Summary of Dakota Gasification Company's CO_2 Capture and Transport, and Future Options for Gasification Systems

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Energy & Environmental Research Center

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More than 254,000 square feet of state-of-the-art laboratory, demonstration, and office space.

Presentation Topics

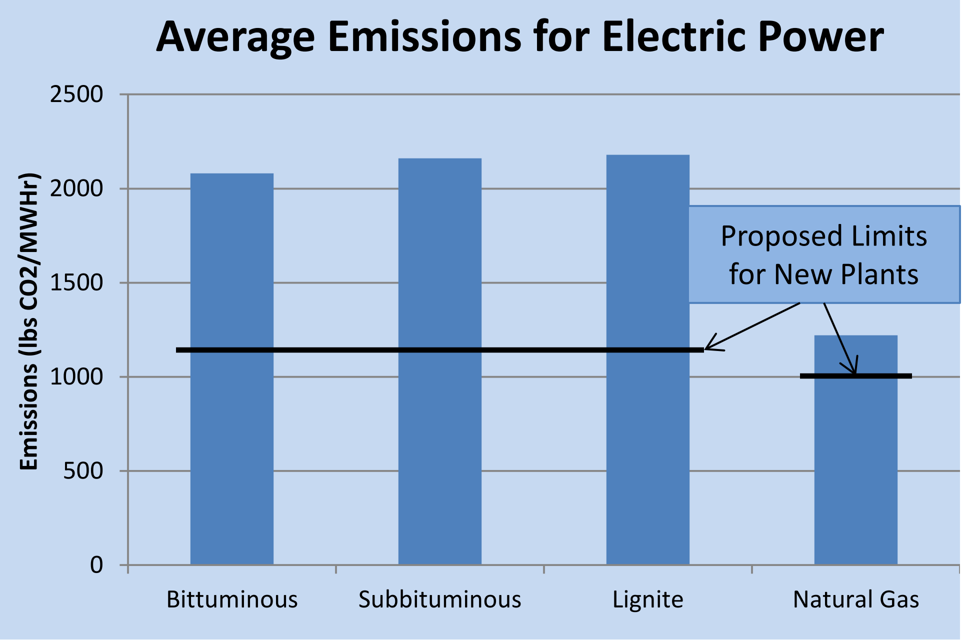
- Why Carbon Management?
- Background and Summary Great Plains Synfuels Plant
- Precombustion Capture Options

Why Carbon Management?

New U.S. Environmental Protection Agency (EPA) Greehouse Gas Rules

Proposed Existing Plant Rules (Reductions by State)

Minnesota	41%
Montana	21%
North Dakota	11%
South Dakota	25%
Wyoming	19%
Washington	72%

