The Brave New World of EOR
New Injectants and Huff-n-Puff Flooding of Hydraulically Fractured Wells

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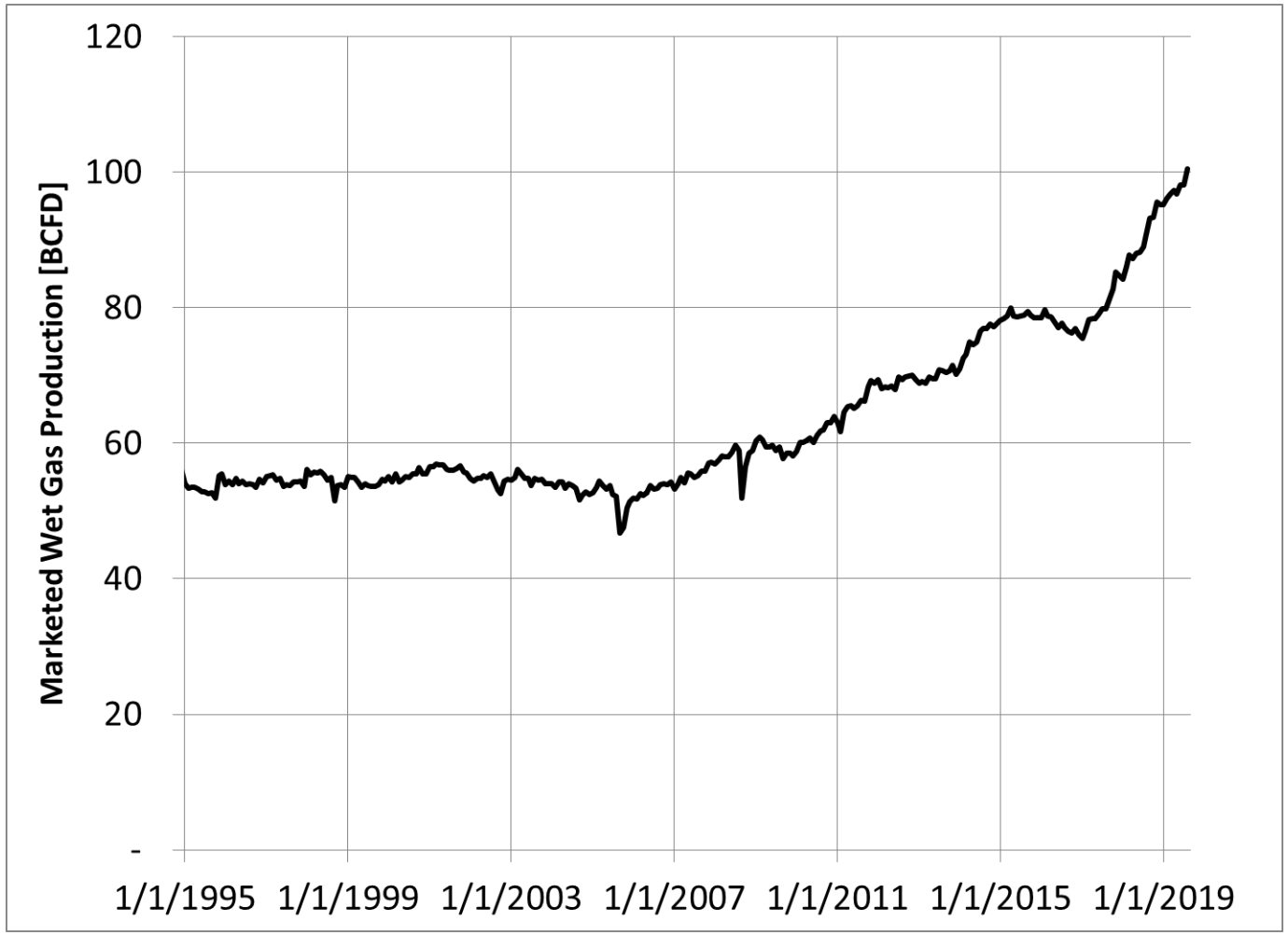
U.S. Production Increases have Disrupted the Petroleum Industry

