

PRODUCTION VERIFICATION TESTS

Final Report – Phase I

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DISCLAIMER

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I. ABSTRACT

A summary of the demonstration of 14 stages (in 10 wells) of a unique liquid-free stimulation process which employs carbon dioxide (CO₂) as the working fluid in ten Candidate Wells. Three were situated in Perry County and seven in Pike County of eastern Kentucky’s Big Sandy gas field. These activities included four individual efforts which have previously been described in detail in four submitted Final Reports, and are herein summarized. These ten Candidate wells produce from the Devonian Shale which is well known to be damaged by liquid based stimulation processes. They were treated with a total of fourteen stages; four as a single stage, and the others in two stages per well all containing approximately 120 tons of CO₂ per stage. These liquid free stimulations also contained proppant quantities on the order of 45,000 lbs per stage. The results show in the three Perry Co Candidate wells that the stimulations were not as effective as the best conventional technology, and resulted in a stimulation cost for produced gas of \$0.69 per Mcf vs \$0.43 for N₂ gas stimulations. The results in the Pike County Candidates, where the shale section is thicker – 1,025 vs. 350 feet, indicated a superior response from the wells stimulated with the CO₂/sand process. A five year production benefit of 67.7 MMcf per stage, or 135.4 MMcf per well over that from the closest competing technology which results in a 3.41 benefit ratio and a stimulation cost for produced gas of \$0.47 per Mcf vs \$1.14 for N₂ gas.

II. INTRODUCTION

The demonstration of a unique liquid-free stimulation treatment technique which utilizes carbon dioxide (CO₂) as the working fluid and which was previously unavailable in the U.S. was initiated and performed under the subject contract. The technology held promise for stimulating liquid-sensitive reservoirs in that the CO₂ is pumped as a liquid to hydraulically create fractures, and then will vaporize at reservoir conditions and a liquid-free induced fracture remains. Additionally, the process which had been developed in Canada utilized specialized equipment to enable proppant to be mixed with and transported by the liquid CO₂ thereby resulting in a propped fracture to prevent it from closing.

These efforts required the cooperation of gas well operators to provide “Candidate Wells” wells for the demonstrations, and in return they received financial cost-shared support for this DOE

sponsored program. The operators provided the Candidate Wells, the specifics on nearby “Control Wells”, and the production data from the Candidates for five years following the stimulations. The production responses from the Candidate Wells, which were stimulated with the CO₂/Sand process were then compared to that from the conventionally stimulated Control Wells to determine if any advantage would be realized from this process.

These efforts were funded to consist of up to 27 stimulation events separated into three contractual codicils. The first (Phase I) consisted of 15 events, the second (Phase II) which could depending on the Phase I experience be funded, and was to consist of 9; and later, after successful experiences in Phases I and II resulted, another 3 were subsequently added by a modification (#7) bringing the total to 27.

Initially, the contract provided for a single-stage stimulation event in each well, but after the work commenced it was recognized that because of some area-specific local practices where in some instances more than one stimulation event or stage is conducted in each well, that the funding was to be directed toward 27 stimulation events irrespective of the number of wells required. In actuality 21 stimulation events were performed in 17 wells.

	Phase #1	Phase #2	Mod #7	Total
Contract	15	9	3	27
Executed	14	7	0	21
Locations	E Ky	NY, PA, WV		

Additional wells were identified which would have resulted in the execution of all 27 stimulation events, the operator was completely supportive in the cost-shared participation, and preparations made to treat them. However, an inability to obtain the necessary resources (CO₂) due to market conditions prohibited these last 6 events from being executed and the unexpended funds were returned to the DOE.

The contract also specified that each demonstration group of Candidate Wells was to include a minimum of three wells. This requirement was to enable the statistical confidence in the results to be

elevated. The 15 stimulations provided for in Phase I, because of these minimum well constraints actually ended up consisting of 14, and the remaining 7 were conducted under Phase II. As it turned out, these first 14 stimulation events (stages) were executed in ten Candidate Wells producing from the Devonian Shale, and were all situated in eastern Kentucky; and those stimulated in Phase II were located in New York, Pennsylvania, and West Virginia. This regional separation between Phases I and II resulted in all of the eastern Ky wells being conducted under Phase I which resulted in only, and all of those wells to be included and summarized in this Report.

Final Reports have been prepared for each of the seven demonstration groups. These four Final Reports address all of the activities conducted in eastern Kentucky which have been prepared, submitted, and the results of which have been combined, and summarized in this Phase I Report:

Pkg #	County	State	Date	Stages	Wells
6	Perry	Ky	1/93	3	3
7	Pike	Ky	1/93	2	2
9	Pike	Ky	5/93	3	3
9	"	"	9/93	2	Same
10	Pike	Ky	10/93	<u>4</u>	<u>2</u>
				14	10

They were all situated in eastern Kentucky, and the remaining seven remaining events (7 wells) were executed under Phase II.

The Phase II demonstrations consisted of three separate well groups situated in New York, Pennsylvania, and West Virginia. The test in Pennsylvania was discontinued after a failed attempt to place proppant was encountered on the first well. Because of the difficulties in treating the uncased, open-hole interval in the first well it was concluded that there would very likely be difficulty in treating additional wells, and the remaining scheduled demonstration was aborted. Therefore, only one well was stimulated.

The stimulation events conducted under Phases I and II are summarized as follows:

Pkg #	County	State	Date	Stages	Wells
	Phase I				
6	Perry	Ky	1/93	3	3
7	Pike	Ky	1/93	2	2
9	Pike	Ky	5/93	3	3
9	"	"	9/93	2	Same
10	Pike	Ky	10/93	<u>4</u>	<u>2</u>
			Sub Total	14	10
	0				
12	Chautauqua	NY	12/93	3	3
16	Mercer	Pa	7/95	1	1
23	Putnam	WV	9/98	<u>3</u>	<u>3</u>
			Sub Total	7	7
			Total	21	17

III. BACKGROUND

The first demonstrations of the CO₂/Sand stimulation process were initiated through this DOE sponsored project were conducted in eastern Kentucky's Big Sandy gas field in January, 1993.

Because the greatest reserves of natural gas in eastern Kentucky are contained within the Big Sandy gas field where the majority of the natural gas resource is contained in, and is produced from the Devonian Shale's. They were identified as a target opportunity for the CO₂/Sand stimulation process primarily because:

- A. It had been clearly demonstrated that the gas production rates were almost always significantly greater when the wells were stimulated with a liquid-free category of treatment, like nitrogen gas (N₂ gas) than when they were treated with liquid based treatments including nitrogen foam (N₂ foam) stimulations, and
- B. The liquid-free properties of the CO₂/Sand stimulations combined with the addition of proppant, which the N₂ gas stimulations cannot provide, were considered to present an increased probability for increased gas production rates over that from the other stimulation types.

The first demonstrations involved two operators, and five Devonian Shale Candidate Wells treated with single-stage stimulations, three were located in Perry County (Pkg #6) and the other two in Pike County (Pkg #7) where the shale section is considerably thicker (350 vs. 900 feet). The results in Pike county were very encouraging, and five additional Candidate Wells located in Pike County were subsequently identified and treated (Pkg #'s 9 & 10).

A Final Report for each of these four packages (6, 7, 9 & 10) has been prepared and submitted to the DOE. They include well-specific details for each group and the findings and conclusions from those reports have been summarized in this document.

IV. METHODOLOGY

The evaluation of the CO₂/sand stimulations was effected through the comparison of the five-year cumulative produced gas volumes from the Candidate wells which were stimulated with CO₂/sand with that from nearby Control wells which had been stimulated with other processes. These other stimulation processes included nitrogen (N₂) gas, N₂ foam, and in some instances through explosive shooting.

The wells with the larger projected five-year cumulative produced gas volumes, after the flush production was removed, were considered to be superior.

A. Mathematical Analog of Production Data

The procedure to remove the flush production volumes utilizes a fit of a mathematic equation of the later time production, and then utilizing that relationship to extrapolate the early production if the flush production rates had not occurred.

There were some instances where the flush production volumes were minimal which reinforces the benefit of being able to more acutely focus in on the reservoir characteristics through the elimination of this bias. This process can also provide a significant benefit when there is missing production data.

B. Removal of Flush Production Rates

The procedure utilized to remove the flush production volumes involves a mathematic fit of the later time production and then utilizing that relationship to determine the what the early production would have been if the flush production rates had not occurred. There were some instances where the flush production volumes were minimal which reinforces the benefit of being able to more acutely focus in on the reservoir characteristics through the elimination of this bias.

C. Missing Data

This process can also provide a significant benefit when there is missing production data. There was only a very limited knowledge of the early production histories and co-metered gas production volumes were commonplace, particularly in Perry County, and the process provided method for utilizing this limited or late time production data.

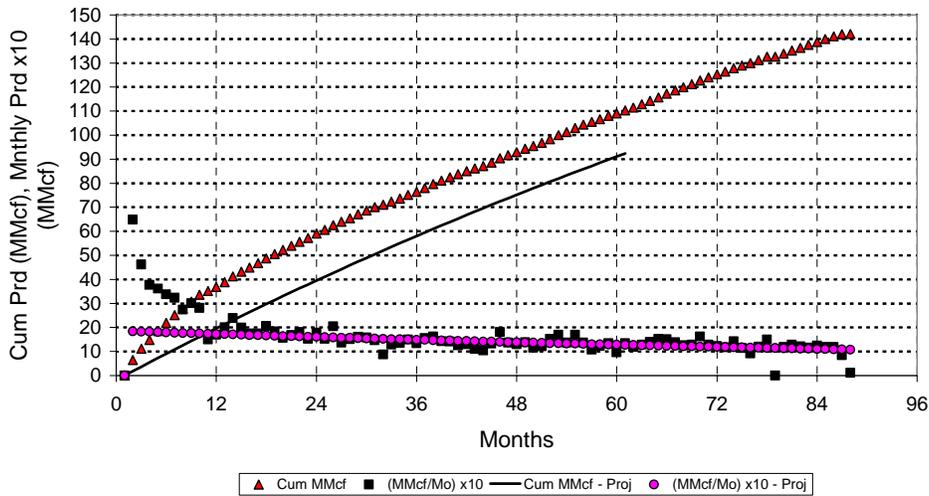
D. Examples

The following examples demonstrate the procedure utilized to remove the gas produced during the flush production period which in this case lasted approximately 13 months. The actual produced gas volume was 41 MMcf while the projected volume was 23 MMcf or a difference of 18 MMcf. The projected five year cumulative production is 92 MMcf whereas the actual production volume measured was 110 MMcf.

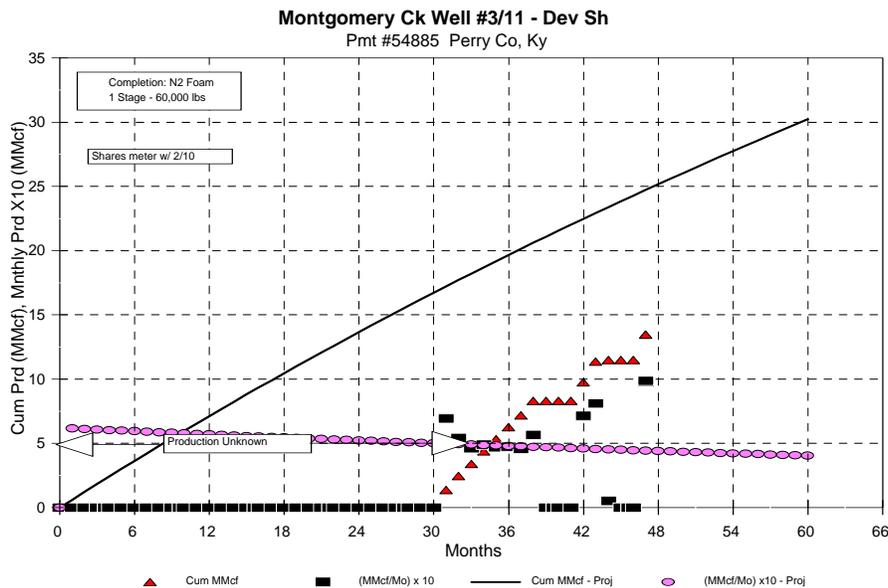
S-29

(84765) Pike Co, KY

Completion: N₂ Gas - 2 Stages - No Proppant



In the second example there was no production data available for the first 29 months, additionally the available data included two shut in periods which are followed by flush production periods. By utilizing a mathematic fit of the steady state production data a realistic projection of the production resulted. The limited data set was then utilized, and the bias resulting from the flush production periods following the shut in periods was removed.



In removing the effects of the flush production volume a more realistic assessment of the response to the different stimulation types resulted. The production plots for each well including the actual and projected values are included in this report.

The wells which were stimulated by N₂ gas or by shooting contained no liquid nor proppant; whereas those stimulated with N₂ foam contained both liquid (water) and proppant. Generally, those wells stimulated with N₂ gas also included some minor quantity of liquid. Hydrochloric (HCl) acid is employed to attack and weaken the cement used to seal the steel casing to the formation. When used, it generally consisted of a volume of 500 gallons which was the only liquid which entered the reservoir during the N₂ gas treatments. The Candidate wells which were stimulated with the CO₂/sand process also required this small quantity of “breakdown acid” which was introduced during the perforation stage and then removed prior to the treatments.