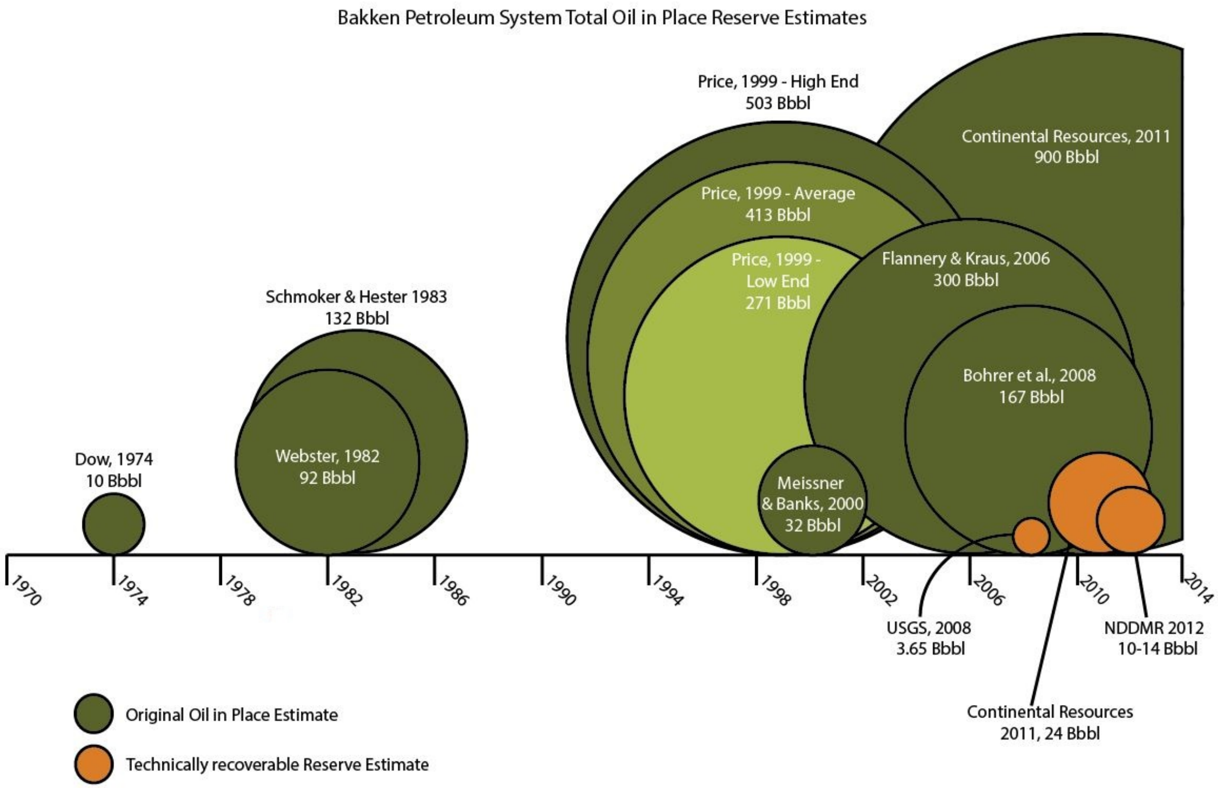


Proposed CO_2 limits for new power generation.

Regulatory and Climate Drivers

How Do We Get More Oil Out of the Bakken?

- The more we understand about the Bakken petroleum system, the more oil we recognize in it.
- Currently, only a 3%–5% recovery factor.
- Small improvements in recovery yield billions of barrels of oil.
- **Can CO_2 be a game changer in the Bakken?**



As a Commodity to Enhance Oil Recovery

Bakken CO_2 Demand for North Dakota – A 30,000-ft View

- Based on the following:
  - Traditional evaluation techniques
  - NDIC OOIP estimates
  - 4% incremental recovery
  - Net utilization of 5000 and 8000 ft^3/bbl
- 2–3.2 Bt of CO_2 needed, yielding 4–7 Bbbl of oil.
- North Dakota currently produces ~33 Mtpy of CO_2.

Why Coal Gasification?

- Coal gasification systems have inherently increased energy conversion efficiency over combustion systems for power generation.
  - Integrated gasification combined cycle (IGCC) – 39%–42%
  - Conventional combustion – 37%
- However, capital costs are high for IGCC systems, and without CO_2 capture requirements, new IGCC system construction can be cost-prohibitive.
- Coal gasification systems have potential cost and performance advantages over conventional coal combustion systems if CO_2 capture is required.
- In addition, gasification has the potential for high-value product creation:
  - Fuels
  - Chemicals

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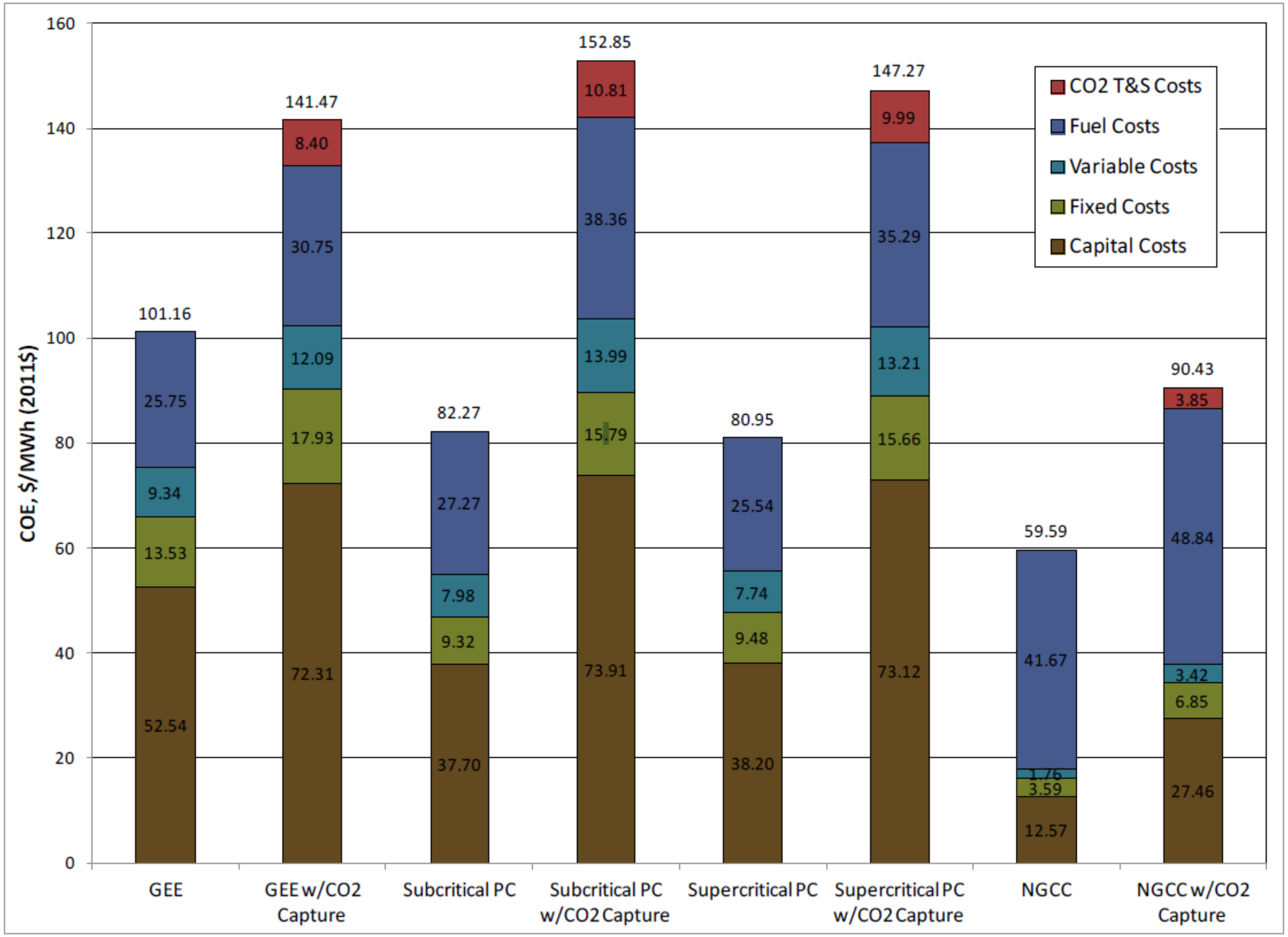
Coal-Fired Power Costs



