EFFECT OF SAND TYPE ON WELL PRODUCTIVITY

12 May 2020
Rystad Energy report represents an objective analysis of sand type impact on well productivity

**Background**

Wisconsin Industrial Sand Association (WISA) is a group of sand producers with significant exposure to the oil and gas industry onshore North America.

Early in the shale revolution, Northern White Sand (NWS) was the preferred option in frac operations among oil companies. However, in recent years, most of the active basins in North America has seen a growth in the use of locally sourced sand, i.e. in-basin sand. NWS is generally perceived to be of higher quality and thus a key question is whether change of sand type will affect well productivity.

**Rystad Energy Report**

Rystad Energy is a global energy consultancy with comprehensive data and a deep industry knowledge in the upstream oil and gas sector, with a specific focus on North America land. Rystad Energy has a relatively even distribution of client groups, including oil companies, service companies (including sand producers) and financial companies/investors.

The scope of this report is to perform an objective analysis on the operators that have switched away from NWS to see whether there has been an impact on their respective well productivity.

The report is structured in three main parts:
1. Executive summary highlighting all the main findings and briefly describing methodology
2. Methodology description with more details
3. Rich basin-by-basin review with detailed case study descriptions
Contents

Executive summary
Methodology
Basin overview
  Permian Midland
  Permian Delaware
  Eagle Ford
  Haynesville
  SCOOP/STACK
New metrics

- In order to better visually highlight the effects of proppant on well productivity, Rystad Energy has introduced the production per ton metric in the updated study.
- Production normalized for proppant pumped per well is a close proxy to revenue per ton, highlighting the economic gains or losses seen after switching to in-basin sand.
- The latest injection of data for each case study in the update also allows us to analyze longer-term IP rates where we did not have a large enough sample size in the previous report.
- The economic analysis now looks at the observed changes in IP270, rather than IP90, after switching to in-basin sand.

Definition of case study classifications

- By comparing the average IP270 rate in the quarters immediately following in-basin sand adoption to the quarters immediately preceding adoption, Rystad Energy has classified each of the case studies as either showing no impact, light impact, or impact.
- **No impact** cases demonstrate increases in average IP270 in the quarters following in-basin sand adoption compared to the quarters prior to adoption.
- **Light impact** cases show signs of production declines after switching to in-basin sand, however, average IP270 rates decline less than the allowable degradation caused in the first year of switching to in-basin sand required to wipe out the cost savings of the switch.
- Finally, cases classified as **impact** show clear signs of productivity declines after switching to in-basin sand where average IP270 rates have declined further than the allowable first year degradation.

Source: Rystad Energy research and analysis
We have analyzed case studies across North America with Permian having the most relevant data:

- Rystad Energy has looked at the following basins for this update of the study – Permian (Midland and Delaware), Eagle Ford, SCOOP/STACK, Haynesville.
- The Permian Basin has seen the highest penetration of in-basin sand historically and hence the study has a high number of cases with sufficient data from that basin.
- Overall, Rystad Energy has studied a total of 15 operator cases across the major North American basins, of which 8 have sufficient data to be studied in detail and included in this updated report. Only operator case studies with high confidence of sand type usage and timing of shift to in-basin have been analyzed.
- The report mainly covers wells drilled up until the end of the second quarter of 2019.

6 out of 7 cases in the Permian exhibit reduced productivity:

- Rystad Energy has analyzed 4 operator case studies in the Midland and 3 operator case studies in the Delaware where there was sufficient data to understand impact on well productivity due to shift to in-basin sand from northern white sand.
- 6 out of 7 Permian case studies exhibit reduced well productivity following switch to in-basin sand, as classified as either light impact or impact outlined in the previous slide.
- Short-term IP rates are holding up in certain case studies following switch to in-basin sand, while latest injection of data points towards declines in longer-term IP rates.

In-basin sand adoption is still in an early phase and operators should monitor longer term well production:

- In-basin sand adoption is still in an early phase in most major basins; outside the Permian, very few case studies have been identified with significant data to analyze well production impact.
- Permian results suggest there is impact on productivity, though for three of the identified cases the reduced production does not outweigh likely cost savings.
- Operators should monitor well results over a longer period of time to fully understand impact of in-basin sand adoption and whether they are optimizing value creation with the choice of sand type.

Source: Rystad Energy research and analysis
In-basin sand has captured a higher market share across the selected basins since 2018.

*Indicative market penetration based on both reported numbers and primary intelligence (i.e. conversations with various market participants)

Source: Rystad Energy research and analysis
The starting point for the analyses is to review public sources to capture what sand type has been used in different wells, i.e., using the FracFocus Chemical Disclosure Registry. However, there is incomplete reporting in FracFocus which makes the analysis more challenging.

Using operator communication and primary research, the sand type for more wells can be identified, e.g., looking into companies with clear announcements around shift to in-basin sand.

Only operator case studies with high confidence of sand type usage and timing of shift to in-basin have been analyzed.

It is critical to do an apples-to-apples comparison to understand the impact on well productivity after a switch from northern white sand to in-basin sand as multiple parameters may impact well production, e.g., lateral length, proppant intensity, target formation, acreage quality, well spacing and more.

The approach used in the study revolves around case studies by operator and formation which ensure that most of those variables are controlled for during the analysis.

Operator cases with too much noise are not included, e.g., significant experimentation in well designs or if the operator switched acreage focus at the time of shift to in-basin.

For the identified operator case studies, trends in well productivity can be analyzed, e.g., reviewing produced oil after 3 months (IP90), 6 months (IP180), 9 months (IP270) and 12 months (IP360).

In this update, we compare productivity normalized for both lateral lengths and the proppant used.

The main value proposition of in-basin sand is reduced up front well costs. As such, for operators to consider northern white, any negative impacts from using in-basin sand must be greater than the cost saving. Hence an economic analysis is performed to estimate how big the impact must be in order for northern white sand to provide more value, i.e., estimating the allowable degradation in well productivity.

Source: Rystad Energy research and analysis
Permian demonstrating impact on well production following in-basin sand adoption

<table>
<thead>
<tr>
<th>Basin</th>
<th>Penetration of in-basin sand</th>
<th>Impact on well productivity</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Midland</td>
<td>In-basin sand 90%</td>
<td>Impact</td>
<td>The in-basin sand adoption happened in early 2018. Three out of four cases analyzed show an impact in average IP270 rates after switching to in-basin sand.</td>
</tr>
<tr>
<td>Delaware</td>
<td>In-basin sand 80%</td>
<td>Impact</td>
<td>The in-basin sand adoption happened in early 2018. There are early indications of reduced productivity in two of the three case studies analyzed, however it is not clear if production declines have been driven purely from a change in sand type.</td>
</tr>
<tr>
<td>Eagle Ford</td>
<td>In-basin sand 50%</td>
<td>Too early to tell</td>
<td>In-basin sand was available in the Eagle Ford in late 2017. However, most mines came on early to mid 2019 and hence it is still too early to understand impact of in-basin sand on well productivity.</td>
</tr>
<tr>
<td>Haynesville</td>
<td>In-basin sand 90%</td>
<td>No impact</td>
<td>In-basin sand adoption began to take off in January 2018. The data analyzed thus far for one operator shows no signs of impact on well productivity. Some in-basin sand used in the Haynesville is similar to northern white sand quality, which may explain lack of impact.</td>
</tr>
<tr>
<td>SCOOP/STACK</td>
<td>In-basin sand 80%</td>
<td>Too early to tell</td>
<td>Well productivity per foot has been deteriorating in SCOOP/STACK prior to in-basin sand adoption; most in-basin mines became active early-to-mid 2019 and hence it is too early to assess impact of in-basin sand on well production.</td>
</tr>
</tbody>
</table>
All Permian Basin case studies except one show either an impact or light impact in well productivity after switching to in-basin sand

<table>
<thead>
<tr>
<th>Basin</th>
<th>Case</th>
<th>Well Count (NWS)</th>
<th>Time Frame Assessed (NWS)</th>
<th>IP270 (NWS)</th>
<th>Well Count (In-Basin)</th>
<th>Time Frame Assessed (In-Basin)</th>
<th>IP270 (In-Basin)</th>
<th>Observed Change in IP270</th>
<th>Allowable Degradation (Year 1)</th>
<th>Impact Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Midland</td>
<td>Operator A</td>
<td>46</td>
<td>4Q17 – 2Q18</td>
<td>15,892</td>
<td>133</td>
<td>3Q18 – 2Q19</td>
<td>15,075</td>
<td>-5.1%</td>
<td>-6.8%</td>
<td>Light Impact</td>
</tr>
<tr>
<td></td>
<td>Operator B</td>
<td>30</td>
<td>3Q17 – 2Q18</td>
<td>18,296</td>
<td>117</td>
<td>2Q18 – 2Q19</td>
<td>16,731</td>
<td>-8.6%</td>
<td>-6.0%</td>
<td>Impact</td>
</tr>
<tr>
<td>Midland</td>
<td>Operator C</td>
<td>32</td>
<td>3Q18 – 4Q18</td>
<td>17,848</td>
<td>43</td>
<td>4Q18 – 2Q19</td>
<td>16,320</td>
<td>-8.6%</td>
<td>-7.1%</td>
<td>Impact</td>
</tr>
<tr>
<td></td>
<td>Operator D</td>
<td>16</td>
<td>1Q18 – 2Q18</td>
<td>13,239</td>
<td>33</td>
<td>3Q18 – 2Q19</td>
<td>12,304</td>
<td>-7.1%</td>
<td>-8.8%</td>
<td>Light Impact</td>
</tr>
<tr>
<td>Delaware</td>
<td>Operator A</td>
<td>61</td>
<td>2Q17 – 3Q18</td>
<td>19,420</td>
<td>81</td>
<td>3Q18 – 2Q19</td>
<td>18,180</td>
<td>-6.4%**</td>
<td>-6.1%</td>
<td>Light Impact</td>
</tr>
<tr>
<td>Delaware</td>
<td>Operator B*</td>
<td>31</td>
<td>3Q18 – 4Q18</td>
<td>31,806</td>
<td>31</td>
<td>1Q19 – 2Q19</td>
<td>27,980</td>
<td>-12.0%</td>
<td>-4.3%</td>
<td>Impact</td>
</tr>
<tr>
<td>Delaware</td>
<td>Operator C</td>
<td>62</td>
<td>1Q18 – 4Q18</td>
<td>29,482</td>
<td>60</td>
<td>4Q18 – 2Q19</td>
<td>31,516</td>
<td>+6.9%</td>
<td>-5.6%</td>
<td>No Impact</td>
</tr>
</tbody>
</table>