V. GEOLOGY

The Upper Devonian age shale’s in eastern Kentucky include black and gray shale’s from the base of the Berea Sandstone (or Bedford shale where present) to the top of the Corniferous Onondaga

limestone (middle Devonian). There are three names for the Devonian Shale groups in Kentucky. In the western half of the state (to the west of the Cincinnati Arch) it is known as the New Albany Shale, over the Cincinnati Arch in south Central Kentucky as the Chattanooga Shale, and to the east it is referred to as the Ohio Shale. The natural fracture systems provide the essential secondary porosity and permeability in the Big Sandy field and other shale gas fields in Kentucky.

The interval of the Devonian Shale sections is approximately 350 feet in Perry County – where the first three Candidate Wells are located, and up to 1,400 feet in Pike County. The shale thickness in the three Pike County test areas was on the order of 1,025 feet.

VI. RESERVOIR

Within the Appalachian Basin the Big Sandy field in eastern Kentucky encompasses an area in excess of 3000 square miles, in Knott, Floyd, Martin, and Pike counties. It accounts for more than 80% of the production from the Upper Devonian black shales. More than 10,000 wells have been drilled into the Big Sandy field with an estimated cumulative production of 2.5 Trillion cubic feet (TCF) of gas reportedly averaging 250 MMcf per well. The initial successes were originally in Floyd County in 1935 where the reservoir pressure was approximately 595 psi. As the pressure diminished additional exploratory drilling resulted in its expansion generally outward from several eastern Kentucky production centers that have subsequently been connected and extended both southwestward and northeastward into West Virginia.

The reservoir pressure in the test areas has diminished and now ranges from 200 to 350 psi, and the production responses following liquid based stimulation treatments has been found to have become limited because the reservoir pressure is insufficient to push the spent stimulation liquids from the shale. These liquids can become trapped within the natural fractures and they can then impede the flow of gas.

A. Reservoir Pressure and Temperature

The reservoir pressure and temperatures for each group were reported as:

Pkg #	Co	Stgs/Wells	Depth	Press (Psig)	Temp (F)
-------	----	------------	-------	--------------	----------

6	Perry	3/3	3,500	200 – 360	64
7	Pike	2/2	3,300	250 – 380	72
9	Pike	4/2	3,500	240 – 380	95
10	Pike	5/3	3,900	340 – 370	104
		14/10			

A review of the phase behavior at these temperatures and pressures confirmed that the CO₂ would vaporize under these conditions. A phase diagram for each well group was prepared and is not included, but accompanies the report for that group

B. Sensitivity to Stimulation Liquids

The liquid sensitivity of the Devonian Shale in areas of lower reservoir pressure is well known and the general stimulation practices have resulted in a trend away from water-based treatments. This sensitivity to liquids is believed to be a consequence of liquid imbibitions within the interstices of the natural fractures and to a lesser extent a result of mineral reaction and swelling

VII. IS THE PROPOSED RESERVOIR LIKELY TO BENEFIT FROM THE CO₂/SAND TECHNOLOGY?

Because the CO₂/sand stimulation utilizes CO₂ as the working fluid which is pumped as a liquid and subsequently vaporizes at formation temperature and flows from the reservoir as a gas, no liquid remains behind and the gas can flow from the reservoir unimpeded.

Because of the absence of produced liquids from the Devonian Shale in this area, and also because of the obvious increase in gas production rates when liquid-free stimulations were used, it was expected that the production rate from wells stimulated with the CO₂/Sand technology would at least equal that of the liquid-free treatments, and it was anticipated that the benefit of proppant would probably result in an improved production rate.

VIII. OPERATORS

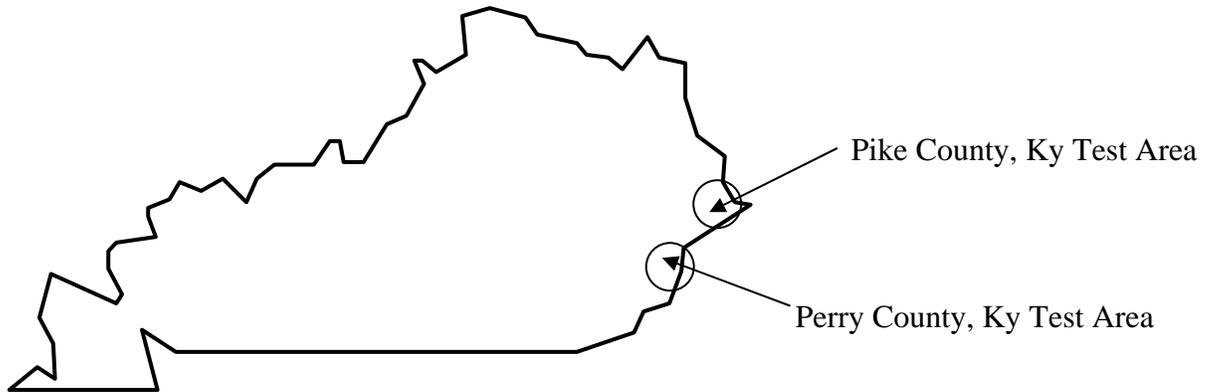
The following questions were considered and each of the operators, and each of the test areas provided or afforded:

- A. An interest in CO₂/Sand technology
- B. An adequate test opportunity
- C. A presently active drilling program
- D. A future for successful results? Is the operator likely to continue implementing this technology without DOE cost support?
- E. An interest in DOE cost-supported participation?
- F. Share production data for five years?
- G. Letter of Intent

The operator provided a letter of intent agreeing to:

1. Provide legitimate well opportunities for a minimum of three mutually agreed upon wells,
2. Provide acceptable background information on the nearby wells including the drilling, completion, and production specifics,
3. Bear the normal additional expenses of cement bond logging, perforating, dozers, and other normally occurring expenses associated with stimulation events,
4. Participate in the demonstration project and the anticipated treatments specifics, and
5. Provide the production and flowing pressure information from the Candidate Wells for five years.

IX. TEST AREAS



A. Test Area #1 - Perry County, Kentucky - Package #6

Three of the Candidate Wells were located in Perry County on Montgomery Creek near the town of Vicco. The wells were all completed in the Devonian shales which is approximately 350 feet in thickness.

They are situated on an active surface mine, and have specific identities which indicate a well number and a block number. The well designation identifies both, i.e.: Well # X/ Block #Y.

B. Test Area #2 - Pike County, Kentucky - Packages #7, 9, &10

The wells were all completed in the Devonian shales which averaged 1,025 feet in thickness in the Candidate wells.

1. Package #7 – Two wells - they are in the Big Creek watershed south of the settlement of Hatfield.
2. Package #9 – Two wells - The test area is situated approximately eight miles south of the town of Nolan, Kentucky, and six and one-half miles southeast of the two Candidate Wells, in Package #7.

3. Package #10 – Three wells - The test area is situated on the Pond Fork drainage approximately two miles south of the town of Williamson, Kentucky, and one mile west of the town of Belfry, Kentucky.

X. CO₂/SAND STIMULATION TREATMENTS

A. Design

A stimulation design was prepared and presented to the operators. Because of the immediate prior successes in placing full blender volumes, it was concluded that the first effort would be to attempt a maximum quantity of 47,500 lbs. The recommended stimulation designs were generally;

PROPPANT FLUID SCHEDULE					
	Cum	Stage	Proppant	Proppant	Cum
	(bbl)	(bbl)	(ppg)	(lb)	(lb)
Stage					
Hole Fill (Liquid CO ₂)	53	53		0	0
Pad (Liquid CO ₂)	190	115		0	2310
Start Sand	55	55	1.0	2,310	2,310
Increase Sand	110	55	2.0	4,620	6,930
Increase Sand	165	55	3.0	6,930	13,860
Increase Sand	383	218	3.5	32,046	45,906
Flush (Liquid CO ₂)	615	44		0	45,906
	Total	615			

TREATMENT FLUID REQUIREMENTS						
	Hole +	Prop	Flush	Tot Pumped	Bottom	Total
Liquid CO ₂ (bbl)	168	403	44	615	10	625
CO ₂ (T)						120
Nitrogen (Mscf)						74

XI. IDENTIFICATION AND SELECTION OF CANDIDATE WELLS

There were 24 Appalachian Basin Candidate Well packages developed and submitted to the DOE seven of which were approved for treatment. These approvals have resulted in 21 Stages (17 wells) being stimulated with the CO₂/Sand process with cost shared participation under the subject contract.

Pkg #	Opr	Form	Depth	County	St	DOE ?	#	Stg	Date	Status/Date
1	Peake			Jackson	WV		3	3	May-92	OP-With
2	Peake			Mingo	WV		1	1	May-92	OP-With
3	EREX			Perry	KY		2	2	May-92	DOE-Rej
3	EREX			Letcher	KY		2	2	May-92	OP-With
4	EREX			Perry	KY		1	1	May-92	OP-With
5	Jura			Johnson	KY		1	1	Jun-92	DOE-Rej
6	Kinzer	Dev Sh	3700	Perry	KY	Y	3	3	Sep-92	Jan-93
7	CD&G	Dev Sh	3300	Pike	KY	Y	2	2	Sep-92	Jan-93
8	Chesterfield			Boone	WV		4	4	Feb-93	DOE-Rej
9	CD&G	Dev Sh	3500	Pike	KY	Y	2	4	Feb-93	Oct-93
9	CD&G	Dev Sh	3500	Pike	KY		1	2	Feb-93	OP-With
10	Kinzer	Dev Sh	3900	Pike	KY	Y	3	3	Mar-93	May-93
10	Kinzer	Dev Sh	3200	Pike	KY	Y	2	2	Sep-93	Sep-93
11	Westar			Morrow	OH		4	4	Mar-93	DOE-Rej
12	Pefley	WP	4300	Chaut	NY	Y	3	3	May-93	Dec-93
12	Pefley	WP	3500	Chaut	NY		1	1	Jul-93	DOE-Rej
13	CNG-P			Westm	PA		1	1	Jun-93	DOE-Rej
14	CNG-P			Somerset	PA		1	1	Jun-93	DOE-Rej
15	ECU			Cattar	NY		3	3	Sep-93	DOE-Rej
16	Seneca	Lockport	5200	Mercer	PA	Y	1	1	Apr-94	Jul-95
16	Seneca	Lockport	5200	Mercer	PA	Y	1	1	Apr-94	Op-With
17	Cabot	Med Snd	5100	Crawford	PA		2	2	Apr-94	DOE-Rej
17	Cabot	Med Snd		Venango	PA		1	1	Apr-94	DOE-Rej
18	Cabot	Big Injun		Kanawha	WV		2	2	May-94	DOE-Rej
19	Penn Va	Weir Snd	3400	Wyoming	WV		4	4	May-94	Op-With
20	Cobham	Gor	2800	Wetzel	WV		6	6	Jul-94	DOE-Rej
21	E States	Dev Sh	3000	Floyd	KY		5	5	Jun-95	DOE-Rej
22	Alamco	Chatt	2300	Campbell	TN		2	2	Jan-96	DOE-Rej
23	Cabot	Dev Sh	4000	Putnam	WV	Y	3	3	Jun-98	Sep-98

Pkg #	Opr	Form	Depth	County	St	DOE ?	#	Stg	Date	Status/Date
24	Blue Fl	DS/Ber	4500	Pike	KY		3	6	Apr-99	CO ₂ Unavail

XII. DOE APPROVALS

A submittal package was prepared for each of the 24 groups and submitted to the DOE for consideration. After their review and some additional information provided, some of the treatments were approved for the cost-shared demonstration.

The treatments were conducted in reservoirs in four states which were selected for their liquid sensitive properties, and involved five operators. The first treatments were conducted in eastern Kentucky where the results were good and ultimately ten wells were treated with a total of 14 stages. The seven groups were located in Kentucky (14 stages, 10 wells), New York (3 stages, 3 wells), Pennsylvania (1 stage, 1 well), and West Virginia (3 stages, 3 wells). They were:

Pkg #	Operator	Co, St	Stages	Wells
Phase I				
6	Kinzer	Perry, Ky	3	3
7	CD & G	Pike, Ky	2	2
9	CD & G	Pike, Ky	4	2
10	Kinzer	Pike, Ky	3	3
10	Kinzer	Pike, Ky	<u>2</u>	<u>Same</u>
			14	10
Phase II				
12	Sinclairville	Chautauqua, Ny	3	3
16	Seneca	Mercer, Pa	1	1
23	Cabot	Putnam, Wv	<u>3</u>	<u>3</u>
			7	7
		Total	21	17

XIII. FIELD ACTIVITIES

A. Preparations

Preparations for the field activities included perforating the candidate wells and the placement of two 60 or 70 ton CO₂ storage vessels on the location and then filling them with liquid CO₂ during the 24 hour period prior to the treatment.