Updated Costs (June 2011 Basis) for Selected Bituminous Baseline Cases, National Energy Technology Laboratory (NETL), August 2012 (accessed May 2013).

NETL

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Great Plains Synfuels Plant

Figure from Basin Electric Power Cooperative Web Site – www.basinelectric.com/Energy_Resources/Gas/index.html

Current Commercial Example

- 18,000 tons per day of lignite in 14 Lurgi gasifiers.
- Producing natural gas (over 54 billion standard cubic feet/year) from coal since 1984.
- Produces a number of by-products, including CO_2 (40 billion standard cubic feet/year) that is piped to Saskatchewan and sold for EOR (8,000 metric tons/day).

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Timeline for the DGC Synfuels Plant

The DGC Synfuels Plant is in large part the result of the energy shortage and high-costs in the U.S. in the 1970's

The project required combined leadership from individuals, industry, and state and federal governments.

Some of the key timeline elements include:

- In 1972 the original coal supply agreement was signed between American Natural Resources (ANR) and North American Coal.
- Primary movers at that time included North Dakota Governor William M. Guy and ANR's Arthur Seder, Jr.
- Things slowed in the mid 1970's with failure to pass federal loan guarantees by one vote.

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Timeline Continued

- In 1978 President Carter signed a bill that paved the way for loan guarantees.
- In parallel a group of five natural gas companies formed a consortium to help fund the plant.
- Construction began in 1982 with 2.02 billion in loan guarantees approved by President Reagan.
  - The original proposal targeted a start of construction in 1977 and $1 billion.

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Timeline Continued

- Spring of 1984, construction was completed and production of SNG began.
- Early operation included fighting low energy prices as well as overcoming challenges with start up and early emissions issues.
- Because of initial financial challenges, DOE took ownership for $1 billion at a sheriff's sale in June of 1986, and sold it to DGC of Basin Electric in October of 1988.

Fulfilling revenue sharing commitments, Dakota Gas shared over $390 million in revenue combined with unused production tax credits to total $1.3 billion of the original DOE investment recovered.

Coproduction

Over time the Great Plains Synfuels Plant added to the revenue stream by adding to a growing list of coproducts.

In addition to SNG products include:

- Ammonia Sulfate
- Anhydrous Ammonia
- Krypton and Xenon
- Liquid Nitrogen
- Dephenolized Crysilic Acid
- Naphtha
- Phenol
- Tar Oil
- Urea and Diesel Exhaust Fluid (DEF)
- Carbon Dioxide

Over half of the annual revenue for the last two years reported has been from coproducts

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Carbon Dioxide Capture and Sales

DGC Captures approximately 50 percent of the carbon dioxide the plant produces at full plant capacity and transports it to the Weyburn and Midale oil fields for EOR through a 205 mile pipeline

- First CO2 sent to Canada in October of 2000
- Exports about 8,000 metric tons per day
- At the end of 2014, 29 million metric tons had been delivered to customers.