*Delaware Operator B has both in-basin and NWS wells in NWS well count bucket for timeframes between 3Q18 and 4Q18; sand type is unknown for wells in 3Q18 and 4Q18

**Change in production per lateral foot is slightly greater than allowable degradation, but production per ton is increasing, hence light impact (see also next page for more commentary)

Source: Rystad Energy research and analysis
Cases with impact have seen IP rates decline since adopting in-basin sand; Other well design factors and mesh size uncertainty make it difficult to be definitive

<table>
<thead>
<tr>
<th>Basin</th>
<th>Case</th>
<th>Well productivity impact</th>
<th>Vertical depth and max treatment pressure</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Midland</td>
<td>Operator A</td>
<td>Light Impact</td>
<td>8,700’ 8,700 PSI</td>
<td>All IP rates show declines in productivity since switching to in-basin sand, however average IP270 still remains below the allowable degradation limit hence only ‘light impact’.</td>
</tr>
<tr>
<td>Midland</td>
<td>Operator B</td>
<td>Impact</td>
<td>9,200’ 8,000 PSI</td>
<td>Midland Operator B is showing an ‘impact’ in well productivity once switching to in-basin sand; IP270 rates have declined further than the allowable degradation.</td>
</tr>
<tr>
<td>Midland</td>
<td>Operator C</td>
<td>Impact</td>
<td>7,800’ 9,200 PSI</td>
<td>Midland Operator C has been classified as a case with ‘impact’ from switching to in-basin sand; Average IP270 rates have declined slightly less than the allowable degradation.</td>
</tr>
<tr>
<td>Midland</td>
<td>Operator D</td>
<td>Light Impact</td>
<td>7,600’ 8,400 PSI</td>
<td>Well spacing is a large contributor to decreasing IP rates since 2016; recent injection of data shows declines in productivity remain below allowable degradation. Any increases in productivity may be driven by increasing proppant intensities and well spacing.</td>
</tr>
<tr>
<td>Delaware</td>
<td>Operator A</td>
<td>Light Impact</td>
<td>10,700’ 10,200 PSI</td>
<td>IP90 and IP180 have remained relatively stable since switching to in-basin sand when normalized for lateral length, while longer term IP rates show decline close to the allowable degradation; Productivity significantly increases when normalized for proppant intensity, making it difficult to draw a definitive conclusion.</td>
</tr>
<tr>
<td>Delaware</td>
<td>Operator B</td>
<td>Impact</td>
<td>10,900’ 10,900 PSI</td>
<td>Delaware Operator B production has been declining since before in-basin sand adoption and continues post adoption. This may be due to increasing laterals or finer mesh sand grades, however, no definitive conclusion can be determined.</td>
</tr>
<tr>
<td>Delaware</td>
<td>Operator C</td>
<td>No Impact</td>
<td>11,100’ 9,700 PSI</td>
<td>Delaware Operator C is front-loading its production schedule and hence there is no impact on short-term well productivity. Injection of latest data also shows significant increases in longer-term IP rates.</td>
</tr>
<tr>
<td>Haynesville</td>
<td>Operator</td>
<td>No Impact</td>
<td>11,900’</td>
<td>For the identified case there has not been any impact on well productivity since in-basin sand adoption for all well productivity metrics.</td>
</tr>
</tbody>
</table>

Source: Rystad Energy research and analysis
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Productivity benchmarking of wells based on thorough operator specific assessments

Overview of methodology

1) Choose operators with high confidence on sand type*
2) Isolating operator controls for important parameters
3) Benchmarking well productivity

The methodology applied for this research is three-fold:

1) Identifying operators with high confidence on sand type
2) Isolating operator, by basin, control for acreage and the most important well design parameters – proppant intensity, lateral length, frac types etc.
3) Well productivity for comparable samples with different sand types is benchmarked with use of Rystad Energy’s proprietary database ShaleWellCube

Source: Rystad Energy research and analysis
Frac forms with sand type references are the primary data source for sand type identification.

The primary source of data for sand type identification are well frac forms submitted by operators to FracFocus, a database containing frac fluid chemicals disclosure for more than 150,000 wells fracked in the US.

Frac forms contain detailed information on frac fluid products used during fracking, broken down to individual chemicals comprising those products.

Rystad Energy performs a thorough cleaning of frac forms that, among other, allows us to identify entries that refer to sand used during hydraulic fracturing.

While not a requirement, operators occasionally include references to exact type of sand in either trade or ingredient name referring to sand (e.g. “100 mesh regional”).

Rystad Energy developed a methodology that looks for and analyzes such textual markers referring to sand type used.
Examples of textual markers in frac forms that allow for identification of sand type

### Examples of entries classified as Northern White Sand

<table>
<thead>
<tr>
<th>Reported trade name</th>
<th>Examples of entries classified as Brown Sand</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Northern White Sand</strong></td>
<td><strong>Reported trade name</strong></td>
</tr>
<tr>
<td>Sand, White, 40/70</td>
<td>16/30 Brady</td>
</tr>
<tr>
<td>Sand (20/40) Ottawa</td>
<td>20/40 Brady</td>
</tr>
<tr>
<td>Sand, White, 100 mesh Ottawa</td>
<td>20/50 Brown Sand</td>
</tr>
<tr>
<td>Sand (40/70) Ottawa</td>
<td>Texas Gold, 30/50</td>
</tr>
<tr>
<td>Sand (30/50) Ottawa</td>
<td>Texas Gold, 100M</td>
</tr>
<tr>
<td>30/50 WHITE</td>
<td>Texas Gold, 40/70</td>
</tr>
<tr>
<td>Sand, White</td>
<td>40/70 Brady</td>
</tr>
<tr>
<td>Sand, White, 30/50</td>
<td>40/70 Brown Sand</td>
</tr>
<tr>
<td>20/40 White</td>
<td>40/70 TG</td>
</tr>
<tr>
<td>Ottawa Sand</td>
<td>12/20 Brady Sand</td>
</tr>
<tr>
<td>100 mesh White Sand, Area 1</td>
<td>Brown Sand</td>
</tr>
<tr>
<td>40/70 White</td>
<td>Sand, Brown, 16/30</td>
</tr>
<tr>
<td>(Special Order)</td>
<td>Brown</td>
</tr>
</tbody>
</table>

Typically, “White”/”Ottawa”/”Northern” and variations of spelling of

### Examples of entries classified as Brown Sand

**Reported trade name**

- Sand
- Sand (Propellant)
- Silica Sand
- CRC SAND
- 100 mesh sand
- Sand (50/140)
- 100 MESH
- Crystalline Silica Quartz
- CRC SAND PREMIUM
- Sand (40/70)
- FRAC SAND
- Sand (20/40)
- SAND (WHOLE GRAIN)
- 20/40 Sand
- Sand (30/50)

Typically, “Brown”/”Brady”/”Texas Gold” and variations of spelling of

### Examples of entries classified as In-Basin Sand

**Reported trade name**

- 100 MESH REGIONAL
- 40/70 REGIONAL
- West TX 100 Mesh
- West TX 40/70
- Regional Sand
- Permian 100 Mesh
- 40/70 Permian
- Permian 40/70
- STX-40/70
- 40/70 REGIONAL SAND
- PERMIAN 100M
- Permian-100 MESH
- STX 100 MESH
- Sand Regional
- STX_100 MESH

Typically, “Regional”/”Permian”/”West TX”/”STX”, and variations of spelling of

### Examples of entries with no reference to exact sand type

**Reported trade name**

- Sand
- Sand (Proppant)
- Silica Sand
- CRC SAND
- 100 mesh sand
- Sand (50/140)
- 100 MESH
- Crystalline Silica Quartz
- CRC SAND PREMIUM
- Sand (40/70)
- FRAC SAND
- Sand (20/40)
- SAND (WHOLE GRAIN)
- 20/40 Sand
- Sand (30/50)

No textual markers allowing for identification of sand type based on trade/ingredient names alone
Pure in-basin sand providers appearing on frac forms improve in-basin sand wells coverage

Among many attributes appearing on a frac form, provider of a given product and its associated chemicals is listed in a form.

We look at suppliers appearing on frac forms and check those against a list of known pure in-basin sand providers.

An example of such companies would be Atlas Sand who are a pure Permian in-basin sand provider, Black Mountain who have in-basin sand mines in the Permian, Eagle Ford and Mid-Con, Preferred Sands (Permian, Eagle Ford, and Mid-Con), and Vista Sands (Permian and Eagle Ford).

Although exact sand type used may not be explicitly mentioned in a frac form (as in example to the right, i.e. “100 MESH SAND”, with no reference to sand type), this sand was supplied by Atlas Sand, who is a pure in-basin sand provider.

In turn, we can tag this entry as Permian In-Basin with high degree of confidence.
Identifying proppant type from public disclosures is a challenge; only 30% to 40% of wells drilled post 2015 have a known proppant type.