B. Stimulations

The well specific details regarding the perforations, stimulation specifics (volumes, rates, pressures) for all of the candidate wells is presented in the Final Reports for each of the four groups. A summary of the CO₂ and proppant volumes for the fourteen Candidate Wells are:

CANDIDATE WELL SUMMARY				
	ID	Stage(s)	CO ₂ (Tons)	Sand (Sxs)
Package #6				
Well #1	W3/B6	1	110	429
Well #2	W6/B11	1	150	402
Well #3	W8/B8	1	120	227
Package #7				
Well #1	Staton #3	1	120	460
Well #2	Stepp #1	1	120	430
Package #9				
Well #1	S-31	2	108 & 102	460 & 460
Well #2	Prather #1	2	108 & 103	455 & 475
Package #10				
Well #1	FH 177	2	120 & 120	435 & 350
Well #2	FH 178	1	120	353
Well #3	FH 179	2	69 & 120	56 & 298

XIV. COSTS

A. Perry Co – Single Stage

The total treatment costs for these single stage treatments including unusually high proppant and transport costs, one standby pump truck (\$1,320) and one standby N₂ pump truck (\$700),

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an unusually high blender charge of \$10,500, and mobilization (\$5,670) is \$135,230 - or an average of \$ 45,076 per well. The per-category costs were:

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	Projected	Actual	Difference
Proppant (lbs)	129,000	113,000	(16,000)
CO ₂ (tons)	360	400	40
<u>Equipment</u>			
Pumping-CO ₂	\$43,961.40	\$39,722.45	(\$4,238.95)
Pumping-N ₂	\$6,450.00	\$6,450.00	\$0.00
Total	\$50,411.40	\$46,172.45	(\$4,238.95)
<u>Materials</u>			
Proppant	\$6,987.00	\$7,740.50	\$753.50
Drayage	\$4,284.00	\$6,060.60	\$1,776.60
Total	\$11,271.00	\$13,801.10	\$2,530.10
N ₂	\$3,745.14	\$4,782.00	<u>\$1,036.86</u>
Total - Ser Co	\$65,427.54	\$64,755.55	(\$671.99)
CO ₂ w/Portables	\$30,000.00	\$33,305.00	\$3,305.00
Blender	\$31,500.00	\$31,500.00	\$0.00
Total	\$126,927.54	\$129,560.55	\$2,633.01
Mobilization	\$6,270.00	\$5,670.00	(\$600.00)
Total	\$133,197.54	\$135,230.55	\$2,033.01
		Variance	-1.5%
Per Well	44,399.18	45,076.85	

B. Pike Co – Two Stage

The total treatment costs for these two stage treatments including one standby pump truck (\$1,320) and one standby N₂ pump truck (\$700), an unusually high blender charge of \$10,000, and mobilization (\$6,000) averages \$ 76,120 per well.

The actual costs for the treatments were within a small variation of those projected.

	<u>Projected</u>	<u>Actual</u>	<u>Difference</u>
<u>Equipment</u>			
Pumping-CO ₂ (\$)	68,000	55,810	-12,190
Pumping-N ₂ (\$)	<u>9,200</u>	<u>9,520</u>	320
Total-Pmpng	77,200	65,330	-11,870
<u>Materials</u>			
Proppant (\$)	13,015	12,399	-617
Drayage (\$)	5,985	9,379	3,394
N ₂	<u>9,300</u>	<u>7,374</u>	-1,926
Total-Matls	28,300	29,151	851
Total-Ser Co	105,500	94,481	-11,019
CO ₂ w/Portables	57,600	41,552	-16,048
Blender	10,000	10,000	0
Total w/o Mob	173,100	146,033	-27,067
Mobilization	<u>6,000</u>	<u>6,208</u>	<u>208</u>
Total w/ Mob	\$179,100	\$152,241	-\$26,859
		Variance	-15.0%
Per Well	\$89,550	\$76,121	

- C. The cost of the three groups of CO₂/sand stimulations including unique demonstration costs including mobilizations and Canadian operating personnel expenses were:

Pkg #	Wells	Stages	Total (\$)	\$/ Stg
7	2	2	91,790	45,895
9	3	5	172,588	34,517
10	<u>2</u>	<u>4</u>	<u>152,241</u>	38,060
Totals	7	11	416,619	
		Average	\$37,874/stage	

And averaged \$37,874 per stage.

XV. PRODUCTION COMPARISONS

The production data comparisons include both that from wells stimulated with single and two-stage stimulations, and is presented on a per-stage basis. The per-stage production reported for the wells, which were stimulated with two-stages is one-half of the total. This ability to compare the results from both single and two stage stimulations provides a basis for comparing the greatest number of treatments; and, as will be shown, provides a greater statistical confidence in the results

A. Perry Co – Package # 6

The 17 well test group (18 stages) was comprised of 14 Control Wells (15 Stages) which were stimulated with various treatments, and 3 Candidate Wells (3 stages) which were stimulated with CO₂/Sand.

Stimulation Type	Stages	Wells
Control		
N ₂ gas	13	12
N ₂ foam	<u>2</u>	<u>2</u>
Total	15	14
Candidate		
(CO ₂ /Sand)	<u>3</u>	<u>3</u>
Total	18	17

1. In reviewing the production and well specifics it became obvious that two wells were unique and were removed from the evaluation. One Candidate well, and one Control well were rejected.
 - a. One of the Candidate Wells is now known to be outside of the field and is a poor producer. Well #8 Block #8, is considered to be unique because it is has been established to be in a field fringe area where the Devonian Shale is marginally productive. It has the smallest five year cumulative production of all of the wells, 31.3 MMcf - other than the two which were stimulated with the N₂ foam treatments, and is

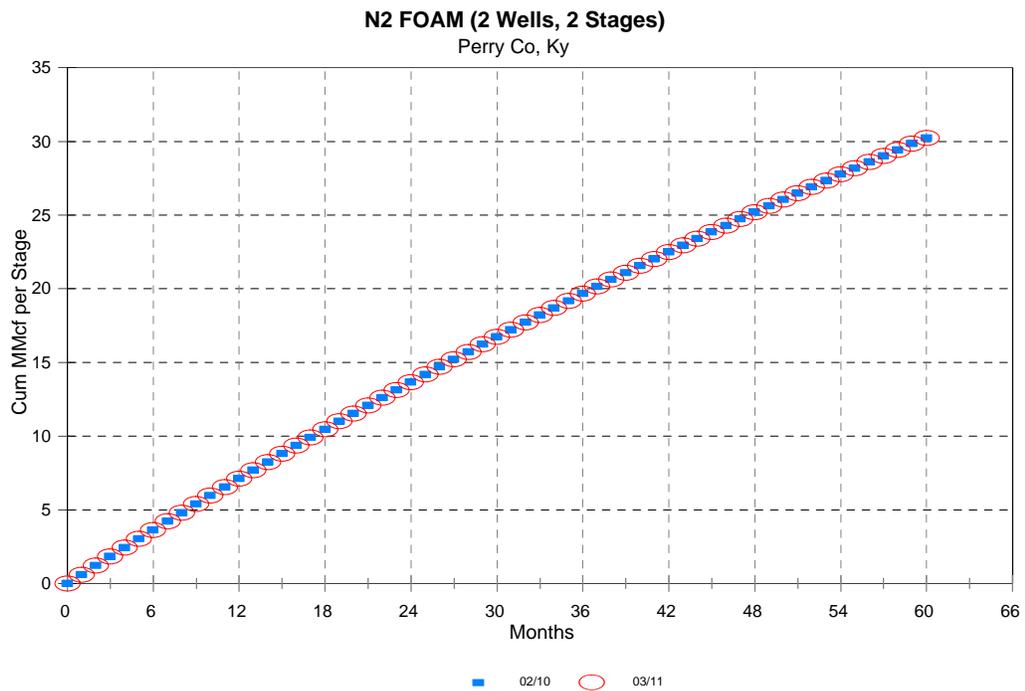
known to be a consequence of its position on the field edge and would have been a poor producer irrespective of the stimulation type.

- b. The Control well, Well #1, Block #3 is unique and considered to be non-typical. It was stimulated with an unusually large single-stage N₂ gas treatment (1.8MMcf), it had the greatest shut-in pressure, 360 psi and the largest five year production, 150.2 MMcf. Because the pressure is so much greater than the other wells, and also because the stimulation volume was twice that of the others; it is, irrespective of the stimulation type considered to be unique and non-representative for the basis of comparison within this study, and was rejected.
2. The remaining 15 well group consisted of 13 Control wells and two Candidate wells for which the stimulation type and number of stages are summarized as follows:

Stimulation Type	Stages	Wells
Control		
N ₂ gas	12	11
N ₂ foam	<u>2</u>	<u>2</u>
Total	14	13
Candidate		
(CO ₂ /Sand)	<u>2</u>	<u>2</u>
Total	16	15

- The two wells (2 stages) which were stimulated with N₂ foam exhibited the smallest production volumes. The five year cumulative production volume, exclusive of any flush production averaged 30.4 MMcf, and 30.4 MMcf per stage.

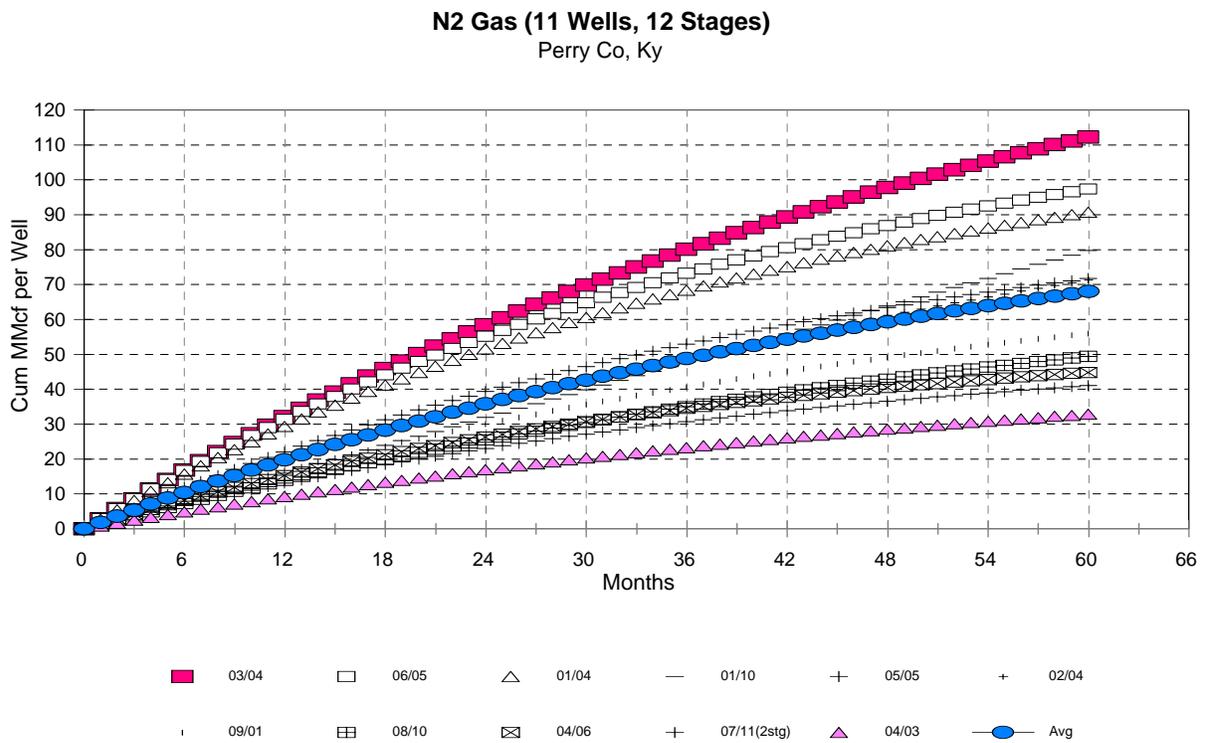
Stimulation	Stages	Wells	Low	High	Mean	Mean
Control			(MMcf/Well)	(MMcf /Well)	(MMcf /Stage)	(MMcf /Well)
N ₂ Foam	2	2	30.4	30.4	30.4	30.4



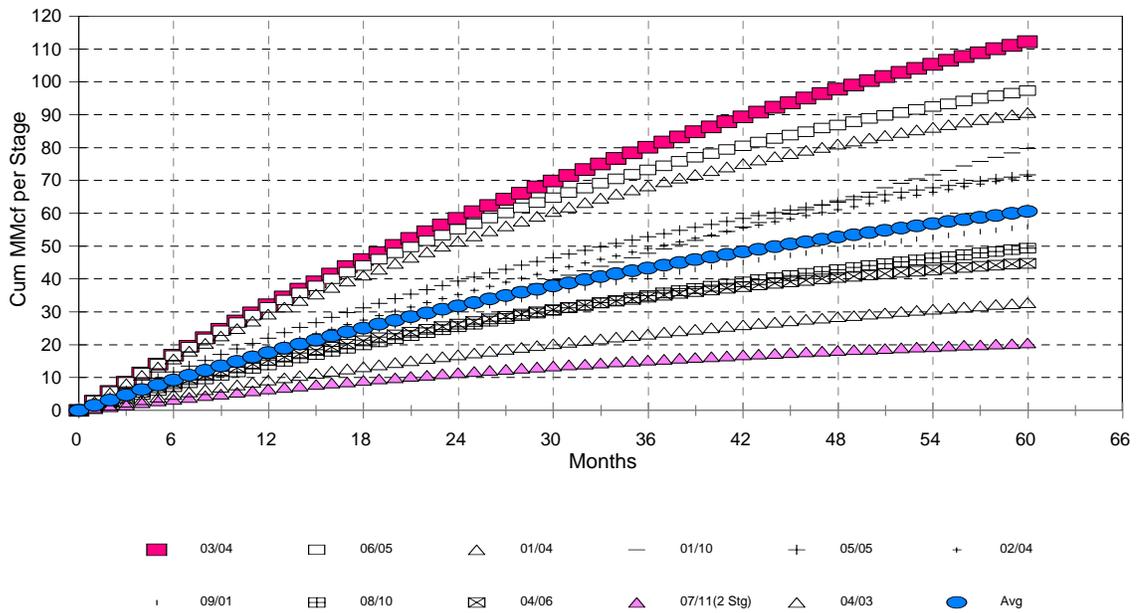
- The 11 wells (12 stages) which were stimulated with N₂ gas produced the largest volumes.

