Economics for CO_2 Capture, Compression and Transportation in the Mid-Continent

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Why we are here today

45 Q is a game changer, making a variety of CCUS projects technically and economically feasible.

4.3 million tonne/yr could be captured in NE and KS ethanol plants and transported to Kansas oil fields for $14 per tonne (0.75/mcf).

- Kansas oil recovery could increase by 28% (10 million BO/yr) through EOR by injecting 4.3 Mt/yr (221 mmcf/d).

Small ethanol plants could capture and directly inject CO_2 into a saline aquifer

- 22% ROI after $85 Million in 45Q credits are applied.
- Might also derive significant benefits with a substantially lowered carbon intensity (i.e.: CA LCFS)

Sources for Economic Modeling and Resources

Pipeline CapEx and OpEx are derived from FE/NETL CO_2 Transport Cost Model

(Grant & Morgan, 2014), modified by Dubois and McFarlane (2017) – see poster)

Capture and compression CapEx and OpEx are based on cost data from three DOE-funded projects

(Details in White Paper: Capturing and Utilizing CO2 from Ethanol)

See your reference sheet for

- Acronyms
- Conversions
- Rules of thumb

See me at the posters for

- Pipeline cost model details
- Economic model inputs and assumptions

Capture and Storage at Variable Scales

Project types and scales are nearly limitless in MidCon

Range from

- Simple: point-to-point (150,000 tonnes/yr)
- Somewhat complex: multiple sources to single market for EOR
- Very complex: multiple sources to multiple fields for EOR

Scenarios presented involve the highlighted boxes

Source Type	Description	Ethanol Volume (Mg/yr)	CO2 Volume (Mt/yr)
Ethanol plants	Single Small	55-110	0.15-0.3
	Single Large	300	0.8
	Multiple - 15 plants	1575	4.3
	Multiple - 34 plants	3643	9.9
Coal Power	Single		1-4
Storage (Market)			
EOR	Single field - small (KS)		0.15-0.3
	Mutliple small fields (KS)		2-4
	Large market (W. TX)		4-10
Saline aquifer	Small local (KS)		0.15-0.3
	Single structure (KS)		1.5-3
	Multi-structure storage complex (KS)		6

CO_2 volume is 90% of calculated nameplate

Four cases discussed today

1. Small-scale Point-to-Point for EOR (0.15 Mt/yr – 2.9 BCF/yr)

2. Small-scale Capture and Inject for Saline Storage (0.15 Mt/yr – 2.9 BCF/yr)

3. Aggregate 15 ethanol plants and transport to multiple Kansas fields (4.3 Mt/yr – 82 BCF/yr)

4. Aggregate 34 ethanol plants and transport to Permian Basin (9.9 Mt/yr – 188 BCF/yr)

But what about Coal-Power CO_2

Petra Nova, Houston

- Operational for 18 months
- 1.4 Mt/yr captured & compressed
- Transported - 82 mile 12" pipeline to West Ranch oil field
- $1B capital costs (no details)

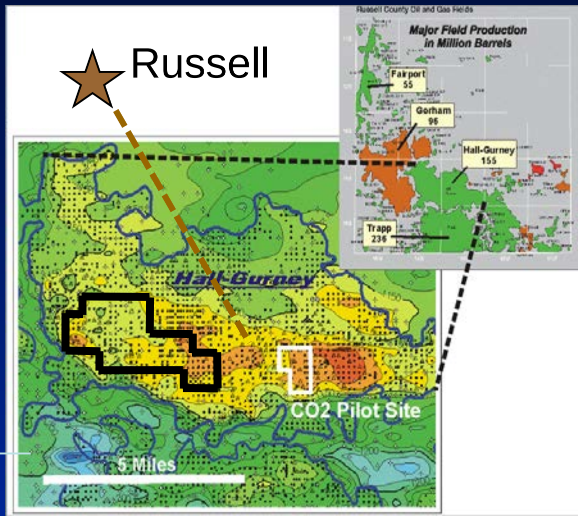
Kansas Coal-Power CO_2 possibilities

- Westar, Sunflower, KCBPU (power) and CHS (refinery) are participants the KGS – ICKan project
- Preliminary engineering study
    - Capture 2.5 Mt/yr from Westar's JEC
    - Cost for Capture/Compression \$46-\$78/tonne over 20-yr project.
- Getting closer – needs to stay in the mix

