percent of Rockies 2004 gas production (Fig. 1). Vintaged gas production profiles provide a visual comparison of the relative production volumes and stage of development for the four major Rockies CBM basins. The charts reveal that substantial CBM production increases in the Powder River, Uinta and Raton basins (1,090 MMCFD) more than offset the loss of about 300 MMCFD in the San Juan Basin that occurred from 1999 through 2002. San Juan Basin CBM production recorded modest increases during 2003 and 2004, while production peaked during 2003 in the Uinta and Powder River Basins.

There have been substantial variances in production decline behavior. Vintage 1991-1994 San Juan Basin production increased for 48 to 60 months before commencing gradual decline rates. The end-2003 San Juan Basin base production decline rate had increased to 15 percent, while the Powder River Basin CBM production declines increased markedly since 1999, exceeding 37 percent in the Wyodak and Anderson reservoirs. Production declines for Ferron CBM production in the Uinta Basin and Raton Basin CBM production have increased moderately over the last four years.

- San Juan Basin CBM delivers the largest gas volume, but production peaked at about 2,700 MMCFD in 1998-1999 and decreased through 2002. Powder River Basin CBM production growth was dynamic – increasing 930 MMCFD from 1997 to a peak of 988 MMCFD in September 2003. Production volumes are directly related to drilling activity. CBM completions increased from 204 wells during 1997 to a high of 3,152 during 2001. But curtailed drilling during 2003 and 2004, when CBM completions averaged only 1,925 wells per year, triggered the production decline (72 MMCFD) during 2004. It is hoped that the combination of higher volume wells from the Big George coal reservoir and increased drilling will be able to reverse the decline in Powder River Basin CBM production.

- The Uinta Basin (Drunkards Wash) production profile also is directly related to the number of wells drilled. Drilling peaked during 2001 with 163 wells but plummeted to only 15 wells during 2004. Correspondingly, production peaked at 294 MMCFD in December 2002 and declined to 245 MMCFD by December 2004. Even though development started later, Raton Basin CBM production surpassed that of the Uinta Basin during 2003 and continued to increase, reaching 297 MMCFD during December 2004. Drilling remains robust, averaging almost 325 wells per year since 2000, and production should continue to increase from this expanding play.

Vintaged average well production plots reveal substantial variation in production performance among the four major Rockies CBM plays and also over time in each of the individual plays.

- San Juan Basin CBM recorded the highest average peak production rates (1,200 MCFD) and the largest number...
of months (60 months) to reach peak production from 1991 vintage wells. The time required to reach peak production decreased to as little as 24 months in recent vintages. Peak production also has varied since 1993, ranging from a low of about 400 MCFD in 1994 to a high of 900 MCFD in 1997-98 (red & orange curves). Since 1999, the vintage curves do not appear to have peaked, but vary from year to year in almost the same range as the 1994-1998 vintage wells.

- During their first three years, Uinta and Raton basin CBM plays also recorded long dewatering periods (42 and 41 months respectively) before reaching peak production. Since 2001, the dewatering periods have decreased, averaging 24 months or less. After reaching peak average well production of 600 MCFD and 500 MCFD, respectively, with 1996 vintage wells, peak well production trends in both the Uinta and Raton basins have decreased, ranging from 170 to 210 MCFD.

- Powder River Basin CBM wells have reached their peak production in about 24 months, about 40% less than in the other basins. However, peak well production in the Powder River Basin also has been lower, ranging from an average of about 201 MCFD for 1996 vintage wells to an average of about 118 MCFD for vintage 2001 through 2004 wells. There is no clear evidence from production performance to-date that the Big George coal will boost overall average Powder River Basin CBM well productivity.

Figure 3. Production from the wells completed during each calendar year from 1991 through 2004 is differentiated by color bands. Production is presented in MMCFD. Note the varying scales for the four basins in this figure and in Figures 4, 7, 8, and 11.
There is a positive correlation between average peak well production and the cumulative production over the first 24 months in Rocky Mountain CBM producing plays (Fig. 5). CBM wells in the San Juan and Uinta basins with the largest peak well productivity also generate the largest production volume during the first 24 months. This pattern also prevails for the other CBM reservoirs on the chart. Average well productivity data for Mesaverde coals in Green River Basin have been erratic but recent vintage wells along the Atlantic Rim have achieved some improvement over the averages indicated in Figure 5. The cumulative well production for the first 24 months for CBM completions since 2000 improved to 80.4 MMCF from the overall average of about 40 MMCF.