The five year cumulative production volume, exclusive of any flush production ranged from 33.3 to 113.5 MMcf, and averaged 68.0 MMcf per well, and 60.6 MMcf per stage.

	Stages	Wells	Low	High	Mean	Mean
Control			(MMcf/Well)	(MMcf /Well)	(MMcf /Stage)	(MMcf /Well)
N ₂ Gas	12	11	33.3	113.5	60.6	68.0

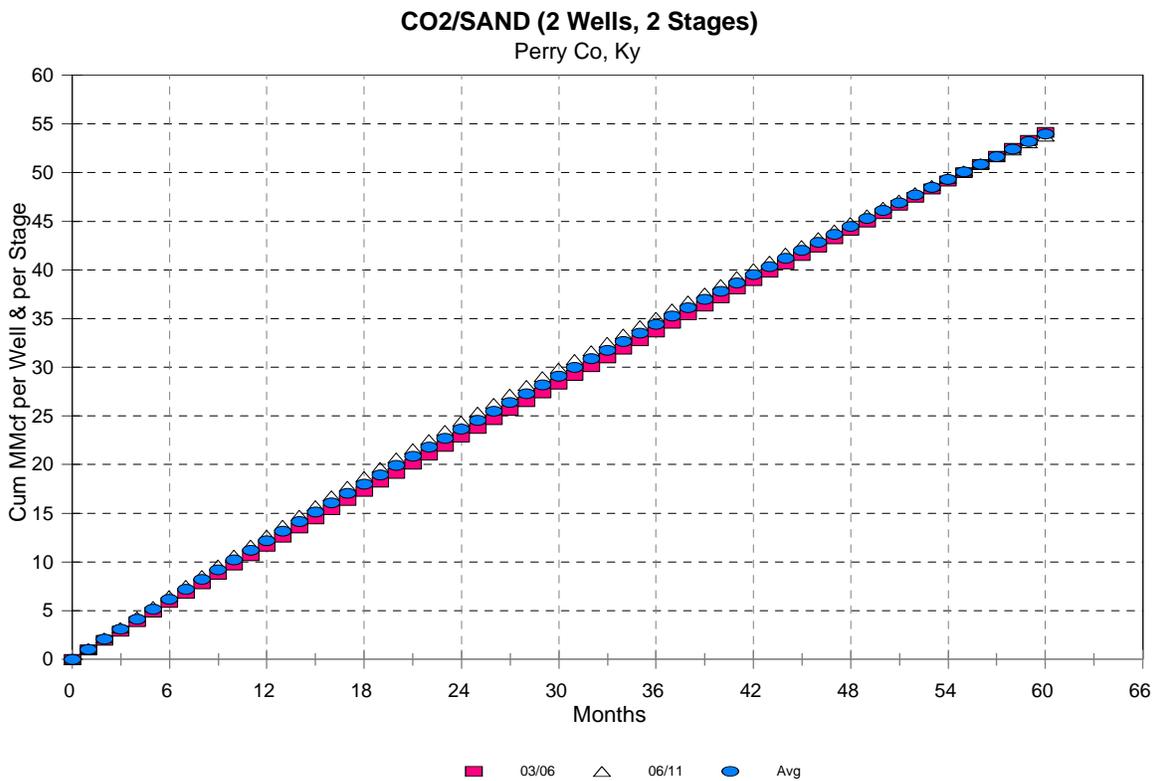


N2 Gas (11 Wells, 12 Stages)
 Perry Co, Ky



5. The 2 Candidate wells (2 stages) which were stimulated with CO₂/sand produced considerably more than those stimulated with the liquid based N₂ foam, but less than those stimulated with N₂ gas. The five year cumulative production volume, exclusive of any flush production ranged from 54.0 to 54.1 MMcf, and averaged 54.0 MMcf per well, and 54.0 MMcf per stage.

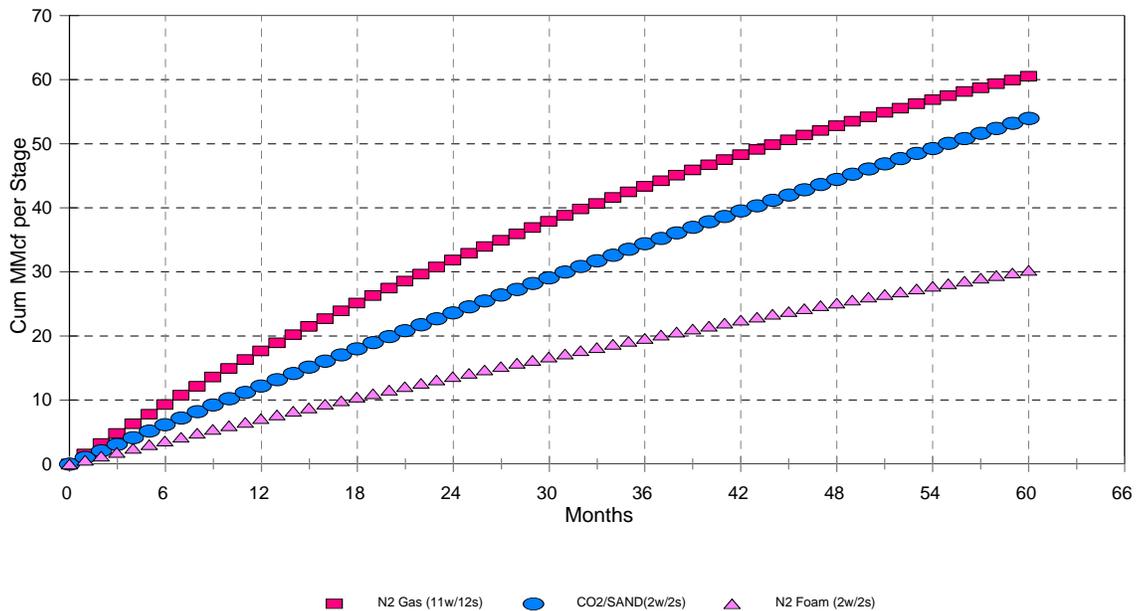
Stimulation	Stages	Wells	Low	High	Mean	Mean
Candidate						
(CO₂/Sand)	2	2	54.0	54.1	54.0	54.0



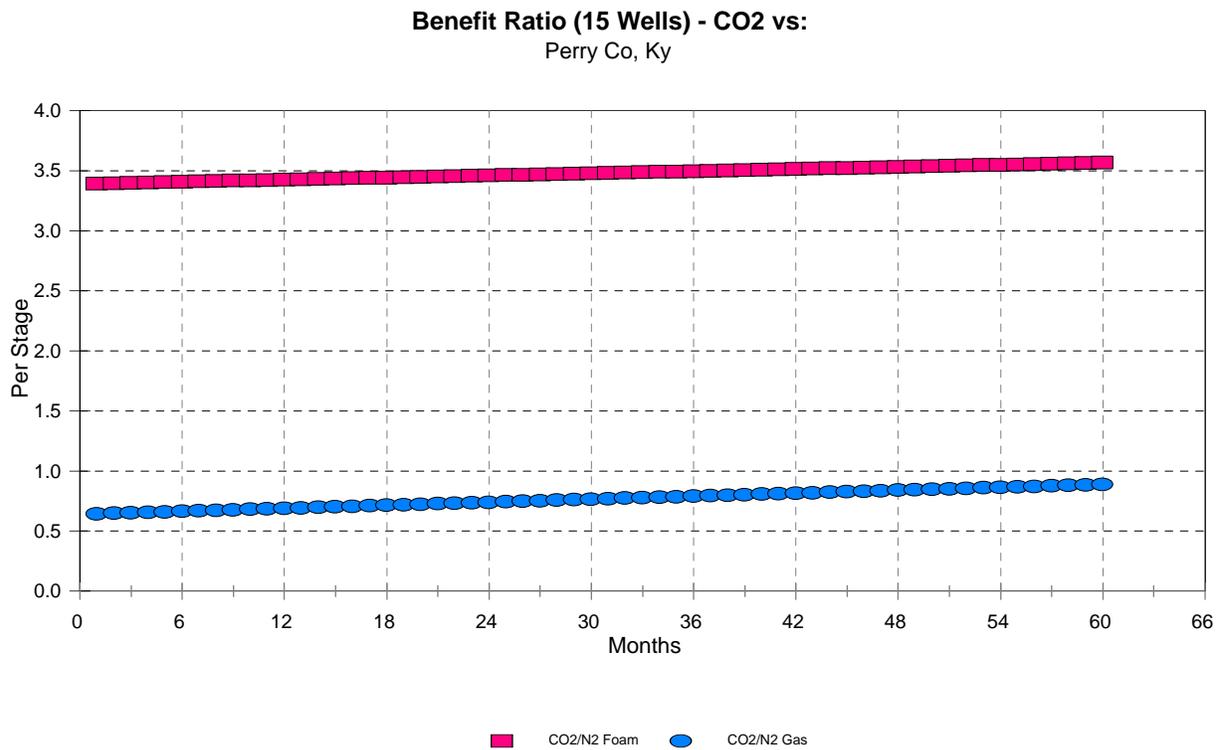
6. The averages for these three stimulation types indicate that the wells treated with the liquid free N₂ gas process resulted in the greatest five year production volumes, 60.6 MMcf per stage as compared to 54.0 and 30.4 MMcf respectively for the CO₂/sand and N₂ foam types.

Stimulation	Stages	Wells	Low	High	Mean	Mean
Control			(MMcf/Well)	(MMcf /Well)	(MMcf /Stage)	(MMcf /Well)
N ₂ Gas	12	11	33.3	113.5	60.6	68.0
N ₂ Foam	<u>2</u>	<u>2</u>	30.4	30.4	30.4	30.4
Total	14	13				
Candidate						
(CO₂/Sand)	<u>2</u>	<u>2</u>	54.0	54.1	54.0	54.0
Total	16	15				

AVERAGES (15 Wells, 16 Stages)
 Perry Co, Ky



- 7. The per-stage benefit ratio for the CO₂/sand stimulations are:
 - a. 0.89 times that for the wells stimulated with N₂ gas (54.0/60.6)
 - b. 3.57 times greater than that for the wells stimulated with N₂ foam (54.0/15.2)



8. The benefit ratio of the CO₂ over the other stimulation types increases with time, and at the end of the five year period is visibly apparent. Possible explanations are:
- a. That the improvement over the N₂ foam stimulation group is a result of the diminishing reservoir pressure being less able to expel the spent stimulation liquids,
 - b. The time dependent increase in the benefit ratio with the N₂ gas group may be a result of the proppant which is contained in the CO₂/Sand stimulations and absent from the N₂ gas treatments:

	1 yr	2 yr	3 yr	4 yr	5 yr
CO ₂ /N ₂ Gas	0.69	0.74	0.79	0.84	0.89
CO ₂ /N ₂ Foam	3.43	3.46	3.50	3.53	3.57

9. Based on very limited shut in wellhead pressure information, the three Candidate Wells had the lowest pressure ratios of the group. And therefore would have been projected to produce lesser gas volumes.