Case 1: Small-scale Point-to-Point for EOR,
Oil Operator Owns CCT System

Current Kansas example: Conestoga's (Garden City KS) to Stewart Oil Field since 2012: 55 mgy plant, 15 miles to field

Future EOR example? Russell Ethanol to Hall-Gurney field via 10-mile line



Modified from Dubois etal. (2002)

Generic economic model assumptions

- Capture and compress 150 kt CO_2/yr
- 20-mile, 4" pipeline
- Owner equity and secured note (net 5% interest)
- 14-yr project, 2 yrs construction, 12 yrs operations
- Injection begins in 2022
- 45Q credits ($25-$35, avg. $33)
- No inflation is factored
- Pay Ethanol plant $10/tonne CO_2

Case 1: Economic Summary

Cost per tonne CO_2

		$/tonne
Capture/Compression	CapEx	$0.66
	OpEx (annual)	$8.58
Pipeline	CapEx	$0.51
	OpEx (annual)	$1.71
TOTAL	$/tonne	$11.45
	$/mcf	$0.60

Tax credits applied directly to CapEx in model to calculate price/tonne

Cost

		$ Million
Capture/Compression	CapEx	$17.25
	OpEx (annual)	$1.28
Pipeline (20 mi, 4")	CapEx	$13.21
	OpEx (annual)	$0.25
TOTAL	CapEx	$30.46
	OpEx (annual)	$1.53

45Q tax credits make this case economically viable

Cost without 45Q
$34/tonne
($1.80/mcf)

Market CO_2 value with WTI = $60
$22.90/t
($1.20/mcf)

Case 1: Risk and Benefit

Oil Operator

Risks

1. Capital exposure
   - $30 M for CCT
   - $10s of M for field upgrade
2. Oil field flood failure
3. CO_2 source (ethanol plant failure)
4. MVA and long-term liability

Benefit

1. Low-cost CO_2............*because of $59 Million 45Q tax credits*

Ethanol Plant

Risks

1. Almost none
2. Loss of lower carbon intensity

Benefit

1. Revenue: $1.5 M/yr ($0.027/ gal) – for this case
2. Greatly reduced carbon intensity

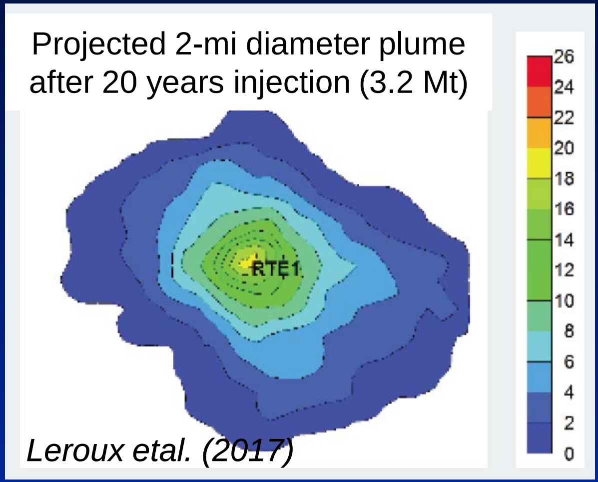
Case 2: Small-scale Point-to-Point for Saline Storage

Ethanol Plant Owns CC System

Saline Aquifer Storage

Planned ND example: Red Trail Energy, Richardson ND inject CO_2 direct into 6500-ft well

50 mgy plant, inject 160 kt CO_2/yr



Economic model assumptions

See poster on this project

- Capture and compress 150 kt CO_2/yr
- Inject onsite, or very close by, into a Class VI well
- Financed with owner equity
- 14-yr project, 2 yrs construction, 12 yrs operations
- Injection begins 2022
- 45Q credits ($39-$50/t, avg. $47.47/t)
- No inflation is factored

Case 2: Economic Summary

Cost		$ Million
Capture/Compression	CapEx	$17.25
	OpEx (annual)	$1.28
Class VI well	CapEx	$2.5
	OpEx (annual)	$0.2
TOTAL	**CapEx**	**$19.75**
	OpEx (annual)	**$1.48**