**CBM Average Well Reserves**

The projected average reserves per well (Fig. 6) also conform to the average well productivity patterns. San Juan Basin CBM wells, with highest historic average peak production rates and long producing life, record the largest reserves. The average reserve per well for vintage 1994 through 2002 completions was 2,050 MMCF but the trend in recent vintages is decreasing, averaging less than 1,500
MMCF during 2002-2003. Average reserves per well for Ferron CBM wells in the Uinta Basin averaged about 1,600 MMCF per well but dropped to only about 425 MMCF per well over the past three years. Vermejo coals in the Raton Basin averaged about 700 MMCF per well but dropped to about 450 MMCF per well over the past two years. The Wyodak and Anderson coals in the Powder River Basin averaged 213 MMCF per well since inception and dropped below 200 MMCF per well since 1999. Vintage Big George reserves per well also have tended to decrease over time but averaged almost 970 MMCF per well through 2003. Low decline rates –averaging about 10 percent – were calculated for Big George producers. If the low decline rates are sustained, projected Big George average reserves per well could be much greater than those in the Wyodak and Anderson coals. The Big George, though, also yields substantially more water per MCF of gas.

If recent trends of increasing decline rates, smaller reserves per well and lower peak production persist, substantial increases in drilling will be required to sustain the current level of Rocky Mountain CBM production.

TIGHT SANDS

Driven by high volume wells from the Upper Cretaceous Lance formation in the Jonah Field and Pinedale Anticline, the Green River Basin spearheads tight sands...
gas production growth in the Rockies. Expanding plays from Mesaverde and equivalent reservoirs in the Piceance and Uinta Basins also add to Rockies gas production, while Tertiary Ft. Union and Lance reservoirs are helping to sustain gas production in the Wind River Basin. Vintaged gas production profiles (Fig. 7) show that gas production in these four basins has increased by 1,865 MMCFD since 1998, a 58 percent increase to 5,085 MMCFD, accounting for a substantial part of the overall Rockies production growth. A striking increase in production decline rates (indicated by increasing left to right slope in the vintage color bands) also is evident in all four basins.

- The Green River Basin had the largest 1990 base gas production of around 1,500 MMCF per day. New drilling since 1999, especially in the Jonah Field and on the Pinedale Anticline, boosted production by some 950 MMCF per day to almost 3,350 MMCF per day in 2004.

- The Piceance Basin has recorded the most striking production growth, a 213 percent increase (480 MMCFD) since 1998, with most of the growth during the last three years. The Uinta Basin Mesaverde play continues to expand, adding 210 MMCFD since 1998. Wind River Basin production grew by almost 35 MMCFD during 2004. Bill Barrett Corporation’s developments at the Waltman and Cooper Reservoir Fields on the northeast flank of the basin in Natrona County plus expansion of Ft. Union pays in the Madden and Frenchie Draw fields contributed to the production growth.

**Tight Sands Performance Green River, Powder River, Uinta and Piceance Basins**

In contrast to coalbed methane, vintaged well peak production (Fig. 8) improved markedly (average 70 percent increase) from 1999 (yellow curves) through 2003 in the Green River, Piceance and Uinta basins. These increases are substantiated in 2004 vintage data. New completion technologies and operating experience have boosted peak well production to around 1,500 MMCFD in the Green River Basin, 800 MMCFD in the Piceance Basin and to around 500 MMCFD in the Uinta Basin. These increases in well productivity have been achieved in spite of a shift to closer well spacing in many active fields. Sustaining positive well performance will be critical in order for operators to expand these plays beyond the current hot spots. Decreasing Wind River Basin well performance is the exception.
After a significant slide in Wind River Basin well productivities from 1996 through 2001, average peak well production jumped during 2002 as a result of high volume Tertiary Ft. Union well completions, but the decline resumed during 2003 when peak well production averaged 1,600 MMCFD.

Tight Sands Peak Production vs. 24 Month Cumulative Production

Average peak well production and cumulative well production over the first 24 months for seven Rockies tight sands plays is shown in Figure 9. Lance reservoirs at Jonah Field and the Pinedale Anticline in the Green River Basin and Ft. Union reservoirs in the Wind River Basin have generated the best productivity. These are followed by Mesaverde and equivalent reservoirs in the Green River Basin, southern Piceance Basin (Garfield County, CO) and the Uinta Basin. The general relationship - the larger the peak well production the larger the cumulative production – holds with exception of Mesaverde wells in Rio Blanco County, CO. The plot for Uinta Basin Jurassic - Triassic production was included to show relative performance parameters for the unique Jurassic Entrada and Triassic Wingate gas production at the Flat Rock Field on the southern flank of the basin. Large initial potential tests (2,400 to 4,300 MCFD) in recent wells may stimulate the search for additional fields in these reservoirs.
The ranking of average well reserves by tight sand play (Fig. 10) is essentially the same as that for well productivity parameters shown in Figure 9. The Lance at Jonah Field and Pinedale Anticline in the Green River Basin is the star with average reserves of almost 4,700 MMCF per well. Ft Union in the Wind River Basin is second with over 2,900 MMCF per well, and Green River Basin Mesaverde is third with 1,400 MMCF per well. Average Mesaverde well reserves in the Piceance Basin, with 614 MMCF per well, and Uinta Basin, with 565 MMCF per well, also track the well performance parameters.