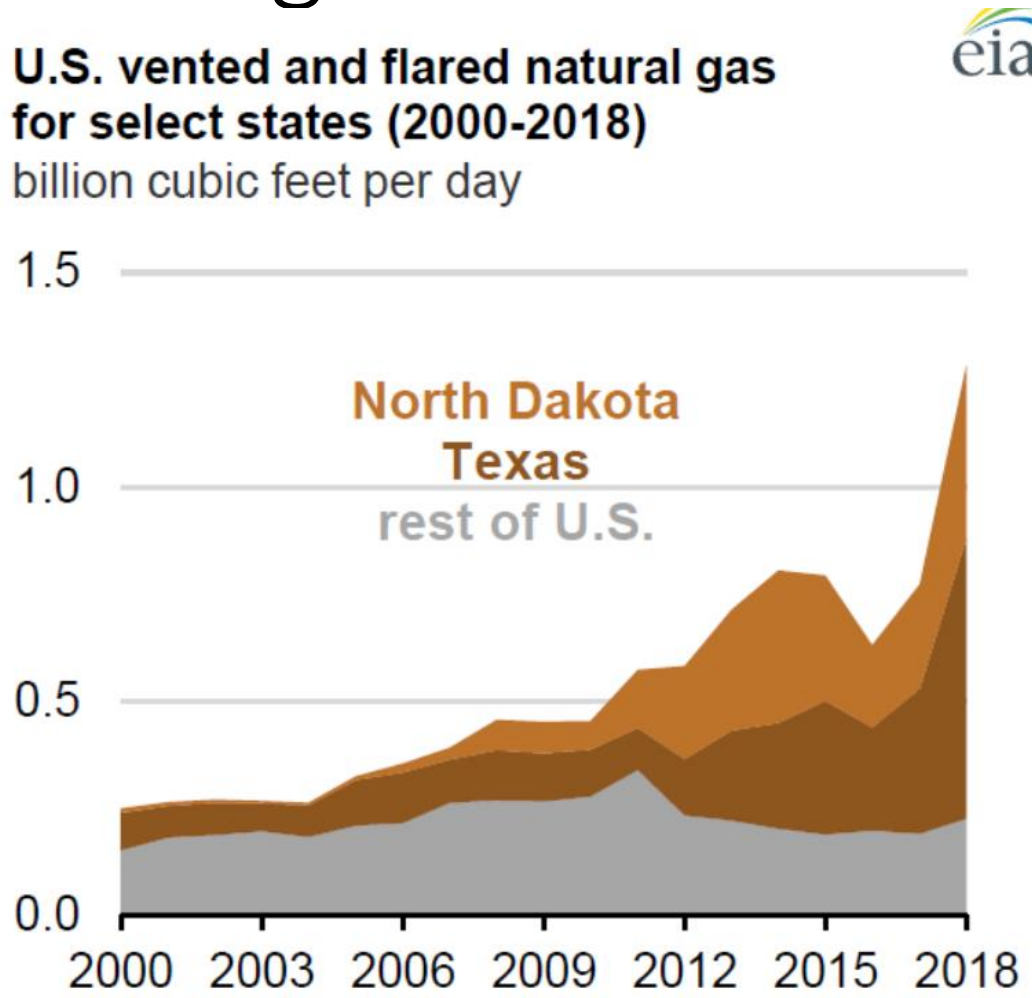
- Horizontal drilling combined with massive hydraulic fracturing technology has disrupted the petroleum industry
- The U.S. has switched from the world's largest importer of energy to an energy surplus
- The U.S. is in the process of becoming the largest exporter of LNG
- The U.S. is the largest exporter of NGL's
- Prices for natural gas and ethane have collapsed. In some cases the prices have dropped below zero.