Fraction of wells* with known sand type, 2015 – 2019 YTD by completion quarter

* Includes all wells drilled in Permian, Eagle Ford and SCOOP/STACK, known sand type refers to wells where sand type can be identified with high confidence

Source: Rystad Energy ShaleWellCube
We analyze communication from players to further improve in-basin sand coverage

<table>
<thead>
<tr>
<th>Examples of communication from E&amp;P companies addressing in-basin sand adoption*</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Operator, Financial and Operating Results</strong>&lt;br&gt;The company communicated in their investor presentation that they have fully switched over to in-basin sand from northern white sand, and thus saw a certain amount of cost savings due to the shift.</td>
<td>• We further analyze communication from major E&amp;P companies with an intention of identifying the timeline when the company switched to in-basin sand completely, and as such, allowing us to tag corresponding completed wells as in-basin with high degree of confidence despite “unknown” tags from public disclosures.</td>
</tr>
<tr>
<td><strong>Operator, Financial and Operating Results</strong>&lt;br&gt;The company communicated in their earnings results that they tested in-basin sand and have now decided to fully utilize in-basin sand in their well designs.</td>
<td>• As an example, one operator explicitly communicated in their earnings of full adoption of in-basin sand in the Midland Basin&lt;br&gt;&lt;br&gt;• An operator communicated over earnings results that they began utilizing in-basin sand on all of their completions during a certain time period.&lt;br&gt;&lt;br&gt;• In some cases, whenever explicit communication on in-basin sand adoption is not available, we use other, secondary indications, e.g. sand costs savings provided by an operator in earnings results suggests full adoption of in-basin sand with high degree of confidence.</td>
</tr>
</tbody>
</table>

Source: Rystad Energy research and analysis; Company reporting
For the identified cases, key metrics are analyzed to assess well productivity.

<table>
<thead>
<tr>
<th>Metrics</th>
<th>Description</th>
<th>Examples from case studies</th>
</tr>
</thead>
</table>
| **Input parameters** | • It is highly critical to do an apples-to-apples comparison to understand the impact on well productivity after a switch from northern white sand to in-basin sand.  
• Different parameters like lateral length, proppant intensity, formation, well spacing etc. impact well production, and hence these variables have to be controlled when assessing impact of in-basin sand usage on well production.  
• Designing case studies by operator and formation ensures most of the above variables are controlled for during the analysis. | ![Illustration placeholder](image1.png)  
Midland Operator A is seeing a decline in well productivity after switching to in-basin sand. 
- Relative changes in short term and long term well production has to be analyzed to fully understand the impact of in-basin sand adoption, main focus is on oil recovery (except for gas basins).  
- IP90 and IP180 were used to quantify short term production whereas IP270 and IP360 were used for long term production; sample size of short term production data is naturally higher than long term production data.  
- Observed changes in the above well production metrics were analyzed to quantify the impact of switching from northern white sand to in-basin sand. Production is normalized against lateral feet and proppant used (tons). |

| **Well production Metrics** | ![Illustration placeholder](image2.png)  
Midland Operative A observed degradation of 5.1% in average IP270 remains less than the allowable first year degradation of 6.0% therefore determining light impact of case.  
- After establishing any changes in production, an economic analysis is performed for each case study to estimate the ‘allowable degradation’ by case (see more details in subsequent pages).  
- As well designs and total productivity will differ by operator, the allowable degradation also varies between the cases, e.g. for the observed cases this value falls between 4% and 9%.  
- Sensitivity analysis is performed looking at both commodity price assumption and time studied (e.g. whether looking at reduced production in year 1, 2 or 3). | ![Illustration placeholder](image3.png)  
Midland Operator A: observed degradation of 5.1% in average IP270 remains less than the allowable first year degradation of 6.0% therefore determining light impact of case.  
- Economic analysis and sensitivities | **Economic analysis and sensitivities** | **Table**: | **Figure**: |

Source: Rystad Energy research and analysis
In-basin sand prices have dropped in the Permian; hence widening the gap between NWS and in-basin delivered sand prices.

Source: Rystad Energy ShaleWellCube, Rystad Energy research and analysis
The Haynesville has the highest proppant cost among all major shale plays and stands to benefit the most from shifting to in-basin sand.
Economic analysis needed to assess productivity impact versus cost savings

Conceptual type curve and assumptions around productivity impact

<table>
<thead>
<tr>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>- The incentive to shift to in-basin sand from northern white sand (NWS) comes from an upfront savings to the well cost. As such, an economic analysis is needed on top of well productivity assessment to fully comprehend the value impact of switching sand type, i.e. the value impact of any reduced productivity must be greater than the cost savings for operators to consider moving away from in-basin sand.</td>
</tr>
<tr>
<td>- We define the allowable degradation as the reduction in well productivity within a certain timeframe where the realized upfront cost savings are wiped out. Allowable degradation for year 1, year 2 and year 3 are calculated using cash flow analysis.</td>
</tr>
<tr>
<td>- We calculate the allowable degradation by shifting the entire type curve down by a defined multiple, as indicated in the chart.</td>
</tr>
</tbody>
</table>

In the analysis, the entire type curve is shifted down to estimate “allowable degradation”

Source: Rystad Energy research and analysis
Example of economic analysis output for Midland Operator B and assumptions used (1/3)

**Midland Operator B: Economic Model Parameters**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>NWS</th>
<th>In-Basin</th>
<th>Actuals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lateral length</td>
<td>9,867</td>
<td>9,867</td>
<td>9.463</td>
</tr>
<tr>
<td>Proppant intensity</td>
<td>1,602</td>
<td>1,602</td>
<td>1,593</td>
</tr>
<tr>
<td>D&amp;C cost ($)</td>
<td>$7.1 MM</td>
<td>$6.8 MM</td>
<td>$6.7 MM</td>
</tr>
<tr>
<td>Oil price, $ per bbl</td>
<td>$50.00</td>
<td>$50.00</td>
<td>$50.00</td>
</tr>
<tr>
<td>Gas price, $ per boe</td>
<td>$6.00</td>
<td>$6.00</td>
<td>$6.00</td>
</tr>
<tr>
<td>Cost savings per ton</td>
<td>$40</td>
<td>$40</td>
<td>$40</td>
</tr>
</tbody>
</table>

**Step 1 in the economic analysis - Input parameters**

- The realized cost savings from switching to in-basin sand varies by operator and is dependent on amount of frac sand pumped in their well design.
- After controlling for operator and geography, a typical northern white sand well is created for each operator using data from Rystad Energy’s proprietary database ShaleWellCube (see example above).
- Assuming a $40 per ton differential between NWS and in-basin sand, realized savings for each operator chosen in the case study is calculated keeping the well design (lateral length, proppant intensity and other factors) the same.
- Further sensitivity analysis, e.g. around cost savings per ton, can be performed in the Excel based model that has been provided separately.

<table>
<thead>
<tr>
<th>Well Count (NWS)</th>
<th>Time Frame Assessed (NWS)</th>
<th>IP90 (NWS)</th>
<th>Well Count (In-Basin)</th>
<th>Time Frame Assessed (In-Basin)</th>
<th>IP90 (In-Basin)</th>
<th>Observed Change in IP90</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>3Q17 – 2Q18</td>
<td>6,336</td>
<td>117</td>
<td>2Q18 – 2Q19</td>
<td>5,750</td>
<td>-9.2%</td>
</tr>
</tbody>
</table>

*CFCF difference is defined as the difference between cumulative net cash flow from a northern white sand and in-basin sand well
Source: Rystad Energy ShaleWellCube, Rystad Energy research and analysis
Step 2 in the economic analysis – Calculate allowable degradation

- Allowable degradation is the reduction in well productivity within a certain timeframe where the realized upfront cost savings are wiped out. This impact is calculated based on net present value (NPV) of cash flows using 10% discount rate for Year 1, 2 and 3. Allowable degradation in Year 1 relates to the necessary negative impact that is needed in order to make up for the cost savings in the first year of production. Similarly, the same applies to Year 2 and Year 3.

- We also highlight the difference in cumulative free cash flow (CFCF), which is defined as the difference in cash generated in year 1, year 2 and year 3 between a typical northern white sand well and an in-basin sand well. It is calculated under different degradation scenarios in each case study to highlight the direct impact on cash flows.

- WTI oil price scenarios for $40/bbl, $50/bbl and $60/bbl price strips are run to understand how allowable degradation varies under different oil prices. The results are compared against both NPV and CFCF for Year 1, 2 and 3, though discounting the cash flows have limited impact compared to the pure CFCF.

Midland Operator B: Economic Model Parameters

<table>
<thead>
<tr>
<th>Year</th>
<th>Allowable Degradation</th>
<th>Total cost savings</th>
<th>CFCF Difference* Year 1</th>
<th>CFCF Difference Year 2</th>
<th>CFCF Difference Year 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-6.0%</td>
<td>$316K</td>
<td>$331K</td>
<td>$501K</td>
<td>$614K</td>
</tr>
<tr>
<td>2</td>
<td>-4.1%</td>
<td>$316K</td>
<td>$226K</td>
<td>$342K</td>
<td>$419K</td>
</tr>
<tr>
<td>3</td>
<td>-3.4%</td>
<td>$316K</td>
<td>$189K</td>
<td>$287K</td>
<td>$351K</td>
</tr>
</tbody>
</table>

Midland Operator B: Allowable degradation

<table>
<thead>
<tr>
<th>Well Count (NWS)</th>
<th>Time Frame Assessed (NWS)</th>
<th>IP90 (NWS)</th>
<th>Well Count (In-Basin)</th>
<th>Time Frame Assessed (In-Basin)</th>
<th>IP90 (In-Basin)</th>
<th>Observed Change in IP90</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>3Q17 – 2Q18</td>
<td>6,336</td>
<td>117</td>
<td>2Q18 – 2Q19</td>
<td>5,750</td>
<td>-9.2%</td>
</tr>
</tbody>
</table>

* CFCF difference is defined as the difference in cumulative net cash flow from a northern white sand and in-basin sand well.

Source: Rystad Energy ShaleWellCube, Rystad Energy research and analysis.
Step 3 in the economic analysis – Comparison against observed change in IP270

- Finally, the observed changes in well productivity for the timeframes described in the table are compared to the calculated allowable degradation to assess whether switch to in-basin sand from northern white sand has had an economic impact.