Tight Sands Average Well Reserves

Figure 8. Average well production profiles from 1991 through 2003 are shown for the four key Rockies tight sands gas plays. Colors are used to highlight profiles from 1996 through 2003.

Even though recent average tight sands well production performance parameters have tended to increase, average well reserves have tended to decrease. This trend is the result of multiple factors including higher gas prices and enhanced technologies that allow producers to boost recoveries and cash flows from less desirable reservoirs. The chart also indicates that operators are harvesting more of the Rockies tight sands resources and that a large number of wells will be required to maximize recoveries from increasingly challenging reservoirs. This tendency is shown in the following table which compares average tight sands reserves per well for 1990 - 2004 completions with average reserves per well for 2000 - 2004 completions. Reserves in this table were deter-
mined by fitting exponential equations to composite monthly vintage (all gas wells completed during each calendar year) production data in each play. Exponential declines represent very conservative projections. The numbers likely represent 90% or better proven recovery estimates.

<table>
<thead>
<tr>
<th>Basin</th>
<th>Reserves Per Well (MMCF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green River Lance</td>
<td>4,664 4,500</td>
</tr>
<tr>
<td>Green River Mesaverde</td>
<td>1,436 625</td>
</tr>
<tr>
<td>Wind River Basin</td>
<td>2,330 750</td>
</tr>
<tr>
<td>San Juan Basin</td>
<td>675 332</td>
</tr>
<tr>
<td>Piceance Basin</td>
<td>614 505</td>
</tr>
<tr>
<td>Uinta Basin</td>
<td>565 388</td>
</tr>
</tbody>
</table>

Performance Parameters: Lance and Mesaverde, Green River Basin

Vintaged gas production profiles can be used to evaluate performance parameters between basins or between different reservoirs or plays in the same basin. The most significant difference between the Lance and Mesaverde plays in the Green River Basin is the general erosion of Mesaverde well performance over the past decade while Lance well performance has varied but has not deteriorated. Differences in maturity, geographic dispersion and specific reservoir parameters certainly account for part of the variances. Average Mesaverde well reserves declined from about 2,500 MMCF per well during the early 1990’s to an average of 625 MMCF per well since 1999. After improving from 1998 through 2000, Mesaverde peak well production slumped from about 1,000 MCFD in 2000 to about 550
MCFD in 2003. Considering gas prices, drilling depths and relevant costs, recent Mesaverde performance parameters in the Green River Basin, though, are not out of line with those in the Piceance and Uinta Basins. Operators in each play will be challenged to balance well performance with costs as the plays extend from known sweet spots into untested parts of these continuous reservoirs. The Lance, so far, is the anomaly. Average peak well production in the Lance, has remained higher than 3,400 MCFD since 1995. Lance well reserves averaged 4,664 MCF since 1992 and no vintage average reserves were less than 3,000 MCF. Lance exceptional performance parameters certainly drive the quest to discover another Jonah Field.

**SUMMARY**

Rocky Mountain producers are challenged to boost annual production by 162 BCFD through 2010. Unconventional reservoirs will play a key role in determining the outcome in response to this challenge.

- The outlook for coalbed methane is mixed. Vintaged average peak well production and average well reserves have declined in the large historic CBM reservoirs. As a result, substantially more wells must be completed each year in order to grow CBM production. It was not yet clear from data used in this study if Big George performance will be sufficient to offset declining CBM production in other Powder River Basin coal reservoirs. Clearly, established CBM fairways must be extended and new CBM plays must be developed in order to extend the growth of Rockies CBM production.

- Tight sands developments likely hold the key for future Rockies gas production trends. Expansion of Upper Cretaceous Mesaverde and equivalent production in the Green River, Piceance and Uinta basins will be essential to sustain future Rockies production. Expanding production and discoveries in high performing reservoirs like the Lance at Jonah Field and the Pinedale Anticline and the Ft. Union in the Wind River Basin are critical to meet the EIA’s production target. Rockies exploration also must increase to test the potential of new plays like the Jurassic-Triassic in the Uinta Basin and deeper plays in established trends.
The evolution of technologies to lower costs and to improve recoveries from increasingly difficult unconventional reservoir conditions is also important. Thanks also are due to Laura Hagan and Doug Meade who created drilling statistics and map files in support of this study.

ACKNOWLEDGEMENTS

The authors are indebted to Curtis Smith and Greg Poyet-Smith on IHS Energy’s Houston Consulting team who handled data retrievals and Gas Business Model processing to create the vintaged gas summaries that were the foundation for the analyses presented in this document.

REFERENCE