U.S. Wet Gas Marketed vs. Year



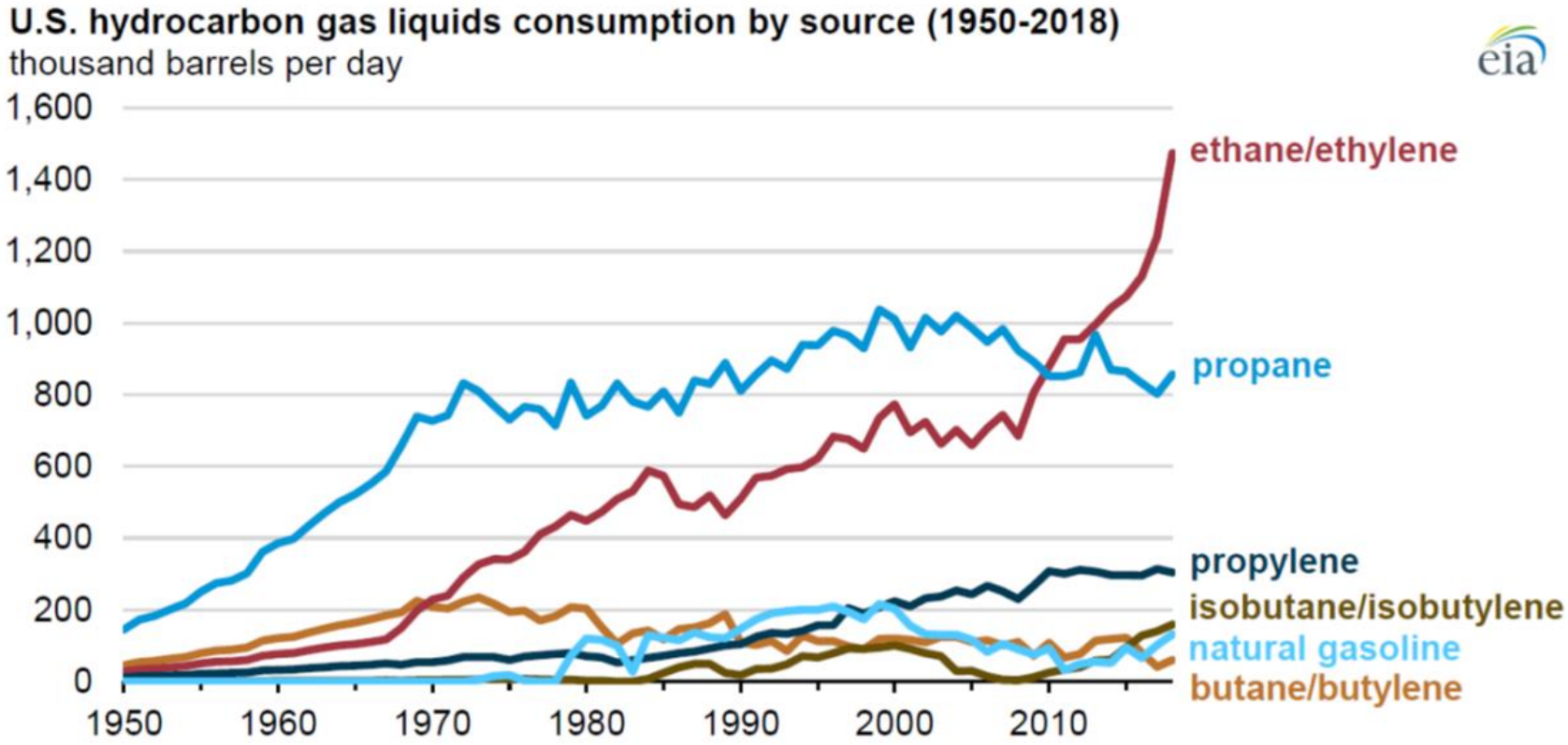
- U.S. gas production has nearly doubled since 2005