	Well	Nat Prod (MMcfd)	Press (psig)	Press Ratio	Proj 5 Yr SS Prod (MMcf)	Stim
1	#1 Blk #3	Small	360	1.00	150.2	N ₂ gas
2	#7 Blk #11	84	260	0.72	41.8	N ₂ gas
3	#3 Blk #6	84	220	0.61	54.1	CO ₂ /sand
4	#6 Blk #11	0	200	0.56	54.0	CO ₂ /sand
5	#8 Blk #8	0	195	0.54	31.3	CO ₂ /sand

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10. Well specific data

	Well	Pmt #	Nat'l	OF	P	T	TD	Prod Yr 5 Excluding Flush Prod	Stim Type
			Mcf/d	Mcf/d	psig	F	ft	MMcf	
1	1 Blk 3 (Cntrl)	7275 6	TSTM	475	360		3315	150.2, Co metered for 39 mo.	N ₂ Gas REJECTED
2	3 Blk 4							113.5	N ₂ Gas
3	6 Blk 5							99.1	N ₂ Gas
4	1 Blk 4							92.2	N ₂ Gas
5	1 Blk 10 (Cntrl)	2423 9		180	304	63	3454	80.0, Prod for 1 st 19.8 yrs is unk, After that it averaged 1,532 Mcf/mo	Shot, N ₂ Gas (after 16yrs), Weir comp'd also
6	5 Blk 5							72.7	N ₂ Gas
7	2 Blk 4							72.1	N ₂ Gas
8	9 Blk 1							56.7	N ₂ Gas
9	3 Blk 6 (Cand)	8378 0	84	454	220		3809	54.1	110T CO ₂ w/ 429 sks
10	6 Blk 11 (Cand)	8396 2	TSTM	298	200		3916	54.0	150T CO ₂ w/ 402 sks
11	8 Blk 10							50.1	N ₂ Gas
12	4 Blk 6							45.7	N ₂ Gas
13	7 Blk 11 (Cntrl)	8405 5	84	223	260		3856	41.8	N ₂ Gas (2 Stg)
14	4 Blk 3							33.3	N ₂ Gas
15	8 Blk 8 (Cand)	8396 1	TSTM	169	195		3528	31.3	120T CO ₂ w/ 227 sks REJECTED
16	2 Blk 10 (Cntrl)	5428 2	73	103			3870	30.4 co metered w/ 3/11	N ₂ Foam w/ 600s
17	3 Blk 11 (Cntrl)	5488 5	33	133			4204	30.4 co metered w/ 2/10	N ₂ Foam w/ 600s
18	2 Blk 6	3288 1				65	3789	???	Shot, N ₂ Gas (after 9 yr)

B. Pike Co –Package #'s 7, 9, & 10

The 37 stage (21 wells) group addressed herein consists of three groups of wells (Package #'s 7, 9, & 10) in which the Control Wells were stimulated with; CO₂/Sand, N₂ gas, and N₂ foam. One of the wells is located in Martin County, but is only a short distance from the others, and although this one well is not in Pike County these three packages have been combined for this review and are referred to as the "Pike County" group.

Stimulation Type	Stages	Wells
Control		
N ₂ gas	17	9
N ₂ foam	<u>9</u>	<u>5</u>
Total	26	14
Candidate		
(CO ₂ /Sand)	<u>11</u>	<u>7</u>
Total	37	21

CANDIDATE WELL SUMMARY					
Well		ID	Stage(s)	CO ₂	Sand
	Package #7				
1	Well #1	Staton #3	1	120	460
2	Well #2	Stepp #1	<u>1</u>	120	430
		Total	2		
	Package #9				
3	Well #1	S-31	2	108 &	460 &
4	Well #2	Prather #1	<u>2</u>	108	455 &
		Total	4		
	Package #10				
5	Well #1	FH 177	2	120 &	435 &
6	Well #2	FH 178	1	120	353
7	Well #3	FH 179	<u>2</u>	69 & 120	56 & 298
		Total	5		
		Totals	11		

There are two hydraulic stimulation types practiced in this area and the production responses from these stimulation types served as the basis for comparison of the CO₂/Sand stimulation process.

They consisted of N₂ gas, and N₂ foam hydraulic fracturing treatments which are generally described as follows:

- The N₂ gas stimulations are generally of 1 MMscf of N₂ per stage which are pumped at rates of approximately 100 Mcf per minute.
 - The N₂ foam stimulations are approximately 75 quality with 20/40 sand proppant volumes generally ranging from 50,000 to 128,500 lbs, although one well which had been stimulated some years earlier had only 9,000 lbs.
 - The CO₂/Sand stimulations generally employed 120 tons of liquid CO₂ with 20/40 sand proppant volumes generally ranging from 30,000 to 46,000 lbs. One well was difficult to treat and is firmly believed to be for geologic reasons because of the high pressure response prior to the arrival of proppant at the formation, and therefore irrespective of stimulation type. Only 5,600 and 29,800 lbs were placed in the first and second stages respectively. It also had the lowest production rate from any of the liquid-free stimulation (CO₂/Sand & N₂ gas) groups.
1. In reviewing the production and well specifics it became obvious that one of the Candidate wells was unique and it was removed from the evaluation. The five year cumulative production from the seven Candidate Wells (11 stages, 7 wells) ranged from 9.1 to 174.1 MMcf per stage. However, one of the Candidate wells, FH 179 was difficult to treat and would have responded the same irrespective of the treatment type and is considered to be non-representative. If well FH 179 is removed, then the range of the 9 stage Candidate well group (6 wells) is from 26.3 to 174.1 MMcf per stage.

Candidate Well Summary						
	Candidate Well	Stim Type	Stage 1 Proppant (M lbs)	Stage 2 Proppant (M lbs)	5-Yr Cum SS Prod (MMcf/stg)	
1	Staton-3	CO ₂ /Sand	46.0	N/A	174.1	
2	S-31	CO ₂ /Sand	42.0	46.0	129.0	
3	FH-178	CO ₂ /Sand	35.3	N/A	56.4	
4	Prather-1	CO ₂ /Sand	45.5	47.5	51.3	
5	FH-177	CO ₂ /Sand	43.5	35.0	31.8	
6	Stepp-1	CO ₂ /Sand	43.0	N/A	26.3	
7	FH-179*	CO ₂ /Sand	5.6	29.8	9.1	REJECTED

Which after removing the problem well, FH-179 results in the following groupings:

Stimulation Type	Stages	Wells
Control		
N ₂ gas	17	9
N ₂ foam	<u>9</u>	<u>5</u>
Total	26	14
Candidate		
(CO ₂ /Sand)	<u>9</u>	<u>6</u>
Total	35	20

2. The five year cumulative production from the:

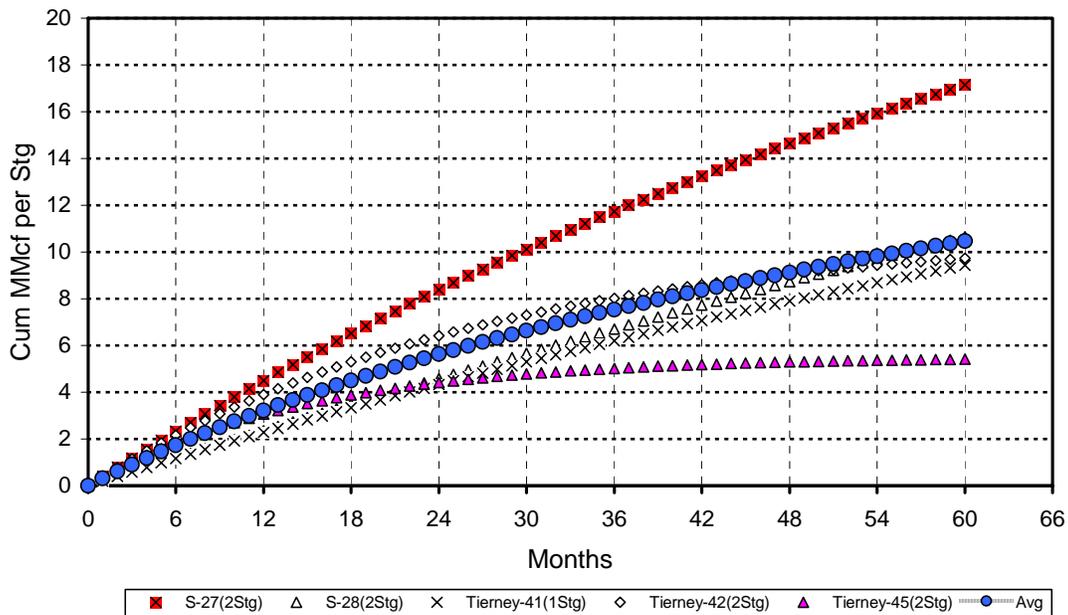
a. 14 Control wells (26 stages) ranged from 5.4 to 46.2 MMcf per stage.

	Control Well	Stim Type	Stage 1 Proppant (M lbs)	Stage 2 Proppant (M lbs)	5-Yr Cum SS Prod (MMcf/stg)
1	S-29	N ₂ Gas	0.0	0.0	46.2
2	Rogers-5	N ₂ Gas	0.0	0.0	28.2
3	S-32	N ₂ Gas	0.0	0.0	26.8
4	SB-3	N ₂ Gas	0.0	0.0	25.1
5	Varney-6	N ₂ Gas	0.0	N/A	23.3
6	S-30	N ₂ Gas	0.0	0.0	19.0
7	S-27	N ₂ Foam	50.0	50.0	17.1
8	Varney-14	N ₂ Gas	0.0	0.0	15.2
9	Varney-15	N ₂ Gas	0.0	0.0	15.2
10	S-28	N ₂ Foam	74.0	70.0	10.7
11	Tierney-42	N ₂ Foam	120.0	128.5	9.7
12	Tierney-41	N ₂ Foam	9.0	N/A	9.4
13	FH-180	N ₂ Gas	0.0	0.0	7.5
14	Tierney-45	N ₂ Foam	120.0	122.0	5.4

- b. Six Candidate wells (9 stages) ranged from 26.3 to 174.1 MMcf per stage – see table above .
- 3. The results of the five year cumulative gas production from this 20 well group are:
 - a. The five year cumulative production volumes from the wells which had been stimulated with N₂ foam were the poorest and ranged between 10.8 and 34.3 MMcf per well and averaged 19.1 MMcf per well (10.5 MMcf per stage).

Stimulation	Stages	Wells	Low	High	Mean	Mean
			(MMcf/Well)	(MMcf /Well)	(MMcf /Stage)	(MMcf /Well)
N ₂ Foam	9	5	10.8	34.3	10.5	19.1

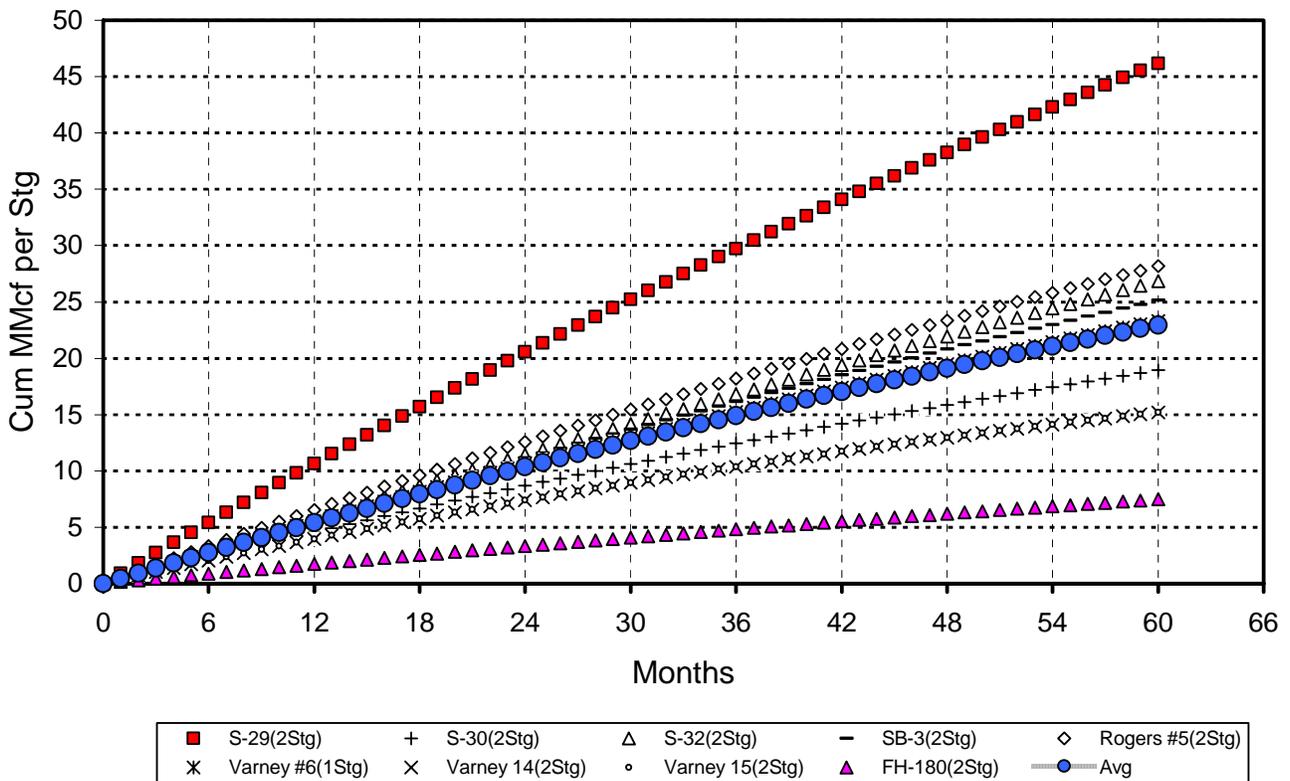
Stim Type: N2 Foam (5 Wells, 9 Stages) - Pike Co, KY



- b. The wells which were stimulated with N₂ gas produced considerably more than those stimulated with the liquid based N₂ foam, but considerably less than those stimulated with the CO₂/sand stimulation technique.