- In the updated analysis, we compare the allowable degradation with the observed change in IP270, i.e. cumulative production after 270 days (9 months). We had previously studied the changes in IP 90 due to sample size constraints, however given the latest injection of data we now have enough production data to study the longer term IP270 rate.
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  Eagle Ford
  Haynesville
  SCOOP/STACK
Latest data suggests potential degradation in full year IP rate in Midland South

Permian-Midland: Median cumulative 2-stream production by production start year-quarter and sub-basin

Barrels of oil equivalent per foot

In-basin sand availability

Source: Rystad Energy ShaleWellCube, Rystad Energy research and analysis
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Permian Delaware
Eagle Ford
Haynesville
SCOOP/STACK
Midland Operator A started using in-basin sand in the Midland in 2Q18

*From Midland Operator A investor presentation. Based on Rystad Energy’s analysis of chemical ingredient and trade names reported to FracFocus Chemical Disclosure Registry
Source: Rystad Energy ShaleWellCube, Midland Operator A investor presentation, Rystad Energy research and analysis
Midland Operator A has exhibited relatively flat proppant intensities and lateral length since switch to in-basin sand.

**Midland Operator A**

- Midland Operator A proppant intensities have fluctuated very little since 2Q 2017.
- Despite a large dip in lateral lengths in 3Q 2018, Midland Operator A has held fairly steady laterals since switching to in-basin sand.
- Recent quarters have seen a modest uptick in lateral lengths.

**Proppant intensity distribution by vintage quarters (HZ wells)**

*Pounds per foot*

**Lateral length distribution by vintage quarters (HZ wells)**

*Thousand feet*

Note: Only wells with at least 40% cumulative light oil content have been included in the analysis.

Source: Rystad Energy ShaleWellCube, Rystad Energy research and analysis
Midland Operator A is seeing a decline in well productivity after switching to in-basin sand

Midland Operator A

- All IP rates for Midland Operator A have exhibited a decline since switching to in-basin sand.
- Poor sample size in 4Q 2018 may be causing sudden and severe drop in production, however overall trend suggests some impact once switching completely to in-basin sand.
- Despite decreases in productivity, average IP270 degradation still remains below allowable degradation (see economic analysis), hence Midland Operator A has been classified as ‘light impact’.

Note: Only wells with at least 40% cumulative light oil content have been included in the analysis
Source: Rystad Energy ShaleWellCube, Rystad Energy research and analysis
Midland Operator A exhibits impact on productivity once switching to in-basin sand; declines in production immediately following switch to in-basin followed by modest recovery.

**Midland Operator A**

- Proppant intensity and lateral length have remained relatively stable since switching to in-basin sand, while production per ton of proppant has declined in the quarters immediately following the switch.

- Decline in barrels per ton proppant is more profound than barrels per lateral length.

---

Note: Only wells with at least 40% cumulative light oil content have been included in the analysis

Source: Rystad Energy ShaleWellCube, Rystad Energy research and analysis
Midland Operator A observed degradation of 5.1% in average IP270 remains less than the allowable first year degradation of 6.8% therefore determining ‘light impact’ of case.

**Midland Operator A : Economic Model Parameters**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>NWS</th>
<th>In-Basin</th>
<th>Actual In-Basin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lateral length</td>
<td>9,658</td>
<td>9,658</td>
<td>9,806</td>
</tr>
<tr>
<td>Proppant intensity</td>
<td>1,661</td>
<td>1,661</td>
<td>1,786</td>
</tr>
<tr>
<td>D&amp;C cost ($)</td>
<td>$7.5 MM</td>
<td>$7.1 MM</td>
<td>$6.9 MM</td>
</tr>
<tr>
<td>Oil price, $ per bbl</td>
<td>$50.00</td>
<td>$50.00</td>
<td>$50.00</td>
</tr>
<tr>
<td>Gas price, $ per boe</td>
<td>$6.00</td>
<td>$6.00</td>
<td>$6.00</td>
</tr>
<tr>
<td>Cost savings per ton</td>
<td>$40</td>
<td>$40</td>
<td>$40</td>
</tr>
</tbody>
</table>

**Midland Operator A : Allowable degradation**

<table>
<thead>
<tr>
<th>Year</th>
<th>Allowable Degradation</th>
<th>Total cost savings</th>
<th>CFCF Difference* Year 1</th>
<th>CFCF Difference Year 2</th>
<th>CFCF Difference Year 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-6.8%</td>
<td>$321K</td>
<td>$334K</td>
<td>$462K</td>
<td>$543K</td>
</tr>
<tr>
<td>2</td>
<td>-5.1%</td>
<td>$321K</td>
<td>$248K</td>
<td>$343K</td>
<td>$404K</td>
</tr>
<tr>
<td>3</td>
<td>-4.4%</td>
<td>$321K</td>
<td>$216K</td>
<td>$299K</td>
<td>$352K</td>
</tr>
</tbody>
</table>

**Midland Operator A : Observed degradation**

<table>
<thead>
<tr>
<th>Well Count (NWS)</th>
<th>Time Frame Assessed (NWS)</th>
<th>IP270 (NWS)</th>
<th>Well Count (In-Basin)</th>
<th>Time Frame Assessed (In-Basin)</th>
<th>IP270 (In-Basin)</th>
<th>Observed Change in IP270</th>
</tr>
</thead>
<tbody>
<tr>
<td>46</td>
<td>4Q17 – 2Q18</td>
<td>15,892</td>
<td>133</td>
<td>3Q18 – 2Q19</td>
<td>15,075</td>
<td>-5.1%</td>
</tr>
</tbody>
</table>

* CFCF difference is defined as the difference between cumulative net cash flow from a northern white sand and in-basin sand well.
Source: Rystad Energy ShaleWellCube, Rystad Energy research and analysis.
CFCF difference would exceed cost savings in Year 1 at a degradation greater than 6.8%.

Note: Only wells with at least 40% cumulative light oil content have been included in the analysis; CFCF difference is defined as the difference between cumulative net cash flow from a northern white and in-basin well.

Source: Rystad Energy ShaleWellCube, Rystad Energy research and analysis

In-basin sand cost savings of $321K

Allowable degradation: -6.8%
$40 per bbl oil price results in an additional 3.1% allowable degradation from $60 oil assuming in-basin sand cost savings of $40/ton.

CFCF difference* by year versus productivity degradation

Note: Only wells with at least 40% cumulative light oil content have been included in the analysis; CFCF difference is defined as the difference between cumulative net cash flow from a northern white and in-basin well.

Source: Rystad Energy ShaleWellCube, Rystad Energy research and analysis.
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Permian Delaware
Eagle Ford
Haynesville
SCOOP/STACK
Midland Operator B: frac job count by reported* sand type

*Based on Rystad Energy's analysis of chemical ingredient and trade names reported to FracFocus Chemical Disclosure Registry

Source: Rystad Energy ShaleWellCube, Rystad Energy research and analysis

Full scale adoption of in-basin sand for Midland Operator B happened in 3Q18

Full-scale adoption of in-basin sand coincided with uptick in activity
Proppant intensity levels have remained steady after switch to in-basin sand except for a 6% increase seen in 2Q19; lateral lengths have shown increased variability.

Midland Operator B

- Since switching to in-basin sand, Midland Operator B has kept proppant intensity levels relatively flat until 2Q19, which has seen a 6% spike from 3Q18.
- Lateral lengths have shown increased variability since switching to in-basin sand, with a dramatic 46% increase from 4Q 2018 to 2Q 2019.

Note: Only wells with at least 40% cumulative light oil content have been included in the analysis

Source: Rystad Energy ShaleWellCube, Rystad Energy research and analysis
Midland Operator B is seeing an impact on well productivity, though subsequent up and down trend makes it more challenging to draw conclusions.

**Midland Operator B**

- All IP rates for Midland Operator B have been declining since late 2017 up until 3Q18.
- This trend could be due to a shift to finer mesh sand; however, mesh size data isn’t available in the public domain to make a definitive conclusion.
- Since switching to in-basin sand, IP rates have continued to decline before showing signs of recovery from 4Q18.
- Midland Operator B has been classified as a case study showing a “impact” from switching to in-basin sand.

*Note: Only wells with at least 40% cumulative light oil content have been included in the analysis*

Source: Rystad Energy ShaleWellCube, Rystad Energy research and analysis
Production per ton has been declining since switch to in-basin sand; Uptick seen in 2Q19 could be due to increased proppant intensity and lateral lengths.

**Midland Operator B**

- Production per ton of proppant pumped signals a significant increase in IP rates in 2Q19, stronger indication than barrels per foot, though there was a clear declining trend in the preceding quarters.
- During 2Q19, Midland Operator B increased both proppant intensity and lateral lengths.
- The Midland Operator B case study has been classified as having “impact” due to decreasing production per ton after switch to in-basin sand.

Note: Only wells with at least 40% cumulative light oil content have been included in the analysis.

Source: Rystad Energy ShaleWellCube, Rystad Energy research and analysis.
Observed degradation of 8.6% greater than allowable degradation of 6.0%, assuming in-basin sand cost savings of $40/ton

**Midland Operator B: Economic Model Parameters**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>NWS</th>
<th>In-Basin</th>
<th>Actuals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lateral length</td>
<td>9,867</td>
<td>9,867</td>
<td>9.463</td>
</tr>
<tr>
<td>Proppant intensity</td>
<td>1,602</td>
<td>1,602</td>
<td>1,593</td>
</tr>
<tr>
<td>D&amp;C cost ($)</td>
<td>$7.1 MM</td>
<td>$6.8 MM</td>
<td>$6.7 MM</td>
</tr>
<tr>
<td>Oil price, $ per bbl</td>
<td>$50.00</td>
<td>$50.00</td>
<td>$50.00</td>
</tr>
<tr>
<td>Gas price, $ per boe</td>
<td>$6.00</td>
<td>$6.00</td>
<td>$6.00</td>
</tr>
<tr>
<td>Cost savings per ton</td>
<td>$40</td>
<td>$40</td>
<td>$40</td>
</tr>
</tbody>
</table>