Risks

1. $20 Million capital exposure
2. Class VI well permitting
3. Class VI injectivity (rate)
4. CO_2 source (ethanol plant)
5. Unable to capture low-carbon potential

Benefits

1. 22% ROI
2. $5.6M Annual Net Cash Flow
3. $85 Million in 45Q tax credits
4. Greatly reduced carbon intensity

Case 3: Fifteen plants to Kansas oil fields

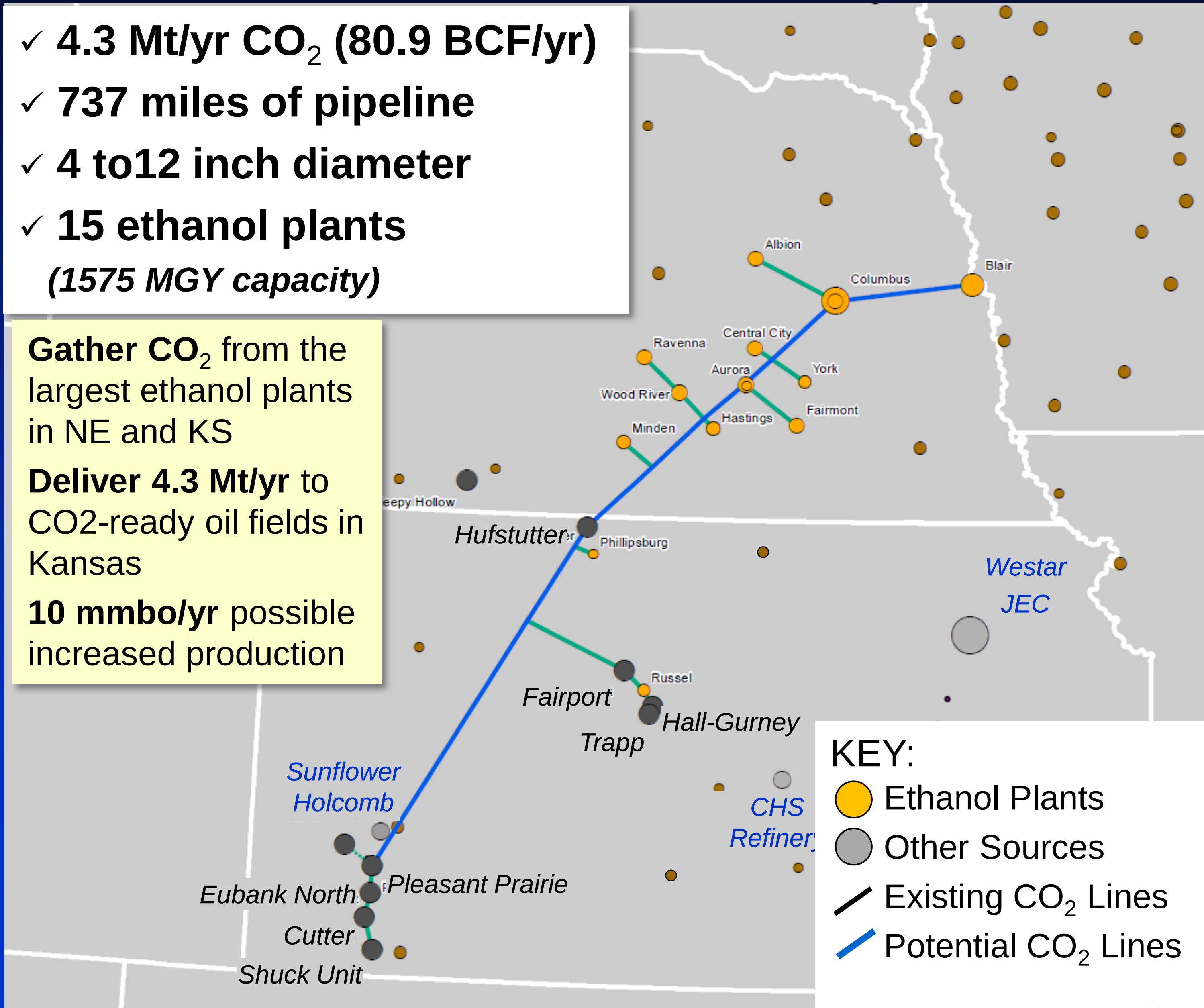
- ✓ **4.3 Mt/yr CO_2 (80.9 BCF/yr)**
- ✓ **737 miles of pipeline**
- ✓ **4 to12 inch diameter**
- ✓ **15 ethanol plants**