Stimulation	Stages	Wells	Low	High	Mean	Mean
Control			(MMcf/Well)	(MMcf /Well)	(MMcf /Stage)	(MMcf /Well)
N ₂ Gas	17	9	15.0	92.4	22.9	50.1

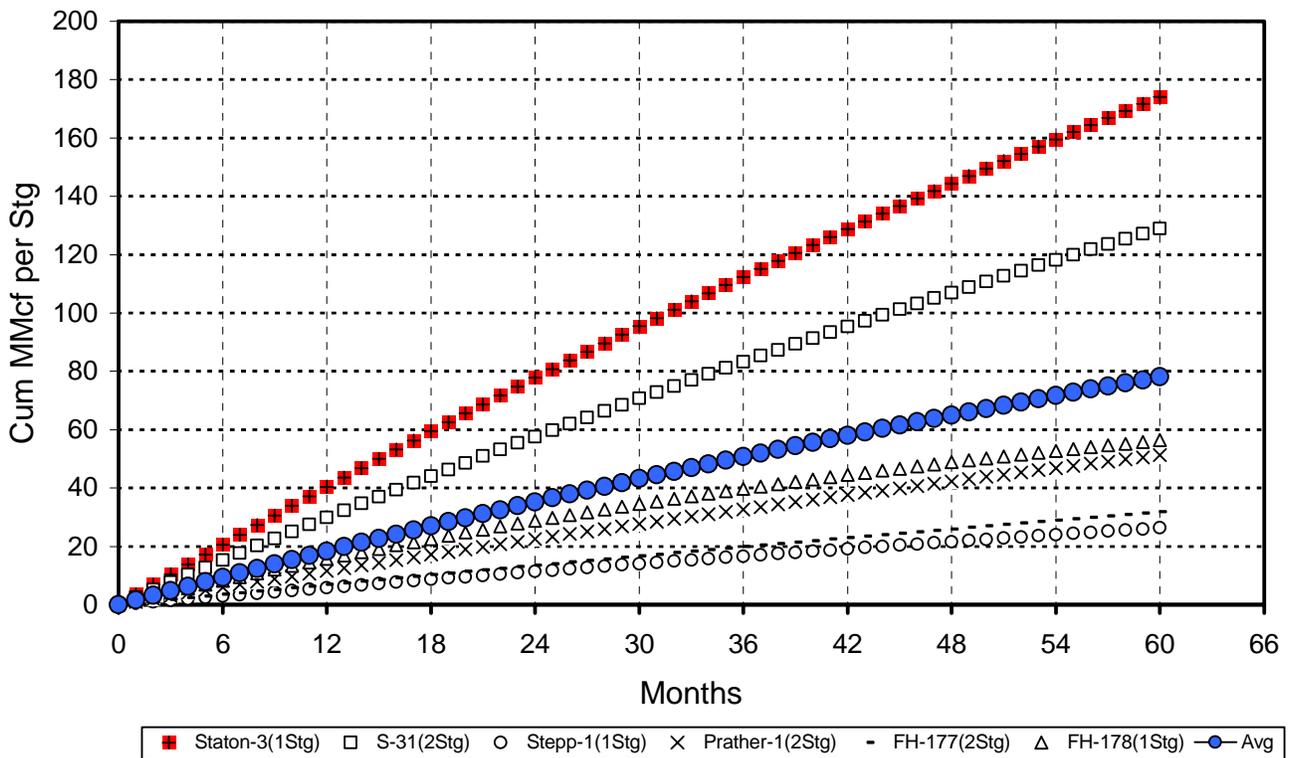
Stim Type: N₂ Gas (9 Wells, 17 Stages) - Pike Co, KY



- c. The wells which were stimulated with CO₂/sand had the largest production volumes. The five year cumulative production volumes ranged between 26.3 and 257.9 MMcf per well and averaged 116.5 MMcf per well (78.1 MMcf per stage).

Stimulation	Stages	Wells	Low	High	Mean	Mean
Candidate						
CO ₂ /Sand	9	6	26.3	257.9	78.1	116.5

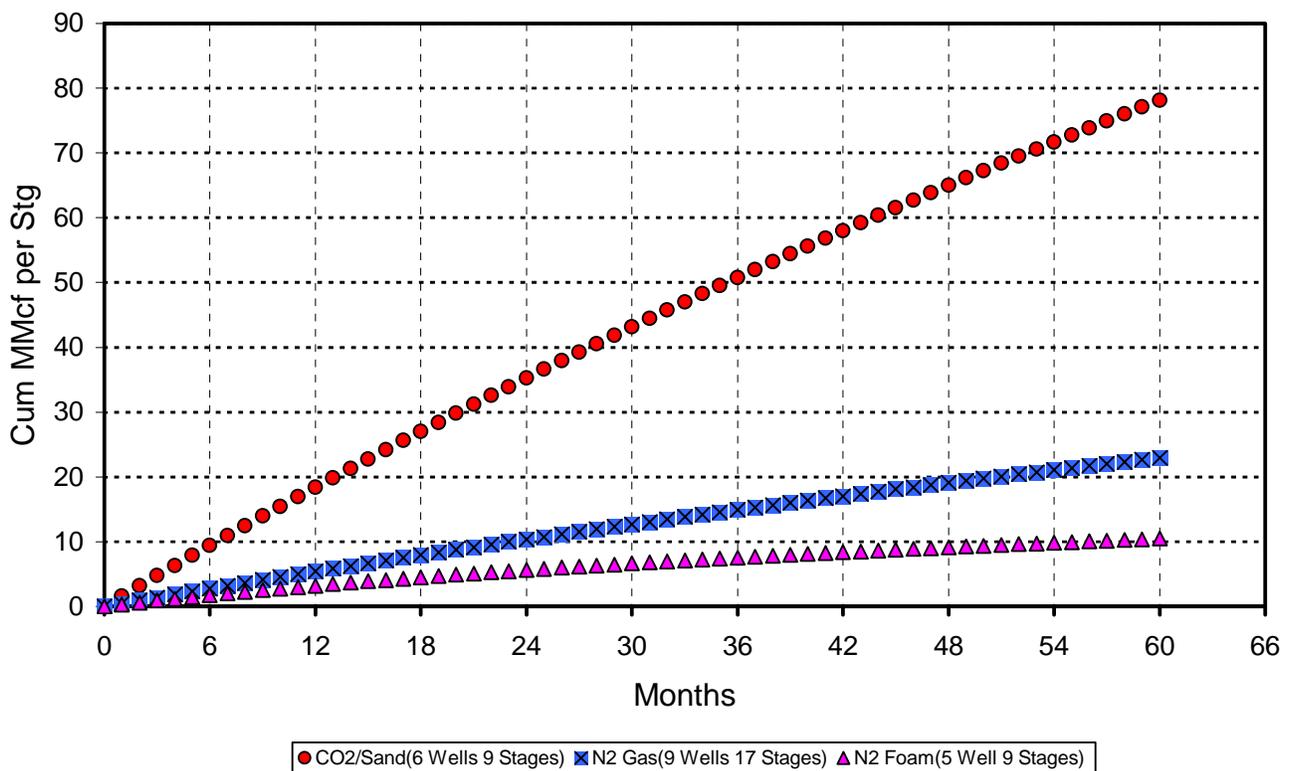
Stim Type: CO₂/Sand (6 Wells, 9 Stages) - Pike Co, KY



- d. In comparing the production responses from it is obvious that the wells which were simulated with the CO₂/Sand process resulted in the superior production, and that the wells which were stimulated with N₂ foam had the lowest production volumes.

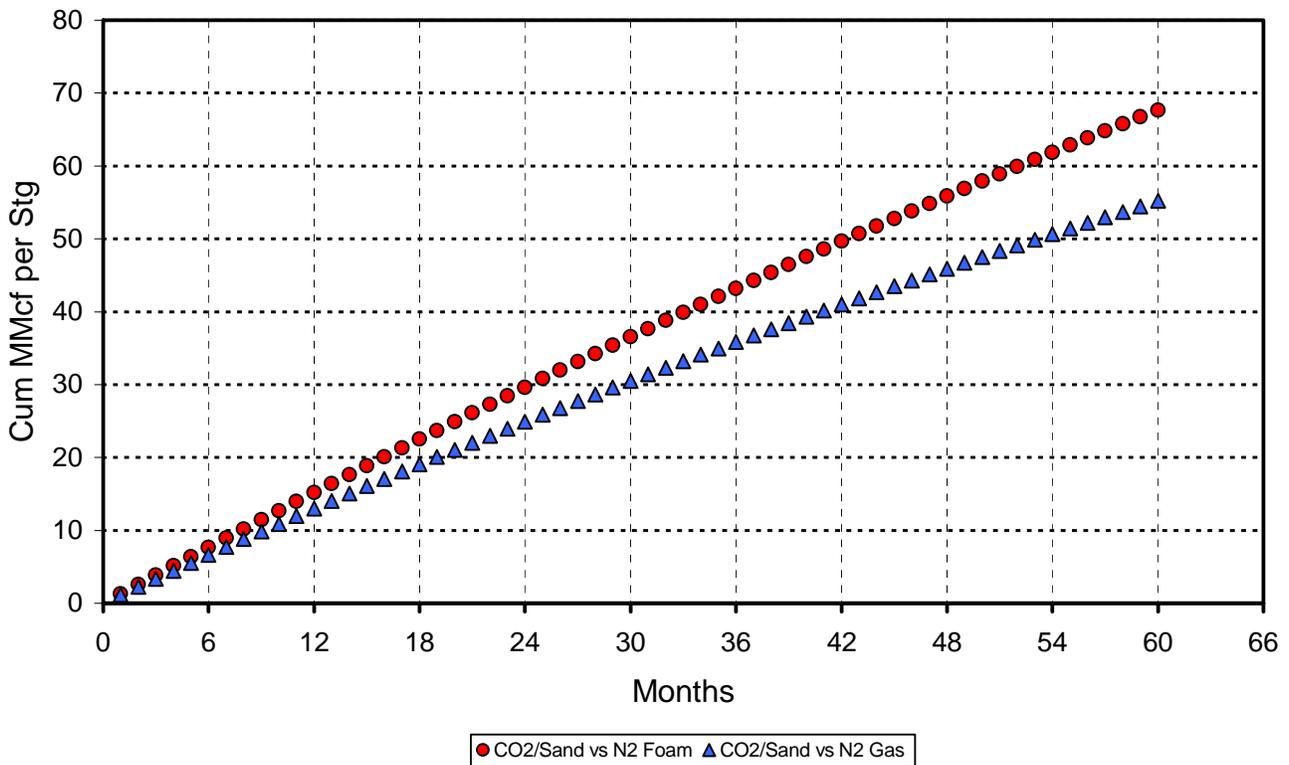
Stimulation	Stages	Wells	Low	High	Mean	Mean
Control			(MMcf/Well)	(MMcf /Well)	(MMcf /Stage)	(MMcf /Well)
N ₂ Gas	17	9	15.0	92.4	22.9	50.1
N ₂ Foam	9	5	10.8	34.3	10.5	19.1
Total	26	14				
Candidate						
CO ₂ /Sand	9	6	26.3	257.9	78.1	116.5
Total	35	20				

Averages (20 Wells, 35 Stages) - Pike Co, KY



- 4. The five year per stage incremental benefit of the production from the CO₂/Sand stimulations is significant resulting in an improvement of 67.7 MMcf per stage over that from N₂ foam stimulations and 55.2 MMcf per stage improvement over N₂ gas stimulations.

**Per - Stage Incremental Production - Pike Co, KY (35 Stages)
CO₂/Sand vs:**



5. The per-stage average five-year cumulative volumes from the wells stimulated with the CO₂/sand stimulation process exceeded that from the:
 - a. N₂ foam stimulations by 67.6 MMcf (78.1-10.5) per-stage, resulting in a CO₂/Sand benefit ratio of 7.4 times (78.1/10.5).
 - b. N₂ gas stimulations by 55.2 MMcf (78.1-22.9) per-stage, resulting in a CO₂/Sand benefit ratio of 3.4 times (78.1/22.9).

6. The benefit ratio of the CO₂/Sand stimulation over that of the N₂ foam stimulations is observed to increase from 5.0 to 6.5 over the five-year producing period whereas that for the N₂ gas stimulations does not. This response indicates that the production rate for the CO₂/Sand and N₂ gas groups are not declining as rapidly as that from the N₂ foam group and is considered to be a consequence of the load water from the N₂ foam stimulations becoming an increasing impediment to gas production as the reservoir pressure diminishes.