**Midland Operator B: Allowable degradation**

<table>
<thead>
<tr>
<th>Year</th>
<th>Allowable Degradation</th>
<th>Total cost savings</th>
<th>CFCF Difference* Year 1</th>
<th>CFCF Difference Year 2</th>
<th>CFCF Difference Year 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-6.0%</td>
<td>$316K</td>
<td>$331K</td>
<td>$501K</td>
<td>$614K</td>
</tr>
<tr>
<td>2</td>
<td>-4.1%</td>
<td>$316K</td>
<td>$226K</td>
<td>$342K</td>
<td>$419K</td>
</tr>
<tr>
<td>3</td>
<td>-3.4%</td>
<td>$316K</td>
<td>$189K</td>
<td>$287K</td>
<td>$351K</td>
</tr>
</tbody>
</table>

**Midland Operator B: Observed degradation**

<table>
<thead>
<tr>
<th>Well Count (NWS)</th>
<th>Time Frame Assessed (NWS)</th>
<th>IP270 (NWS)</th>
<th>Well Count (In-Basin)</th>
<th>Time Frame Assessed (In-Basin)</th>
<th>IP270 (In-Basin)</th>
<th>Observed Change in IP270</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>3Q17 – 2Q18</td>
<td>18,296</td>
<td>117</td>
<td>2Q18 – 2Q19</td>
<td>16,731</td>
<td>-8.6%</td>
</tr>
</tbody>
</table>

* CFCF difference is defined as the difference between cumulative net cash flow from a northern white sand and in-basin sand well

Source: Rystad Energy ShaleWellCube, Rystad Energy research and analysis
CFCF difference would exceed cost savings in Year 1 at a degradation greater than 6.2%

CFCF difference* by year versus productivity degradation

Million dollars

Oil price: $50 per barrel
Cost savings: $40 per ton

Note: Only wells with at least 40% cumulative light oil content have been included in the analysis; CFCF difference is defined as the difference between cumulative net cash flow from a northern white and in-basin well

Source: Rystad Energy ShaleWellCube, Rystad Energy research and analysis
$40 per bbl oil price results in 2.7% allowable degradation, close to observed productivity drop, with cost savings from in-basin sand of $40/ton

Note: Only wells with at least 40% cumulative light oil content have been included in the analysis; CFCF difference is defined as the difference between cumulative net cash flow from a northern white and in-basin well.

Source: Rystad Energy ShaleWellCube, Rystad Energy research and analysis
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  - Permian Delaware
  - Eagle Ford
  - Haynesville
  - SCOOP/STACK
Midland Operator C completed full in-basin sand adoption in September 2018

Midland Operator C: frac job count by reported* sand type (LHS) and proppant cost index (RHS)

# of wells

Indexed to January 2018

Most likely NWS

Most likely in-basin

First in-basin sand purchases

Full adoption

Downward pressure on prices

Unknown sand type

High-confidence in-basin

Reported proppant cost index* (RHS)

*From Midland Operator C’s investor presentation. Based on Rystad Energy’s analysis of chemical ingredient and trade names reported to FracFocus Chemical Disclosure Registry
Source: Rystad Energy ShaleWellCube, Midland Operator C investor presentation, Rystad Energy research and analysis
Midland Operator C has kept lateral length and proppant intensity flat since switching to in-basin sand

**Midland Operator C**

- Proppant intensity levels for Midland Operator C have held pretty steady between 1,850 and 1,900 pounds per foot before and after the switch to in-basin sand.

- Lateral lengths have shown very little variability and has remained at ~10,000 feet since 2Q17.

---

**Proppant intensity by vintage quarters (HZ wells)**

<table>
<thead>
<tr>
<th>Vintage Quarters</th>
<th>Pounds per foot</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>1Q16</td>
<td>2,000</td>
</tr>
<tr>
<td>2Q16</td>
<td>2,000</td>
</tr>
<tr>
<td>3Q16</td>
<td>2,000</td>
</tr>
<tr>
<td>4Q16</td>
<td>2,000</td>
</tr>
<tr>
<td>1Q17</td>
<td>1,900</td>
</tr>
<tr>
<td>2Q17</td>
<td>1,900</td>
</tr>
<tr>
<td>3Q17</td>
<td>1,900</td>
</tr>
<tr>
<td>4Q17</td>
<td>1,900</td>
</tr>
</tbody>
</table>

**Lateral length by vintage quarters (HZ wells)**

<table>
<thead>
<tr>
<th>Vintage Quarters</th>
<th>Thousand feet</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>1Q16</td>
<td>10</td>
</tr>
<tr>
<td>2Q16</td>
<td>10</td>
</tr>
<tr>
<td>3Q16</td>
<td>10</td>
</tr>
<tr>
<td>4Q16</td>
<td>10</td>
</tr>
<tr>
<td>1Q17</td>
<td>10</td>
</tr>
<tr>
<td>2Q17</td>
<td>10</td>
</tr>
<tr>
<td>3Q17</td>
<td>10</td>
</tr>
<tr>
<td>4Q17</td>
<td>10</td>
</tr>
</tbody>
</table>

*Note: Only wells with at least 40% cumulative light oil content have been included in the analysis*

*Source: Rystad Energy ShaleWellCube, Rystad Energy research and analysis*
Midland Operator C has seen an impact on productivity since switching to in-basin sand

Midland Operator C
• Lateral lengths have stayed remarkably stable since 2Q17, even once switching to in-basin sand, while production normalized for lateral length has declined immediately following the switch.
• Recent data for 2Q19 suggests a modest increase in productivity, although still not recovering to levels seen prior to switching to in-basin sand.
• Therefore, Midland Operator C has been classified as a case with ‘impact’ from switching to in-basin sand.

Note: Only wells with at least 40% cumulative light oil content have been included in the analysis
Source: Rystad Energy ShaleWellCube, Rystad Energy research and analysis
Productivity per ton proppant more volatile, but clear drop from older vintages

**Midland Operator C**

- Despite proppant intensity levels remaining flat since the point of full-scale in-basin sand adoption, production per ton of proppant immediately declined after the switch.

- The production per ton is more volatile than production per lateral foot, e.g. steeper drop from older vintages, but also stronger increase seen in the 2Q19 vintage.

- The 2Q19 observation makes it harder to draw firm conclusions, but Midland Operator C has still been identified as a case with ‘impact’ from switching to in-basin sand.

---

Note: Only wells with at least 40% cumulative light oil content have been included in the analysis

Source: Rystad Energy ShaleWellCube, Rystad Energy research and analysis
Midland Operator C observed degradation of 8.6% is greater than the allowable degradation of 7.1%.

Midland Operator C: Economic Model Parameters

<table>
<thead>
<tr>
<th>Parameters</th>
<th>NWS</th>
<th>In-Basin</th>
<th>Actuals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lateral length</td>
<td>10,288</td>
<td>10,288</td>
<td>11,119</td>
</tr>
<tr>
<td>Proppant intensity</td>
<td>1,890</td>
<td>1,890</td>
<td>2,421</td>
</tr>
<tr>
<td>D&amp;C cost ($)</td>
<td>$7.9 MM</td>
<td>$7.5 MM</td>
<td>$7.1 MM</td>
</tr>
<tr>
<td>Oil price, $ per bbl</td>
<td>$50.00</td>
<td>$50.00</td>
<td>$50.00</td>
</tr>
<tr>
<td>Gas price, $ per boe</td>
<td>$6.00</td>
<td>$6.00</td>
<td>$6.00</td>
</tr>
<tr>
<td>Cost savings per ton</td>
<td>$40</td>
<td>$40</td>
<td>$40</td>
</tr>
</tbody>
</table>

Midland Operator C: Allowable degradation

<table>
<thead>
<tr>
<th>Year</th>
<th>Allowable Degradation</th>
<th>Total cost savings</th>
<th>CFCF Difference* Year 1</th>
<th>CFCF Difference Year 2</th>
<th>CFCF Difference Year 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-7.1%</td>
<td>$389K</td>
<td>$405K</td>
<td>$558K</td>
<td>$653K</td>
</tr>
<tr>
<td>2</td>
<td>-5.3%</td>
<td>$389K</td>
<td>$302K</td>
<td>$416K</td>
<td>$487K</td>
</tr>
<tr>
<td>3</td>
<td>-4.7%</td>
<td>$389K</td>
<td>$264K</td>
<td>$364K</td>
<td>$426K</td>
</tr>
</tbody>
</table>

Midland Operator C: Observed degradation

<table>
<thead>
<tr>
<th>Well Count (NWS)</th>
<th>Time Frame Assessed (NWS)</th>
<th>IP270 (NWS)</th>
<th>Well Count (In-Basin)</th>
<th>Time Frame Assessed (In-Basin)</th>
<th>IP270 (In-Basin)</th>
<th>Observed Change in IP270</th>
</tr>
</thead>
<tbody>
<tr>
<td>32</td>
<td>3Q18 – 4Q18</td>
<td>17,848</td>
<td>43</td>
<td>4Q18 – 2Q19</td>
<td>16,320</td>
<td>-8.6%</td>
</tr>
</tbody>
</table>

*CFCF difference is defined as the difference between cumulative net cash flow from a northern white and in-basin well.

Source: Rystad Energy ShaleWellCube, Rystad Energy research and analysis.
CFCF difference would exceed cost savings in Year 1 at a degradation of 7.1%.

CFCF difference* by year versus productivity degradation

Oil price: $50 per barrel
Cost savings: $40 per ton

In-basin sand cost savings of $389K
Allowable degradation: -7.1%

Note: Only wells with at least 40% cumulative light oil content have been included in the analysis; CFCF difference is defined as the difference between cumulative net cash flow from a northern white and in-basin well.

Source: Rystad Energy ShaleWellCube, Rystad Energy research and analysis
$40 per bbl oil price results in an additional 3.2% allowable degradation from $60 oil assuming in-basin sand cost savings of $40/ton

CFCF difference* by year versus productivity degradation

**Note:** Only wells with at least 40% cumulative light oil content have been included in the analysis; CFCF difference is defined as the difference between cumulative net cash flow from a northern white and in-basin well.