Venting/Flaring has Increased Dramatically



- Texas and North Dakota now vent/flare more than 1 BCFD

U.S. Ethane Production Increased Dramatically



- Ethane has more than doubled since 2005.
- 1,600 MBBL/D of Ethane = 2.5 BSCFD of Vapor

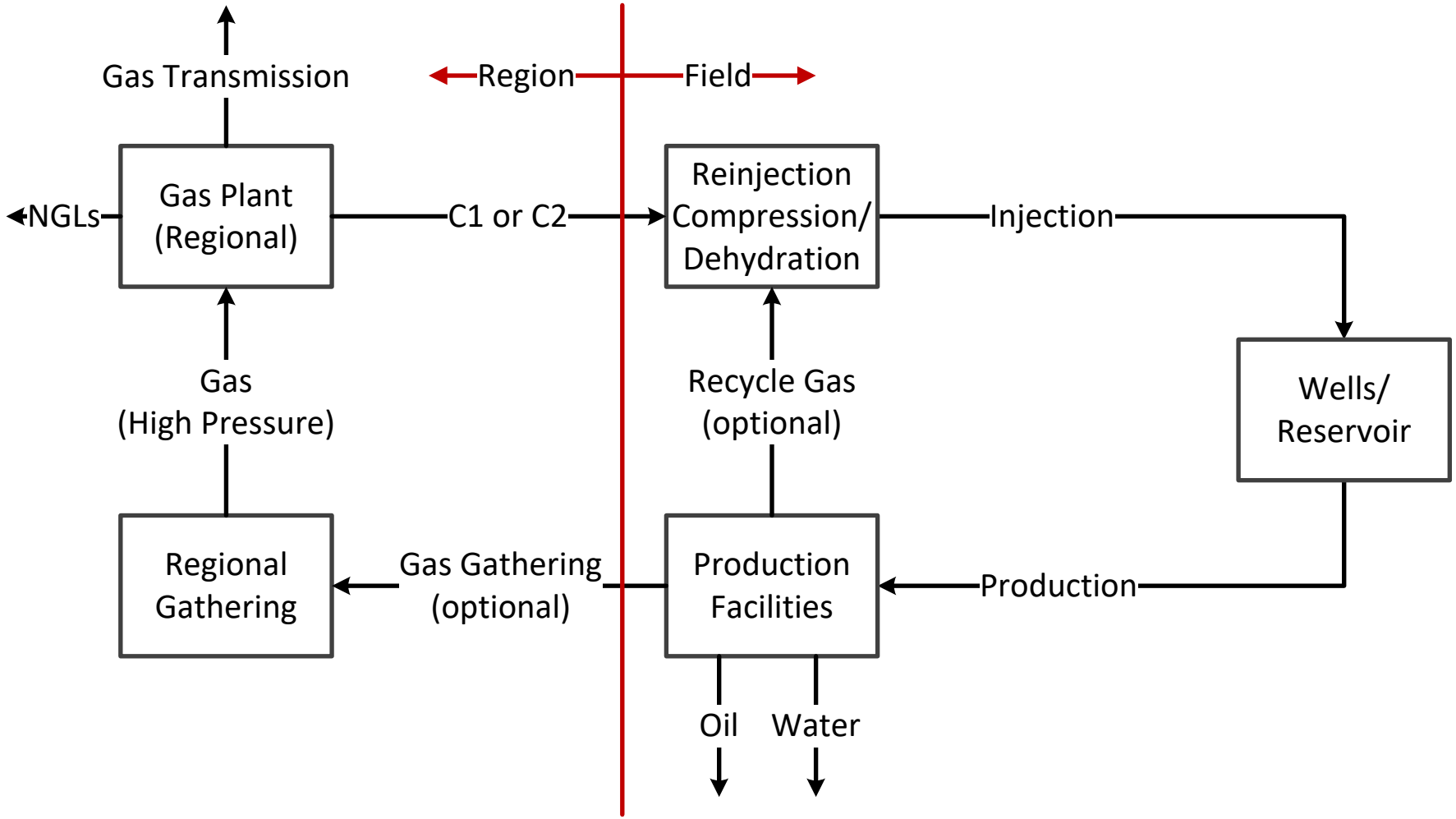
Natural Gas and Ethane are the New EOR Injectants – Hydraulically Fractured Wells are the New Floods