Year	1	2	3	4	5
CO ₂ Prod/N ₂ foam Prod	5.0	5.5	5.9	6.2	6.5
CO ₂ Prod/N ₂ gas Prod	3.0	3.0	3.0	3.0	3.0

7. Well specific data

Stimulation Treatments				
Well	Pmt #	Stage 1 Proppant	Stage 2 Proppant	5-Yr Cum SS Prod
		M lbs	M lbs	MMcf/stg
N ₂ Foam (9 stages & 5 wells)				
S-27	84699	50.0	50.0	17.1
S-28	84700	74.0	70.0	10.7
Tierney-41	32995	9.0		9.4
Tierney-42	81938	120.0	128.5	9.7
Tierney-45	81926	120.0	122.0	5.4
			Avg	10.5
N ₂ Gas (17 stages & 9 wells)				
FH-180	84766	0.0	0.0	7.5
Rogers-5	82963	0.0	0.0	28.2
S-29	84765	0.0	0.0	46.2
S-30	84766	0.0	0.0	19.0
S-32	80701	0.0	0.0	26.8
SB-3	84184	0.0	0.0	25.1
Varney-6	72782	0.0	N/A	23.3
Varney-14	79111	0.0	0.0	15.2
Varney-15	79112	0.0	0.0	15.2
			Avg	22.9
CO ₂ /Sand (11 stages & 7 wells)				
FH-177	84498	43.5	35.0	31.8
FH-178	84529	35.3	N/A	56.4
FH-179*	84575	5.6	29.8	9.1
Prather-1	84560	45.5	47.5	51.3
S-31	84819	42.0	46.0	129.0
Staton-3	83739	46.0	N/A	174.1
Stepp-1	83706	43.0	N/A	26.3
* problem well – see dialog			Avg	68.3
CO ₂ /Sand (9 stages & 6wells)			Avg	78.1

XVI. COST COMPARISONS

A. Perry Co – Package # 6

1. CO₂/sand stimulations

The cost of the three CO₂/sand stimulations including unique demonstration costs including mobilizations and Canadian operating personnel expenses averaged \$45,077 per well, and because these wells were stimulated with a single stage treatment the per stage costs would be the same. It has been projected that if the service were provided locally, that the costs would be on the order of \$37,000.

2. Conventional Stimulations

The commercially available technology which provides the best results is the liquid free N₂ gas stimulations. For single stage treatments of the size (80 to 100 Mscf) and rate (900 Mscf per minute) the stimulation costs are projected to be on the order of \$26,000.

3. Comparison CO₂ vs conventional stimulation technologies

The stimulation costs based on the produced gas volumes for the different stimulation processes are:

a. CO ₂ /sand	\$0.69 per Mcf	(\$37,000 / 54.0 MMcf)
b. N ₂ gas	\$0.43 per Mcf	(\$26,000 / 60.6 MMcf)
c. N ₂ foam	\$0.79 per Mcf	(\$24,000 / 30.4 MMcf)

B. Pike Co – Package #'s 7, 9, &10

The cost of the three CO₂/sand stimulations including unique demonstration costs including mobilizations and Canadian operating personnel expenses averaged \$37,874 per stage, and because these wells were stimulated with a single stage treatment the per stage costs would be the same. It has been projected that if the service were provided locally, that the costs would be on the order of \$37,000.

1. Conventional Stimulations

The commercially available technology which provides the best results is the liquid free N₂ gas stimulations. For single stage treatments of the size (80 to 100 Mscf) and rate (900 Mscf per minute) the stimulation costs are projected to be on the order of \$26,000.

2. Comparison CO₂ vs conventional stimulation technologies

The stimulation costs based on the produced gas volumes for the different stimulation processes are:

a. CO ₂ /sand	\$0.47 per Mcf	(\$37,000 / 78.1 MMcf)
b. N ₂ gas	\$1.14 per Mcf	(\$26,000 / 22.9 MMcf)
c. N ₂ foam	\$2.29 per Mcf	(\$24,000 / 10.5 MMcf)

XVII. CONCLUSIONS

A. Overall – Both Test Areas (Perry & Pike County)

1. Full proppant volume (40,000 pound) liquid CO₂/sand stimulations were executed in the Devonian Shale in both the Perry County (3 Stages) and Pike County (5 stages) test areas with the exception of one well FH-179. It is considered to be an anomaly because the treating pressure was abnormally high and its nature is irrespective of the stimulation type.
2. The maximum sand concentration for CO₂/sand stimulations being pumped at 44 barrels per minute is approximately 4.3 pounds per gallon. This was the maximum rate available from the blender and the maximum sand acceptance rate may have been greater.

B. Production Comparisons

1. Perry Co

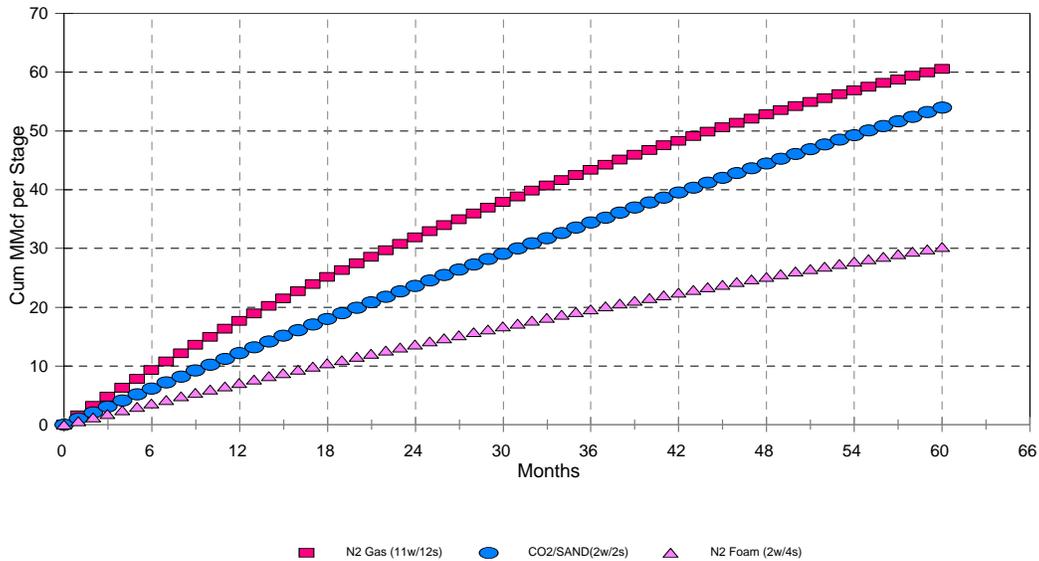
After rejecting two wells on the basis that they were non representative and would add bias to the statistically small sample a 15 well group resulted. It consisted of 13 Control wells and two Candidate wells for which the stimulation type and number of stages are summarized as follows:

Stimulation Type	Stages	Wells
Control		
N ₂ gas	12	11
N ₂ foam	<u>2</u>	<u>2</u>
Total	14	13
Candidate		
(CO ₂ /Sand)	<u>2</u>	<u>2</u>
Total	16	15

- a. The per stage cumulative production comparisons indicated that the five year produced volumes from those wells stimulated with N₂ gas stimulations slightly out performed those stimulated with CO₂/Sand. The five year cumulative productions were 60.6 and 54.0 MMcf per stage respectively.
- b. The five year per stage production from the wells stimulated with N₂ foam was considerably less than that from the other treatments, and averaged 30.4 MMcf.

Stimulation	Stages	Wells	Low	High	Mean	Mean
Control			(MMcf/Well)	(MMcf /Well)	(MMcf /Stage)	(MMcf /Well)
N ₂ Gas	12	11	33.3	113.5	60.6	68.0
N ₂ Foam	<u>2</u>	<u>2</u>	30.4	30.4	30.4	30.4
Total	14	13				
Candidate						
(CO ₂ /Sand)	<u>2</u>	<u>2</u>	54.0	54.1	54.0	54.0
Total	16	15				

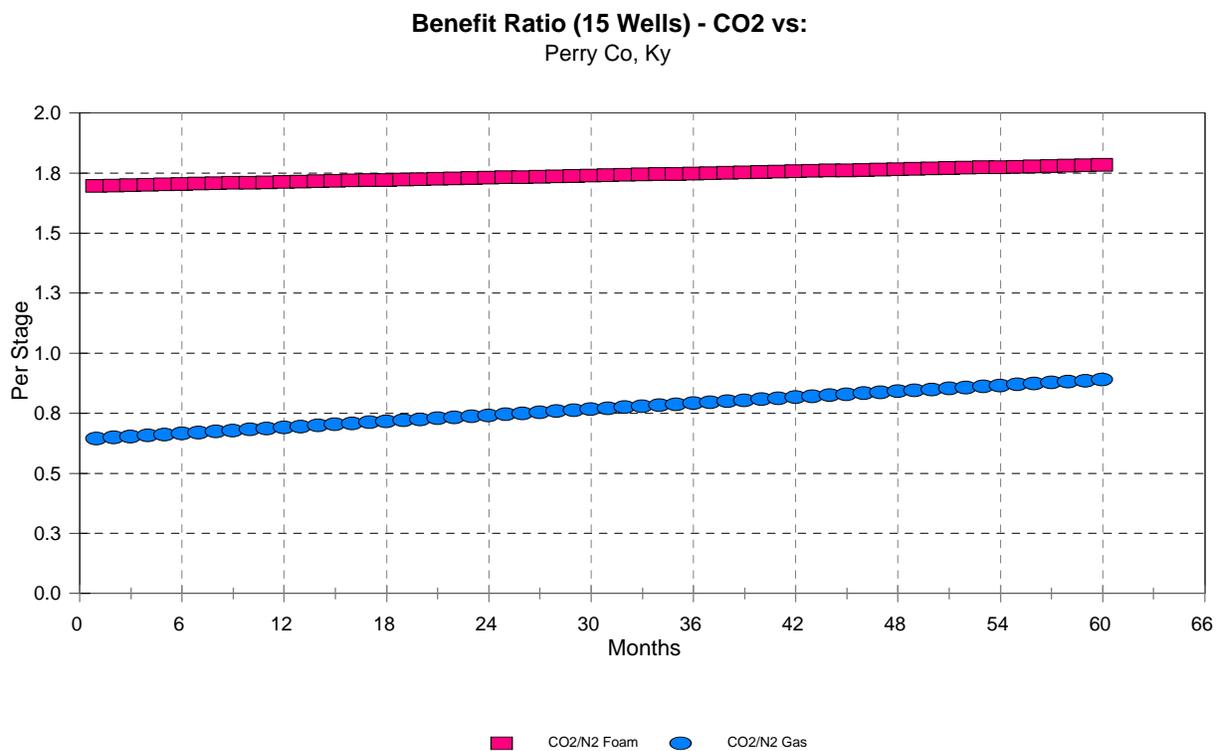
AVERAGES (15 Wells, 16 Stages)
Perry Co, Ky



c. The per-stage benefit ratio for the CO₂/sand stimulations are:

(1) 0.89 times that for the wells stimulated with N₂ gas (54.0/60.6)

(2) 1.78 times greater than that for the wells stimulated with N₂ foam (54.0/30.4)



2. The benefit ratio of the CO₂ over the other stimulation types increases with time, and at the end of the five year period is visibly apparent. Possible explanations are:

- (1) That the improvement over the N₂ foam stimulation group is a result of the diminishing reservoir pressure being less able to expel the spent stimulation liquids,
- (2) The time dependent increase in the benefit ratio with the N₂ gas group may be a result of the proppant which is contained in the CO₂/Sand stimulations and absent from the N₂ gas treatments:

	1 yr	2 yr	3 yr	4 yr	5 yr
CO ₂ /N ₂ Gas	0.69	0.74	0.79	0.84	0.89
CO ₂ /N ₂ Foam	1.71	1.73	1.75	1.77	1.79

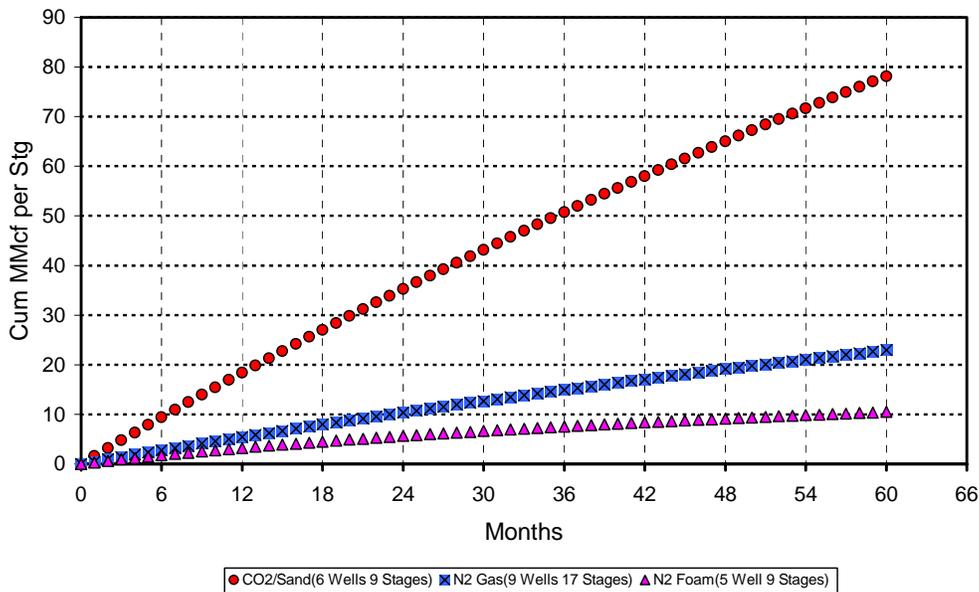
3. Pike Co

- a. The CO₂/Sand stimulations were readily executed and the design proppant volumes were, excepting one well, FH-179 generally placed without difficulty. The production from this well was significantly less than that from the other wells which were stimulated with CO₂/Sand and because of the difficulty in treating it is considered to be non conventional and was rejected resulting in the following well groupings:

Stimulation Type	Stages	Wells
Control		
N ₂ gas	17	9
N ₂ foam	<u>9</u>	<u>5</u>
Total	26	14
Candidate		
(CO ₂ /Sand)	<u>9</u>	<u>6</u>
Total	35	20

- b. In the remaining 35 stage (20 wells) comparison of what are considered to be typical responses, the CO₂/Sand stimulations resulted in a significant improvement over the other treatment types.
- c. The five year cumulative production volume from the wells which were stimulated with CO₂/Sand is 78.1 MMcf per stage versus 22.9 and 10.5 MMcf for wells stimulated with N₂ gas and N₂ foam respectively.