Source: Rystad Energy ShaleWellCube, Rystad Energy research and analysis
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SCOOP/STACK
Midland Operator D completed full in-basin sand adoption in October 2018

**Midland Operator D: frac job count by reported* sand type (LHS)**

*From Midland Operator D’s investor presentation. Based on Rystad Energy’s analysis of chemical ingredient and trade names reported to FracFocus Chemical Disclosure Registry
Source: Rystad Energy ShaleWellCube, Midland Operator D investor presentation, Rystad Energy research and analysis
Midland Operator D has increased all well design parameters since switching to in-basin sand

**Midland Operator D**

- Midland Operator D has consistently pointed towards closer well spacing as a smoking gun for production declines seen since mid-2016.
- Lateral lengths started increasing in 3Q 2018, before in-basin adoption, with 2Q 2019 increasing sharply after the complete switch to in-basin sand.
- Well spacing has sharply risen in 2Q 2019 returning to levels not seen since 2017.
- Proppant intensity levels dropped immediately following in-basin sand adoption but have since been recovering.

**Well spacing distribution by vintage quarters (HZ wells)**

**Lateral length by vintage quarters (HZ wells)**

Note: Only wells with at least 40% cumulative light oil content have been included in the analysis
Source: Rystad Energy ShaleWellCube, Rystad Energy research and analysis
Midland Operator D exhibits some impact on productivity following the switch to in-basin sand

**Midland Operator D**

- Since the adoption of in-basin sand Midland Operator D has seen a decline in overall productivity once normalized for lateral length, however still within the allowable degradation limit (see economic analysis).
- Increases in productivity following in-basin sand adoption may be attributed to Midland Operator D increasing their well spacing and proppant intensity during this same time period.
- Despite decreases in productivity, average IP270 degradation still remains below allowable degradation, hence Midland Operator D has been classified as ‘light impact’.

![Graph showing production per lateral foot for Midland Operator D](image)

Note: Only wells with at least 40% cumulative light oil content have been included in the analysis
Source: Rystad Energy ShaleWellCube, Rystad Energy research and analysis
Midland Operator D

- Since switching completely to in-basin sand, Midland Operator D has seen an overall decline in production per ton of proppant as proppant intensity levels rise.
- Trends and changes are similar to production per foot, despite the lateral lengths having more variability than proppant loading.

Production per ton proppant seeing similar trends for Midland Operator D case

Note: Only wells with at least 40% cumulative light oil content have been included in the analysis
Source: Rystad Energy ShaleWellCube, Rystad Energy research and analysis
Midland Operator D exhibits a 7.1% decline in IP270 following switch, below the 8.8% allowable degradation

**Midland Operator D: Economic Model Parameters**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>NWS</th>
<th>In-Basin</th>
<th>Actual In-Basin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lateral length</td>
<td>8,905</td>
<td>8,905</td>
<td>10,634</td>
</tr>
<tr>
<td>Proppant intensity</td>
<td>1,806</td>
<td>1,806</td>
<td>1,682</td>
</tr>
<tr>
<td>D&amp;C cost ($)</td>
<td>$7.2 MM</td>
<td>$7.0 MM</td>
<td>$6.7 MM</td>
</tr>
<tr>
<td>Oil price, $ per bbl</td>
<td>$50.00</td>
<td>$50.00</td>
<td>$50.00</td>
</tr>
<tr>
<td>Gas price, $ per boe</td>
<td>$6.00</td>
<td>$6.00</td>
<td>$6.00</td>
</tr>
<tr>
<td>Cost savings per ton</td>
<td>$40</td>
<td>$40</td>
<td>$40</td>
</tr>
</tbody>
</table>

**Midland Operator D: Allowable degradation**

<table>
<thead>
<tr>
<th>Year</th>
<th>Allowable Degradation</th>
<th>Total cost savings</th>
<th>CFCF Difference* Year 1</th>
<th>CFCF Difference Year 2</th>
<th>CFCF Difference Year 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-8.8%</td>
<td>$329K</td>
<td>$343K</td>
<td>$480K</td>
<td>$566K</td>
</tr>
<tr>
<td>2</td>
<td>-6.4%</td>
<td>$329K</td>
<td>$253K</td>
<td>$353K</td>
<td>$417K</td>
</tr>
<tr>
<td>3</td>
<td>-5.6%</td>
<td>$329K</td>
<td>$219K</td>
<td>$306K</td>
<td>$362K</td>
</tr>
</tbody>
</table>

**Midland Operator D: Observed degradation**

<table>
<thead>
<tr>
<th>Well Count (NWS)</th>
<th>Time Frame Assessed (NWS)</th>
<th>IP270 (NWS)</th>
<th>Well Count (In-Basin)</th>
<th>Time Frame Assessed (In-Basin)</th>
<th>IP270 (In-Basin)</th>
<th>Observed Change in IP270</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>1Q18 – 2Q18</td>
<td>13,239</td>
<td>33</td>
<td>3Q18 – 2Q19</td>
<td>12,304</td>
<td>-7.1%</td>
</tr>
</tbody>
</table>

*CFCF difference is defined as the difference between cumulative net cash flow from a northern white and in-basin well
Source: Rystad Energy ShaleWellCube, Rystad Energy research and analysis
CFCF difference would exceed cost savings in year 1 at a degradation of 8.8%.

CFCF difference* by year versus productivity degradation

**Note:** Only wells with at least 40% cumulative light oil content have been included in the analysis; CFCF difference is defined as the difference between cumulative net cash flow from a northern white and in-basin well.

**Source:** Rystad Energy ShaleWellCube, Rystad Energy research and analysis

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Oil price: $50 per barrel  
Cost savings: $40 per ton
$40 per bbl oil price results in an additional 3.9% allowable degradation from $60 oil with in-basin sand cost savings of $40/ton

Note: Only wells with at least 40% cumulative light oil content have been included in the analysis; CFCF difference is defined as the difference between cumulative net cash flow from a northern white and in-basin well.

Source: Rystad Energy ShaleWellCube, Rystad Energy research and analysis.
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Eagle Ford
Haynesville
SCOOP/STACK
Midland Operator E began moving away from brown sand to in-basin sand in 4Q18

### Midland Operator E: frac job count by reported* sand type

![Bar chart showing the number of wells for high-confidence brown sand and in-basin sand from January 2018 to June 2019.](chart)

- **First purchase of in-basin**
- **Full Adoption of in-basin**

*Based on Rystad Energy's analysis of chemical ingredient and trade names reported to FracFocus Chemical Disclosure Registry.

Midland Operator E has significantly reduced proppant intensities since switching to in-basin sand

**Midland Operator E**

- After years of increasing proppant intensities, Midland Operator E has drastically reduced proppant loading since switching to in-basin sand
- Lateral lengths have remained very stable over the last several years right around 10,000 feet

Note: Only wells with at least 40% cumulative light oil content have been included in the analysis.

Source: Rystad Energy ShaleWellCube, Rystad Energy research and analysis
Midland Operator E has seen limited productivity impact since switching from brown to in-basin sand

**Midland Operator E**

- Production per lateral foot has exhibited similar quarterly fluctuations once switching completely to in-basin sand as experienced prior.

- Productivity has only moderately declined immediately following switch to in-basin sand despite significant reductions in proppant intensity levels.

- Midland Operator E has been classified as a case with ‘no impact’ from switching to in-basin sand, although being compared to brown sand.

---

**Midland Operator E, production per lateral foot**

- **Barrels of oil per lateral foot**

---

**Note:** Only wells with at least 40% cumulative light oil content have been included in the analysis

Source: Rystad Energy ShaleWellCube, Rystad Energy research and analysis
Normalized by proppant use, productivity metric shows different trends, but same conclusion

**Midland Operator E**

- Normalizing production by ton proppant shows a steeper drop in productivity before the switch to in-basin sand, compared with the lateral length normalization.

- Since the full-scale adoption of in-basin sand Midland Operator E has significantly reduced proppant intensities, which helps explain why production per ton has been increasing during the same period.

- The resulting combination of reduced proppant cost through lower intensities and rising production results in significant increases in margin per ton of proppant.

- Though productivity is not back to peak output from older vintages, it still tops the latest pre-switch vintages.

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**Note:** Only wells with at least 40% cumulative light oil content have been included in the analysis

Source: Rystad Energy ShaleWellCube, Rystad Energy research and analysis
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Latest data indicates continued degradation in Delaware Texas longer term IP rates

Permian Delaware: Median cumulative 2-stream production by production start year-quarter and sub-basin

Source: Rystad Energy ShaleWellCube, Rystad Energy research and analysis
Recent degradation observed in the oil stream of Reeves and Loving counties paired with a steady increase in lateral length during this period.

**Loving and Reeves counties: average cumulative oil IP360 and key well design metrics**

Source: Rystad Energy ShaleWellCube, Rystad Energy research and analysis
There could be an increase in finer grades usage as 20/40 and 30/50 sand grades are not showing up like they used to post 2015

Despite a significant share of unknown mesh sizes, coarser grades used to show up in frac forms back in 2015, but not anymore

Source: Rystad Energy research and analysis
Delaware Operator A started using in-basin sand from 3Q18

Delaware Operator A: frac job count by reported* sand type

*From Delaware Operator A’s investor presentation. Based on Rystad Energy’s analysis of chemical ingredient and trade names reported to FracFocus Chemical Disclosure Registry
Source: Rystad Energy ShaleWellCube, Delaware Operator A’s investor presentation, Rystad Energy research and analysis
Proppant intensities have shown increased variability since switching to in-basin sand while lateral lengths have remained consistent.

Delaware Operator A

- Lateral length has remained steady at around 10,000 feet since switching to in-basin sand.
- Overall, proppant intensity has decreased since switching to in-basin sand, but the variability has increased during this time.

Note: Only wells with at least 40% cumulative light oil content have been included in the analysis.
Source: Rystad Energy ShaleWellCube, Rystad Energy research and analysis
Delaware Operator A exhibits some decline in productivity since switching to in-basin sand due to declines in longer term IP rates

**Delaware Operator A**

- Despite stable lateral lengths, production per lateral foot has seen a reduction following complete adoption of in-basin sand.
- Longer-term IP rates have seen a greater impact on productivity since switching to in-basin sand, compared to relatively flat production per lateral foot for IP90 and IP180.
- Delaware Operator A has been classified as a case with 'light impact' from switching to in-basin sand as we do observe some decline.