- Availability and affordable cost are two main prerequisites for an EOR Injectant
- Natural gas and ethane have become abundant and inexpensive
- Natural gas is easiest to procure as it is always present where horizontal fractured wells exist
- Ethane, as a product, is present when gas plants are designed to recover it.
  - Caveat: Ethane may overwhelm the design capacity of portions of the plant. Upgrading plants may be necessary.

Comparison: Natural Gas, Ethane, and CO_2

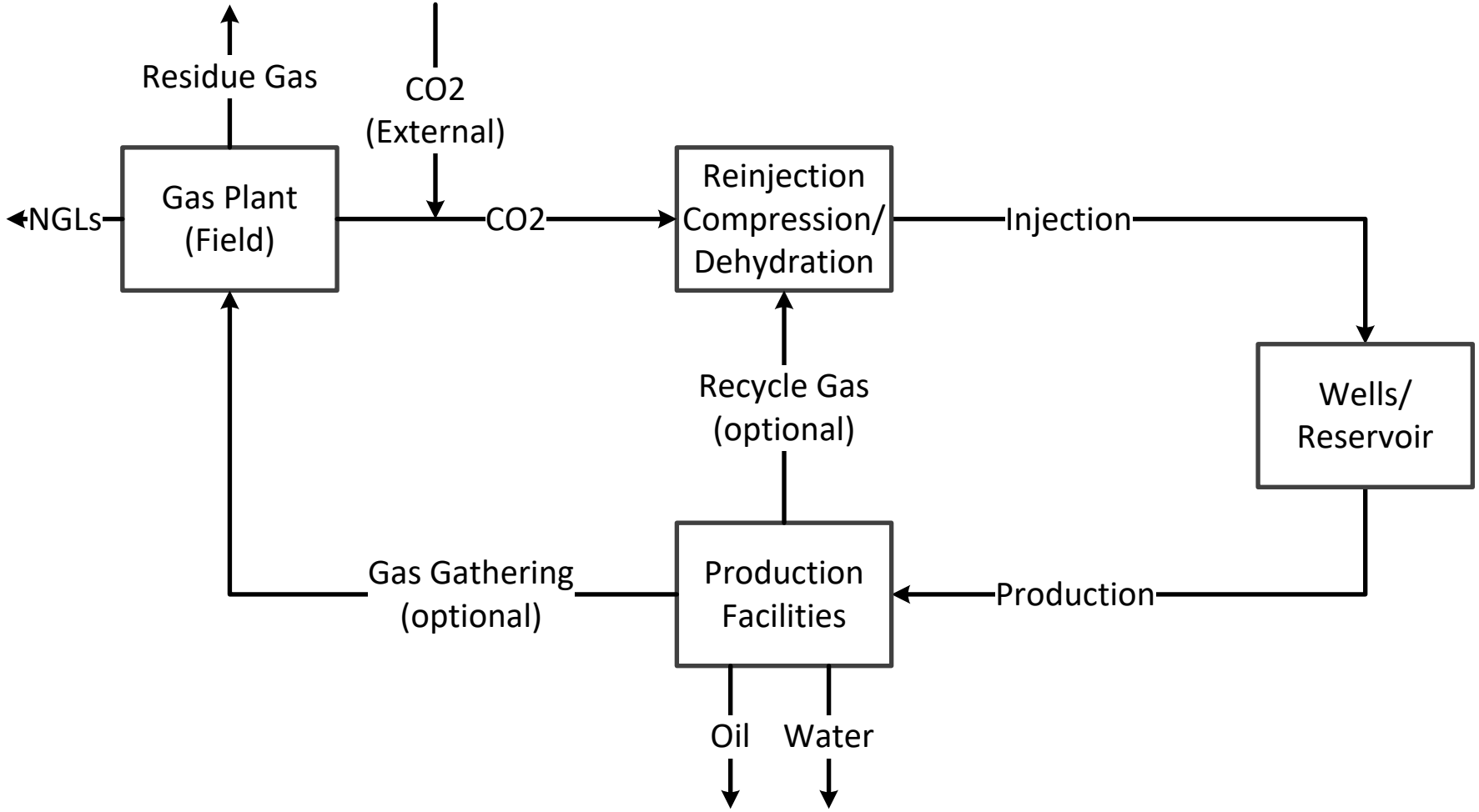
Line	Description	Methane	Ethane	CO2
1	Availability	Abundant	From Gas Plants	Variable
2	MMP	Poor	Excellent	Good
3	Added Reserves	Fair	Superior	Good
4	Supercritical density	~11 lb/cuft	~27 lb/cuft	~55 lb/cuft
5	Permian injection pressure	~3600 psi	~3050 psi	~2000 psi
6	Aftercooler needed above critical	Yes	No	No
7	Wellbore lifting	Excellent	Good	Good
8	Compatable with current field facilities	Yes	Yes	No
9	Flaring Issues (BTU, Dispersion)	No	No	Yes
10	Corrosion Issues	No	No	Yes
11	Flow Capacity Issues (Derate Existing?)	No	Limited	Significant
12	Elastomer Issues	No	No	Yes
13	Infrastructure	Uses Existing	Uses Existing - May Overload Plant	Requires New
14	High Pressure Transportation	Fair	Good	Excellent