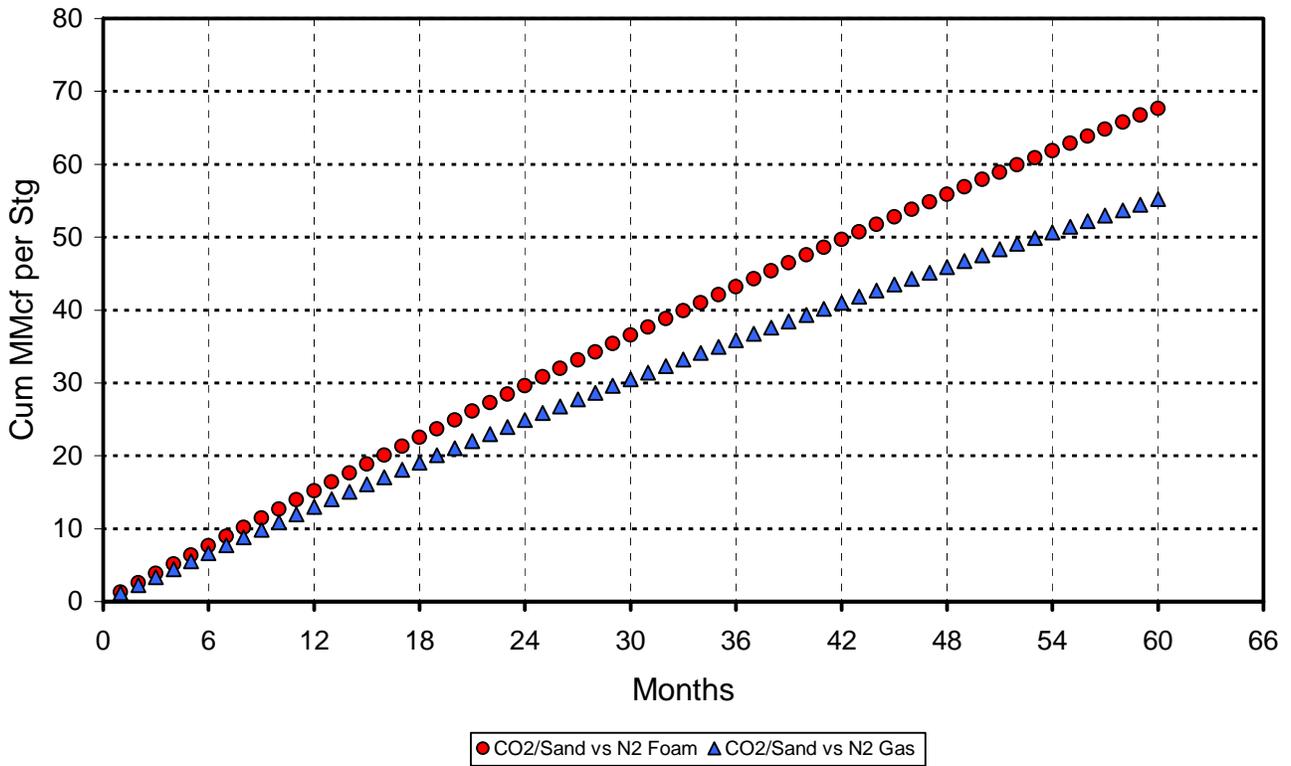
Averages (20 Wells, 35 Stages) - Pike Co, KY



Stimulation	Stages	Wells	Low (MMcf/Well)	High (MMcf /Well)	Mean (MMcf /Stage)	Mean (MMcf /Well)
Control						
N ₂ Gas	17	9	7.5	46.2	22.9	50.1
N ₂ Foam	9	5	5.4	17.1	10.5	19.1
Total	26	14				
Candidate	9	6	26.3	174.1	78.1	116.5
Total	35	20				

- d. The five year per stage incremental benefit of the production from the CO₂/Sand stimulations is significant resulting in an improvement of 67.7 MMcf over that from N₂ foam stimulations and 55.2 MMcf improvement over N₂ gas stimulations.

**Per - Stage Incremental Production - Pike Co, KY (35 Stages)
CO₂/Sand vs:**

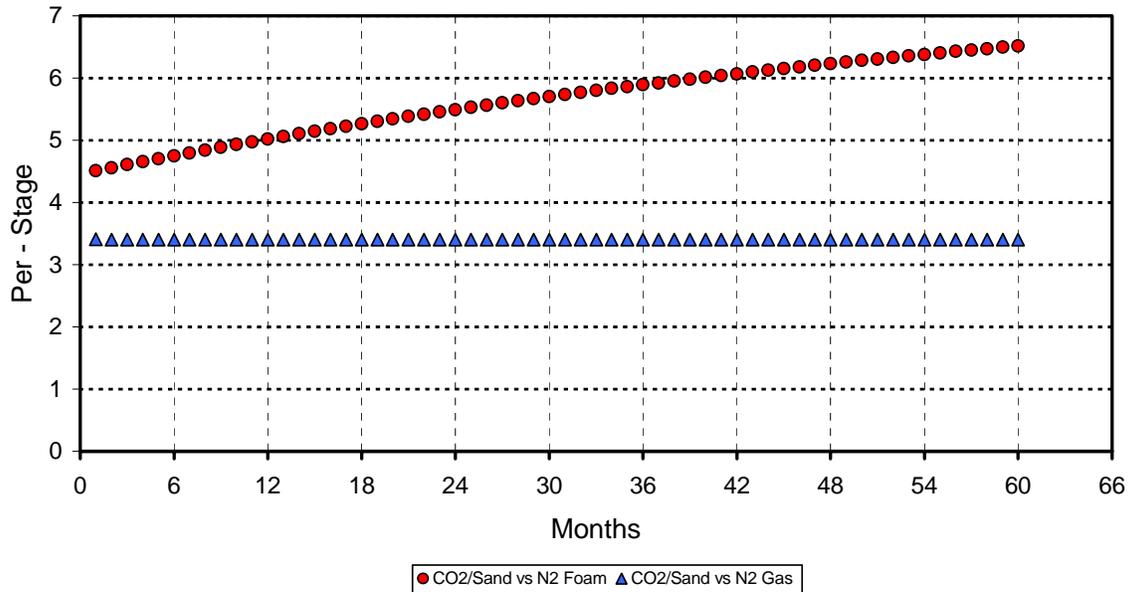


e. The per-stage benefit ratio for the CO₂/sand stimulations are:

(1) 3.41 times that for the wells stimulated with N₂ gas (78.1/22.9)

(2) 7.48 times greater than that for the wells stimulated with N₂ foam (78.1/10.5)

**Per - Stage Benefit Ratio - Pike Co, KY (37 Stages)
 CO₂/Sand vs:**



f. The benefit ratio of the CO₂ over the other stimulation types increases with time, and at the end of the five year period is visibly apparent. Possible explanations are:

(1) That the improvement over the N₂ foam stimulation group is a result of the diminishing reservoir pressure being less able to expel the spent stimulation liquids,

- (2) The time dependent increase in the benefit ratio with the N₂ gas group may be a result of the proppant which is contained in the CO₂/Sand stimulations and absent from the N₂ gas treatments:

	1 yr	2 yr	3 yr	4 yr	5 yr
CO ₂ /N ₂ Gas	3.4	3.4	3.4	3.4	3.4
CO ₂ /N ₂ Foam	5.0	5.5	5.9	6.2	6.5

C. Cost Comparisons

a. Perry Co

- (1) The most cost effective stimulation process is N₂ gas at \$0.43 per Mcf
- (2) The stimulation cost of the CO₂/sand process is \$0.69 per Mcf, and more expensive than that for N₂ gas treatments.
- (3) The least cost effective stimulation process is N₂ foam at \$0.79 per Mcf

b. Pike Co

- (1) The most cost effective stimulation process is CO₂/sand at \$0.47 per Mcf.
- (2) The stimulation cost of the N₂ gas process is \$1.14 per Mcf.
- (3) The least cost effective stimulation process is N₂ foam at \$2.29 per Mcf

D. Other

a. Perry Co

- (1) Based on very limited shut in wellhead pressure information, the three Candidate Wells had the lowest pressure ratios of the group. And therefore would have been projected to produce lesser gas volumes.

		Nat Prod	Press	Press	Proj 5 Yr SS Prod	
	Well	(MMcfd)	(psig)	Ratio	(MMcf)	Stim
1	#1 Blk #3	Small	360	1.00	150.2	N ₂ gas
2	#7 Blk #11	84	260	0.72	41.8	N ₂ gas
3	#3 Blk #6	84	220	0.61	54.1	CO ₂ /sand
4	#6 Blk #11	0	200	0.56	54.0	CO ₂ /sand
5	#8 Blk #8	0	195	0.54	31.3	CO ₂ /sand

- (2) In every instance which could be verified a cement loss to the formations of from 25 to 55 cu ft was observed.
- (3) The CO₂ decay time following the treatments exhibited the following responses:
- (i) An increase in CO₂ concentrations was measured during the second producing week,
 - (ii) Higher production rates result in an accelerated reduction in the CO₂ concentrations, apparently irrespective of the quantity of CO₂ used. That is, the CO₂ concentration may have been more influenced by the production rate rather than the volume of CO₂ pumped.

In summary there are several items which should be recognized:

- The data set although limited, and that because of the small quantity of data that the statistical confidence is lacking , but it is clear that the CO₂/sand stimulation technology is the superior choice for stimulating the Devonian shales in Pike County.
- It is evident that in Pike county the stimulation costs based on the produced gas volumes resulting from the CO₂/sand stimulation process are considerably lower than that for the other treatment types.

Stimulation Type	Stimulation Cost (\$/Mcf)
CO ₂ /sand	\$0.47
N ₂ gas	\$1.14
N ₂ foam	\$2.29

- The ability to routinely obtain CO₂ for these treatments ins the most significant element in moving this technology forward. If Co2 were readily available for this process, Then it could very likely be the stimulation process of choice.

XVIII. DELIVERABLES

A. Target Area Work Plans

The descriptions of the Control and Candidate Wells were included with the submittal packages for each individual group with the request for DOE cost-shared support

B. Geophysical Well Logs

The well logs for both the Control Wells and in most cases for the Candidate Wells were included with the submittal packages, in some instances they were also included in the Final Reports for each of the 24 groups.

C. TV Camera Tape

D. Well Stimulation Plans

The stimulation plans have been included in the seven Final Reports which have been submitted for each approved well group.

E. Stimulation Records

The stimulation plans have been included in the seven Final Reports which have been submitted for each approved well group.

F. Production and Pressure Records

The production and pressure records have been plotted and included in the seven Final Reports which have been submitted for each approved well group, and summarized in this Report..

G. Well Data

The well data for both the Control and Candidate Wells were included with the submittal packages, and in the seven Final Reports which have been submitted for each approved well group, and summarized in this Report..

H. Final Reports

1. Phase I - This document
2. Pkg #'s 6&7 – Submitted
3. Pkg # 9 – Submitted
4. Pkg # 10 – Submitted

These Reports include all of the well specific information on all of the wells situated in eastern Kentucky and stimulated under the provisions of this contract.

Final Report – Phase I

Contract #DE-AC21-90MC26025 – “Production Verification Tests”

This completes the efforts to summarize the specifics and findings of these demonstrations of the liquid-free stimulation process. More detailed well-specific information i.e.: production plots, figures, logs, etc. relative to these efforts accompany the individual reports for each group.

Respectfully Submitted,

Raymond L. Mazza, P.E.
Project Manager