![Graph showing production per lateral foot for Delaware Operator A](image-url)

Note: Only wells with at least 40% cumulative light oil content have been included in the analysis.

Source: Rystad Energy ShaleWellCube, Rystad Energy research and analysis
Production per ton shows different trends, likely driven by higher proppant loading variability

**Delaware Operator A**

- Proppant intensity variability has increased since switching to in-basin sand, which may explain the increases shown in all IP rates once normalized for proppant.

- In addition to increased variability, the overall proppant loading has slightly declined since the switch to in-basin, thus yielding an increase in productivity, which is the opposite trend of the production per foot metric, thus making the case less conclusive.

*Note: Only wells with at least 40% cumulative light oil content have been included in the analysis*

*Source: Rystad Energy ShaleWellCube, Rystad Energy research and analysis*
Delaware Operator A average IP270 per foot declined 6.4% once switching completely to in-basin sand, slightly greater than the allowable degradation of 6.1%.

**Delaware Operator A: Economic Model Parameters**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>NWS</th>
<th>In-Basin</th>
<th>Actual In-Basin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lateral length</td>
<td>8,174</td>
<td>8,174</td>
<td>9,000</td>
</tr>
<tr>
<td>Proppant intensity</td>
<td>1,987</td>
<td>1,987</td>
<td>1,905</td>
</tr>
<tr>
<td>D&amp;C cost ($)</td>
<td>$8.8 MM</td>
<td>$8.5 MM</td>
<td>$8.5 MM</td>
</tr>
<tr>
<td>Oil price, $ per bbl</td>
<td>$50.00</td>
<td>$50.00</td>
<td>$50.00</td>
</tr>
<tr>
<td>Gas price, $ per boe</td>
<td>$6.00</td>
<td>$6.00</td>
<td>$6.00</td>
</tr>
<tr>
<td>Cost savings per ton</td>
<td>$40</td>
<td>$40</td>
<td>$40</td>
</tr>
</tbody>
</table>

**Delaware Operator A: Allowable degradation**

<table>
<thead>
<tr>
<th>Year</th>
<th>Allowable Degradation</th>
<th>Total cost savings</th>
<th>CFCF Difference* Year 1</th>
<th>CFCF Difference Year 2</th>
<th>CFCF Difference Year 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-6.1%</td>
<td>$325K</td>
<td>$339K</td>
<td>$503K</td>
<td>$618K</td>
</tr>
<tr>
<td>2</td>
<td>-4.3%</td>
<td>$325K</td>
<td>$236K</td>
<td>$350K</td>
<td>$430K</td>
</tr>
<tr>
<td>3</td>
<td>-3.6%</td>
<td>$325K</td>
<td>$198K</td>
<td>$293K</td>
<td>$360K</td>
</tr>
</tbody>
</table>

**Delaware Operator A: Observed degradation**

<table>
<thead>
<tr>
<th>Well Count (NWS)</th>
<th>Time Frame Assessed (NWS)</th>
<th>IP270 (NWS)</th>
<th>Well Count (In-Basin)</th>
<th>Time Frame Assessed (In-Basin)</th>
<th>IP270 (In-Basin)</th>
<th>Observed Change in IP270</th>
</tr>
</thead>
<tbody>
<tr>
<td>61</td>
<td>2Q17 – 3Q18</td>
<td>19,420</td>
<td>81</td>
<td>3Q18 – 2Q19</td>
<td>18,180</td>
<td>-6.4%</td>
</tr>
</tbody>
</table>

*CFCF difference is defined as the difference between cumulative net cash flow from a northern white sand and in-basin sand well.
Source: Rystad Energy ShaleWellCube, Rystad Energy research and analysis.
CFCF difference would exceed cost savings in Year 1 at a degradation greater than 6.1%

Note: Only wells with at least 40% cumulative light oil content have been included in the analysis; CFCF difference is defined as the difference between cumulative net cash flow from a northern white and in-basin well.

Source: Rystad Energy ShaleWellCube, Rystad Energy research and analysis
$40 per bbl oil price results in an additional 2.8% allowable degradation from $60 oil assuming in-basin sand cost savings of $40/ton

**CFCF difference* by year versus productivity degradation**

Note: Only wells with at least 40% cumulative light oil content have been included in the analysis; CFCF difference is defined as the difference between cumulative net cash flow from a northern white and in-basin well.

Source: Rystad Energy ShaleWellCube, Rystad Energy research and analysis
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Delaware Operator B fully adopted in-basin sand in 2019 after having tested it throughout 2018

*From primary intelligence sources. Based on Rystad Energy’s analysis of chemical ingredient and trade names reported to FracFocus Chemical Disclosure Registry
Source: Rystad Energy ShaleWellCube, primary intelligence, Rystad Energy research and analysis
Delaware Operator B has increased both lateral lengths and proppant intensity since switching to in-basin sand.

**Delaware Operator B**

- Delaware Operator B began significantly increasing lateral lengths after the first initial use of in-basin sand, continuing into full-scale adoption.
- Proppant intensity levels began increasing around the same time, perhaps in an effort to offset production declines from increasing laterals.

Note: Only wells with at least 40% cumulative light oil content have been included in the analysis.

Source: Rystad Energy ShaleWellCube, Rystad Energy research and analysis.
Delaware Operator B exhibits clear decline in productivity, but production declines prior to and after in-basin adoption makes it more challenging to draw firm conclusions.

**Delaware Operator B**

- As expected, production per lateral foot has been decreasing as Delaware Operator B has steadily increased lateral lengths from 3Q 2017.
- Given that it is normative to see degradation in normalized production with increasing laterals it is difficult to pinpoint the exact cause of production declines after switching to in-basin sand, as the declines started before the switch.
- This trend could be due to a shift to finer mesh sand; however, mesh size data isn’t available in the public domain to make a definitive conclusion.
- Overall though, the decline in productivity is still strong so Delaware Operator B has been classified as a case with 'impact' from switching to in-basin sand.

Note: Only wells with at least 40% cumulative light oil content have been included in the analysis.
Source: Rystad Energy ShaleWellCube, Rystad Energy research and analysis.
Production per ton across all IP rates shows same trends as productivity per foot

**Delaware Operator B**

- Production per ton has been steadily decreasing since 3Q 2017, when Delaware Operator B began significantly increasing lateral lengths, similar to production per lateral foot, though the trend is even clearer.

- From the point of first in-basin usage Delaware Operator B began increasing proppant intensity levels as well, which has not done any material good to stop production declines, but trend could also be due to a shift to finer mesh sand.

**Note:** Only wells with at least 40% cumulative light oil content have been included in the analysis.

**Source:** Rystad Energy ShaleWellCube, Rystad Energy research and analysis
Delaware Operator B exhibits a 12.0% reduction in average IP270 once switching completely to in-basin sand, much greater than the allowable first year degradation of 4.3%.

**Delaware Operator B: Economic Model Parameters**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>NWS</th>
<th>In-Basin</th>
<th>Actual In-Basin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lateral length</td>
<td>4,795</td>
<td>4,795</td>
<td>6,973</td>
</tr>
<tr>
<td>Proppant intensity</td>
<td>2,069</td>
<td>2,069</td>
<td>2,580</td>
</tr>
<tr>
<td>D&amp;C cost ($)</td>
<td>$5.8 MM</td>
<td>$5.6 MM</td>
<td>$5.4 MM</td>
</tr>
<tr>
<td>Oil price, $ per bbl</td>
<td>$50.00</td>
<td>$50.00</td>
<td>$50.00</td>
</tr>
<tr>
<td>Gas price, $ per boe</td>
<td>$6.00</td>
<td>$6.00</td>
<td>$6.00</td>
</tr>
<tr>
<td>Cost savings per ton</td>
<td>$40</td>
<td>$40</td>
<td>$40</td>
</tr>
</tbody>
</table>

**Delaware Operator B: Allowable degradation**

<table>
<thead>
<tr>
<th>Year</th>
<th>Allowable Degradation</th>
<th>Total cost savings</th>
<th>CFCF Difference* Year 1</th>
<th>CFCF Difference Year 2</th>
<th>CFCF Difference Year 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-4.3%</td>
<td>$198K</td>
<td>$207K</td>
<td>$295K</td>
<td>$354K</td>
</tr>
<tr>
<td>2</td>
<td>-3.1%</td>
<td>$198K</td>
<td>$150K</td>
<td>$213K</td>
<td>$256K</td>
</tr>
<tr>
<td>3</td>
<td>-2.6%</td>
<td>$198K</td>
<td>$128K</td>
<td>$181K</td>
<td>$218K</td>
</tr>
</tbody>
</table>

**Delaware Operator B: Observed degradation**

<table>
<thead>
<tr>
<th>Well Count (NWS)</th>
<th>Time Frame Assessed (NWS)</th>
<th>IP270 (NWS)</th>
<th>Well Count (In-Basin)</th>
<th>Time Frame Assessed (In-Basin)</th>
<th>IP270 (In-Basin)</th>
<th>Observed Change in IP270</th>
</tr>
</thead>
<tbody>
<tr>
<td>31</td>
<td>3Q18 – 4Q18</td>
<td>31,806</td>
<td>31</td>
<td>1Q19 – 2Q19</td>
<td>27,980</td>
<td>-12.0%</td>
</tr>
</tbody>
</table>

Note: Only wells with at least 40% cumulative light oil content have been included in the analysis; CFCF difference is defined as the difference between cumulative net cash flow from a northern white and in-basin well.

Source: Rystad Energy ShaleWellCube, Rystad Energy research and analysis.
CFCF difference would exceed cost savings in Year 1 at a degradation greater than 4.3%

Note: Only wells with at least 40% cumulative light oil content have been included in the analysis; CFCF difference is defined as the difference between cumulative net cash flow from a northern white and in-basin well.

Source: Rystad Energy ShaleWellCube, Rystad Energy research and analysis
Allowable degradation at $40 per bbl oil still far below observed decline in productivity

CFCF difference* by year versus productivity degradation

Note: Only wells with at least 40% cumulative light oil content have been included in the analysis; CFCF difference is defined as the difference between cumulative net cash flow from a northern white and in-basin well.