  (1575 MGY capacity)

Gather CO_2 from the largest ethanol plants in NE and KS

Deliver 4.3 Mt/yr to CO2-ready oil fields in Kansas

10 mmbo/yr possible increased production



Case 3 Economics

Estimated Project Costs

Cost $million	Plant Capture	Pipeline Transport	Total
CapX	$364	$642	$1,006
Annual OpX	$37	$16	$53

*Note: Rule of thumb $100k/inch-mile yields **$613** million CapX for pipeline*

Summary:

- **Total CapEx $1,006 M**
- **45Q tax credits $1,774 M**
- **Cost of Capital = 10%**
- 2-yr construction and 20 yrs operations (ops in 2024)
- 12 yrs of 45Q credits - Avg. $34.48/t

Costs per Unit of CO_2

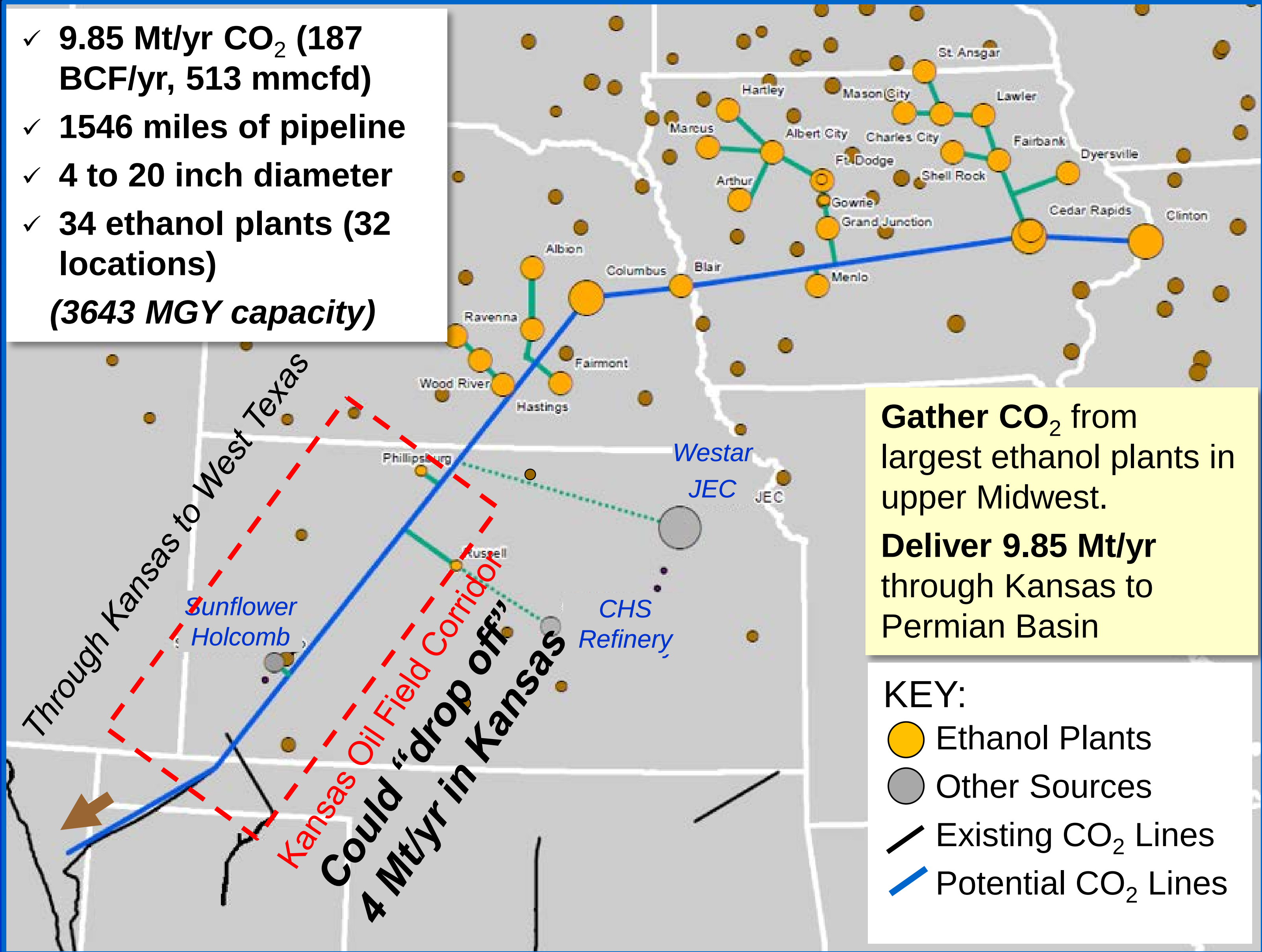
	Pipeline	Capture & Compress	Combined
CapEx ($/t)	$1.71	$0.69	$1.90
OpEx ($/t)	$3.80	$8.58	$12.39
Total ($/t)	**$5.02**	**$9.27**	**$14.29**
Tax credits applied directly to CapEx in model to calculate price/tonne		**$/mcf**	**$0.75**