Methane and Ethane EOR Flows



- Both Methane and Ethane can utilize external infrastructure to facilitate operations. Note: ethane can include propane+

CO_2EOR Flows



- If CO_2 processing is installed each field installs its own plant
- An external source of CO_2 is required

Huff-n-Puff: An option for EOR

- Horizontal fractured wells in tight zones (read: shales) have poor primary recovery, often less than 10% of OOIP.
- Even small improvements in recovery can result in large increases in Recovery
- Huff-n-Puff appears to be the most effective way to enhance oil recovery. It may be the only way. Natural Gas, ethane, and CO_2 should all be viable. The key is to have a low viscosity fluid.
- Waterflooding is unlikely to work; water is too viscous. It follows that WAGing is also impossible where huff-n-puff is employed.
- Pattern flooding would be preferable but is often not feasible in many horizontal fractured wells due to the inability to transmit the fluids through the reservoir

Huff-n-Puff is Batch EOR

- Huff-n-puff flooding is batch EOR; pattern flooding is continuous EOR (even with WAG). In some respects it resembles well stimulation jobs.
- All injectors are producers
- Constant rate injection is difficult and requires flow control
- Flow control via a control valve causes a pressure drop to each injection well which resulting in more power required
- Constant rate production is likely not easily achieved and would be undesirable if it could be achieved. Wellhead pressure as well as flow would tend to decline as the well is produced.

Huff-n-Puff is Batch EOR (continued)

- Declining producer flow and pressure tends to cause poor utilization of equipment with the biggest impacts on compression
- Composition will rapidly change over a matter of days as a well continues through its production cycle
- Reciprocating compression is less susceptible to composition variation than centrifugal compression. It would be preferred.
- Utilization and composition issues can be addressed by having many wells in the field and staggering injection/production cycles.
  - Staggered injection/production would also likely require separate injection and gathering systems although the last pipe to each well could be shared injection/production
  - This would mimic constant injection and constant production.

The Future

- Natural gas and ethane are suitable EOR injectants
- A major reason they are suitable is the low cost of these injectants
- What happens when natural gas and ethane prices increase?
- A future wherein a field would convert from one injectant to a less valuable injectant should be considered.

Thank you

- Thanks to OTSO Energy Solutions, LLC. for sponsoring this paper
  - Manufacturer of engineered production equipment and processing modules
  - OTSO Knows CO_2™

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