Source: Rystad Energy ShaleWellCube, Rystad Energy research and analysis
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Delaware Operator C shifted to full-scale in-basin sand adoption from March 2019

*From Delaware Operator C’s investor presentation

**Based on Rystad Energy’s analysis of chemical ingredient and trade names reported to FracFocus Chemical Disclosure Registry

Source: Rystad Energy ShaleWellCube, Delaware Operator C investor presentation, Rystad Energy research and analysis
Delaware Operator C has kept proppant intensity relatively flat since switching to in-basin sand

Delaware Operator C

- Since complete adoption of in-basin Delaware Operator C has slightly reduced proppant intensity and sharply reduced average lateral lengths.
- Lateral lengths were steadily on the rise from the first use of in-basin sand until 1Q 2019, though the variability has been similar across the whole period.

Note: Only wells with at least 40% cumulative light oil content have been included in the analysis
Source: Rystad Energy ShaleWellCube, Rystad Energy research and analysis
With more production history, Delaware Operator C exhibits no impact on productivity following switch to in-basin sand

**Delaware Operator C**

- Since the first use of in-basin sand for Delaware Operator C, there has been an increase in normalized production, despite increasing lateral lengths.

- Amount of well data for 3Q 2018 is less than half that of neighboring quarters, perhaps explaining the sudden contraction in productivity.

- Delaware Operator C is a case that has been classified as 'no impact' from switching to in-basin sand.

*Note: Only wells with at least 40% cumulative light oil content have been included in the analysis*

*Source: Rystad Energy ShaleWellCube, Rystad Energy research and analysis*
Delaware Operator C

- Production normalized for proppant pumped per well has increased significantly since first adopting in-basin sand, despite proppant intensities staying relatively flat during this period.

- Similar to the production per foot metric, the productivity normalized per proppant also supports the conclusion of no impact from switching to in-basin sand.

Note: Only wells with at least 40% cumulative light oil content have been included in the analysis
Source: Rystad Energy ShaleWellCube, Rystad Energy research and analysis
Delaware Operator C’s allowable degradation assuming $40/ton cost savings from switching to in-basin sand is 5.6%.

### Delaware Operator C: Economic Model Parameters

<table>
<thead>
<tr>
<th>Parameters</th>
<th>NWS</th>
<th>In-Basin</th>
<th>Actual In-Basin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lateral length</td>
<td>6,695</td>
<td>6,695</td>
<td>7,208</td>
</tr>
<tr>
<td>Proppant intensity</td>
<td>2,499</td>
<td>2,499</td>
<td>2,351</td>
</tr>
<tr>
<td>D&amp;C cost ($)</td>
<td>$9.1 MM</td>
<td>$8.8 MM</td>
<td>$8.6 MM</td>
</tr>
<tr>
<td>Oil price, $ per bbl</td>
<td>$50.00</td>
<td>$50.00</td>
<td>$50.00</td>
</tr>
<tr>
<td>Gas price, $ per boe</td>
<td>$6.00</td>
<td>$6.00</td>
<td>$6.00</td>
</tr>
<tr>
<td>Cost savings per ton</td>
<td>$40</td>
<td>$40</td>
<td>$40</td>
</tr>
</tbody>
</table>

### Delaware Operator C: Allowable degradation

<table>
<thead>
<tr>
<th>Year</th>
<th>Allowable Degradation</th>
<th>Total cost savings</th>
<th>CFCF Difference* Year 1</th>
<th>CFCF Difference Year 2</th>
<th>CFCF Difference Year 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-5.6%</td>
<td>$334K</td>
<td>$351K</td>
<td>$559K</td>
<td>$712K</td>
</tr>
<tr>
<td>2</td>
<td>-3.7%</td>
<td>$334K</td>
<td>$228K</td>
<td>$363K</td>
<td>$462K</td>
</tr>
<tr>
<td>3</td>
<td>-3.0%</td>
<td>$334K</td>
<td>$185K</td>
<td>$294K</td>
<td>$375K</td>
</tr>
</tbody>
</table>

### Delaware Operator C: Observed degradation

<table>
<thead>
<tr>
<th>Well Count (NWS)</th>
<th>Time Frame Assessed (NWS)</th>
<th>IP270 (NWS)</th>
<th>Well Count (In-Basin)</th>
<th>Time Frame Assessed (In-Basin)</th>
<th>IP270 (In-Basin)</th>
<th>Observed Change in IP270</th>
</tr>
</thead>
<tbody>
<tr>
<td>62</td>
<td>1Q18 – 4Q18</td>
<td>29,482</td>
<td>60</td>
<td>4Q18 – 2Q19</td>
<td>31,516</td>
<td>+6.9%</td>
</tr>
</tbody>
</table>

Note: Only wells with at least 40% cumulative light oil content have been included in the analysis; CFCF difference is defined as the difference between cumulative net cash flow from a northern white and in-basin well. Source: Rystad Energy ShaleWellCube, Rystad Energy research and analysis.
CFCF difference would exceed cost savings in Year 1 at a degradation greater than 7.0%

Note: Only wells with at least 40% cumulative light oil content have been included in the analysis; CFCF difference is defined as the difference between cumulative net cash flow from a northern white and in-basin well.

Source: Rystad Energy ShaleWellCube, Rystad Energy research and analysis

允许降解：-5.6%

年份1
年份2
年份3

在盆地中开采成本节省334K美元

油价：$50每桶
成本节省：$40每吨
$40 per bbl oil price results in an additional 2.6% allowable degradation from $40 oil

CFCF difference* by year versus productivity degradation

Note: Only wells with at least 40% cumulative light oil content have been included in the analysis; CFCF difference is defined as the difference between cumulative net cash flow from a northern white and in-basin well.

Source: Rystad Energy ShaleWellCube, Rystad Energy research and analysis
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Basin overview
  Permian Midland
  Permian Delaware
  Eagle Ford
  Haynesville
  SCOOP/STACK
Eastern portion of Eagle Ford remains the most proppant-intensive as wells are shorter. Comparable evolution of lateral length and proppant loadings across all other areas.

Eagle Ford shale, core*: Median proppant intensity and perforated lateral length (PLL) by completion quarter

*Includes the following counties: Atascosa, La Salle, Live Oak, McMullen (Central); De Witt, Gonzales, Karnes, Lavaca (East); Dimmit, Webb (West)

Source: Rystad Energy research and analysis, Rystad Energy ShaleWellCube
Latest injection of data continues to show limited evidence for impact on Eagle Ford IP rates; Potential impact among longer term IP rates but historically data has been noisy

Eagle Ford shale, core*: Median cum. 2-stream production by production start year-quarter and sub-basin

In-basin sand availability

*Includes the following counties: Atascosa, La Salle, Live Oak, McMullen (Central); De Witt, Gonzales, Karnes, Lavaca (East); Dimmit, Webb (West)

Source: Rystad Energy research and analysis, Rystad Energy ShaleWellCube
Latest injection of data in the Haynesville signals increases in productivity among all IP rates.

Haynesville basin: Median cumulative gas production by production start year-quarter and area

Source: Rystad Energy ShaleWellCube, Rystad Energy research and analysis
Proppant loadings and lateral lengths keep increasing on both the Texas and Louisiana side of the Haynesville border.

Haynesville basin*: Median proppant intensity and perforated lateral length (PLL) by completion quarter

*Note: PLL refers to perforated lateral length

Source: Rystad Energy ShaleWellCube, Rystad Energy research and analysis
Full in-basin adoption began for this operator in 1Q18

Haynesville: frac job count by reported* sand type (LHS)

*Based on Rystad Energy’s analysis of chemical ingredient and trade names reported to FracFocus Chemical Disclosure Registry
Source: Rystad Energy ShaleWellCube, Rystad Energy research and analysis
Small sample size contributes to noisy data, however lateral lengths and proppant intensity levels show minimal changes since switching to in-basin sand.

Haynesville Operator

- Proppant intensity data has been historically noisy, with some quarters only containing one well.
- Overall, proppant intensity levels have increased marginally and lateral lengths have stayed relatively stable with modest declines since switching completely to in-basin sand despite noisy and insufficient data.

Proppant intensity by vintage quarters (all wells)

Lateral length by vintage quarters (all wells)

Note: Only wells with at least 40% cumulative light oil content have been included in the analysis
Source: Rystad Energy ShaleWellCube, Rystad Energy research and analysis
The Haynesville operator has been no impact from switching to in-basin sand

Hayneville Operator

- Since complete adoption of in-basin sand this Haynesville operator has experienced significant growth in production per lateral foot.

- Quality of in-basin sand in the Haynesville region is more comparable to northern white sand rather than in-basin sand.

- As such, this Haynesville operator has been identified as a case with 'no impact' from switching to in-basin sand.

Note: Only wells with at least 40% cumulative light oil content have been included in the analysis
Source: Rystad Energy ShaleWellCube, Rystad Energy research and analysis
Productivity trend similar, but not as strong when normalizing for proppant use

**Haynesville Operator**

- Proppant intensity levels increased immediately following in-basin sand adoption back to levels seen while utilizing northern white sand.

- Production normalized for proppant has increased significantly since this point, signaling gains not driven purely through increased proppant intensity.

- Given the smaller sample size historically, there is larger variation in the 2016 vintages, more than a year before the switch to in-basin sand.

Note: Only wells with at least 40% cumulative light oil content have been included in the analysis

Source: Rystad Energy ShaleWellCube, Rystad Energy research and analysis
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New data shows recovery in SCOOP IP90 and IP180 while IP360 performs worse.
STACK has recently seen increasing proppant intensity levels at reduced cost per foot; this is likely driven by in-basin sand adoption.

Increasing proppant intensity will theoretically imply higher completion cost per foot. However, in STACK the opposite has been observed post 4Q18.
STACK proppant intensity and lateral length increasing since in-basin sand adoption while SCOOP intensity has stayed relatively flat with lateral lengths increasing until 4Q19.

Source: Rystad Energy ShaleWellCube, Rystad Energy research and analysis