Without 45Q
$42 / tonne ($2.19 / mcf)

Case 4: Large-scale, 10 Mt/yr

- ✓ 9.85 Mt/yr CO_2 (187 BCF/yr, 513 mmcfd)
- ✓ 1546 miles of pipeline
- ✓ 4 to 20 inch diameter
- ✓ 34 ethanol plants (32 locations)

(3643 MGY capacity)



Gather CO_2 from largest ethanol plants in upper Midwest.

Deliver 9.85 Mt/yr through Kansas to Permian Basin

KEY:
- Ethanol Plants
- Other Sources
- Existing CO_2 Lines
- Potential CO_2 Lines

Case 4 Economics

Estimated Project Costs

Cost $million	Plant Capture	Pipeline Transport	Total
CapX	$809	$1,857	$2,667
Annual OpX	$85	$47	$131

*Note: Rule of thumb $100k/inch-mile yields **$1821** million CapX for pipeline*

Summary:

- **Total CapEx $2,667 M**
- **45Q tax credits $4,064 M**
- **Cost of Capital = 10%**
- 2-yr construction and 20 yrs operations (ops in 2024)
- 12 yrs of 45Q credits, Avg. $34.48/t

Costs per Unit of CO_2

	Pipeline	Capture & Compress	Combined
CapEx ($/t)	$4.28	$1.86	$6.14
OpEx ($/t)	$4.77	$8.58	$13.35
Total ($/t)	**$9.05**	**$10.44**	**$19.49**
Tax credits applied directly to CapEx in model to calculate price/tonne		**$/mcf**	**$1.03**

Without 45Q
$47 / tonne ($2.46 / mcf)

Parting Comments

45Q extension and expansion is now the law

Preliminary economics favorable for myriad of scenarios

- Saline aquifer storage (small and large-scale)
- EOR storage (small and large-scale)

Lots of issues yet to be resolved

Later today in breakout session – get involved

- Define critical issues by sector *and* cross-cutting sector
- Discuss remedies *and* how we can collectively tackle the issues
- What's next?

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45 Q Tax Credits Applied

45Q specifics*

Enacted 2/9/2018 as part of a Federal budget bill

- Begin construction before February 9, 2025
- Credits claimed 12 yrs from day capture begins
- Can be claimed by capture facility, transferred to the storage facility, but not directly by transporter
- 2017 tax credits are $12.83/tonne for EOR and $22.66/tonne for saline storage.
- Credit escalates linearly through 2026 to $35 for EOR and $50 for saline storage and is flat beyond.
- Adjusted for inflation after 2026
- Injected into a qualified EOR project in a secure geologic storage or injected and sequestered in a secure geologic storage

** Sources: NEORI (Kurt Walzer), CLATF, State CO2 EOR Workgroup (Brad Crabtree), and S. 1535 document*

Credit Values ($/tonne)

Credits (no inflation)		
	EOR	Saline
2017	$12.83	$22.66
2018	$15.29	$25.70
2019	$17.76	$28.74
2020	$20.22	$31.77
2021	$22.68	$34.81
2022	$25.15	$37.85
2023	$27.61	$40.89
2024	$30.07	$43.92
2025	$32.54	$46.96
2026 - 2035	$35.00	$50.00

Inflation adjustment after 2026 not applied here