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Lessons Learned About the DGC Compression Approach

- The 8-stage integrally geared centrifugal compressors developed specifically for the DGC CO_2 stream work well for this application.
- Initial seal problems were mechanical in nature and were resolved by a redesign of the carbon seal pack. A change from Fluoraz to Chemraz material solved the o-ring issues.
- Compression to a relatively high pressure may reduce the number of booster stations needed to provide an oil field with CO_2 at the desired pressure.

10-stage integrally geared centrifugal compressor

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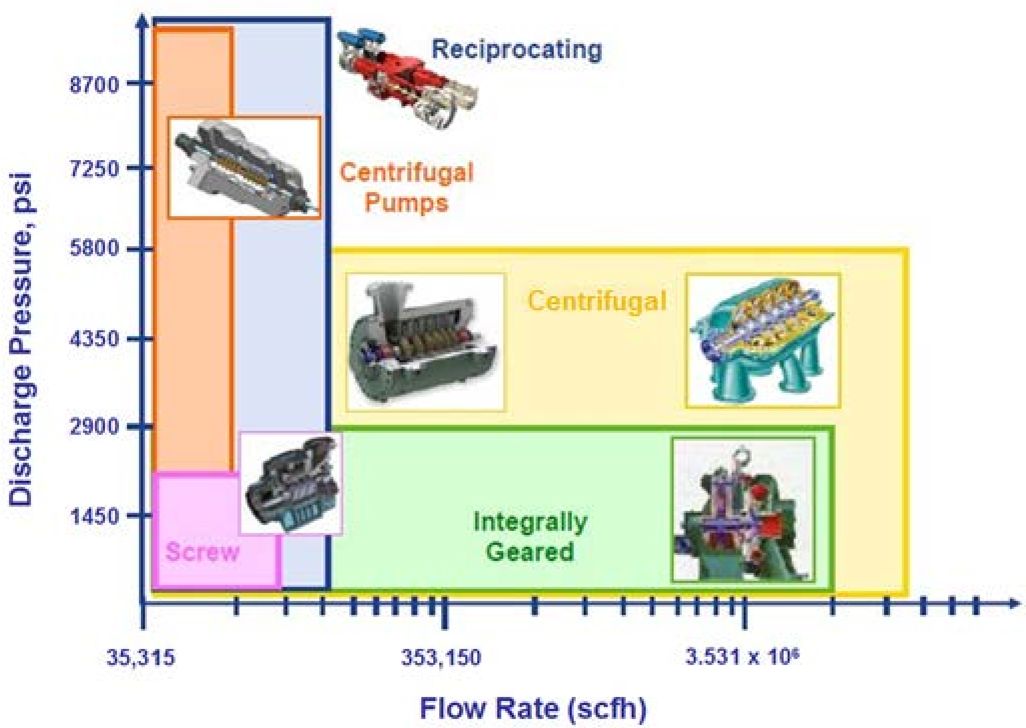
CO_2 Compressors



Compressor choice is made based on the volume of CO_2 and the pressure to which it must be compressed.

CO_2 Pipelines

CO_2 has been transported via pipeline to EOR fields for more than 40 years. It is a well-understood, off-the-shelf transport technology. Today there are about 4200 miles of CO_2 pipeline in the United States.

Existing CO_2 Pipelines in the U.S.

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Lessons Learned From the DGC Pipeline

- Adding tees to the trunk pipeline can increase the pipeline's ability to deliver CO_2 to additional EOR opportunities.
- Meeting Kinder Morgan (or other agreed-upon) CO_2 pipeline quality specifications will enable additional CO_2 sources to be added to the pipeline.
- Having H_2S in the CO_2 stream can make it less valuable for EOR opportunities in fields producing sweet crude.
- If the pipeline will be sited in a location that could benefit other sources and sink opportunities, consider designing it for a larger capacity than originally needed.
- A wider ROW could be useful for laying in a second trunk line to add capacity.

Estimated Pipeline Costs
(2009 vintage)

Kinder-Morgan Pipeline Cost Estimates

Terrain	Capital Cost ($/inch-diameter/mile)
Flat, Dry	$50,000
Mountainous	$85,000
Marsh, Wetland	$100,000
River	$300,000
High Population	$100,000
Offshore (150−200 ft depth)	$700,000

from: Carbon Dioxide Transport and Storage Costs in NETL Studies Quality Guidelines for Energy System Studies, May 2014

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CO_2 Capture Methods

CO_2 Capture Technology Status

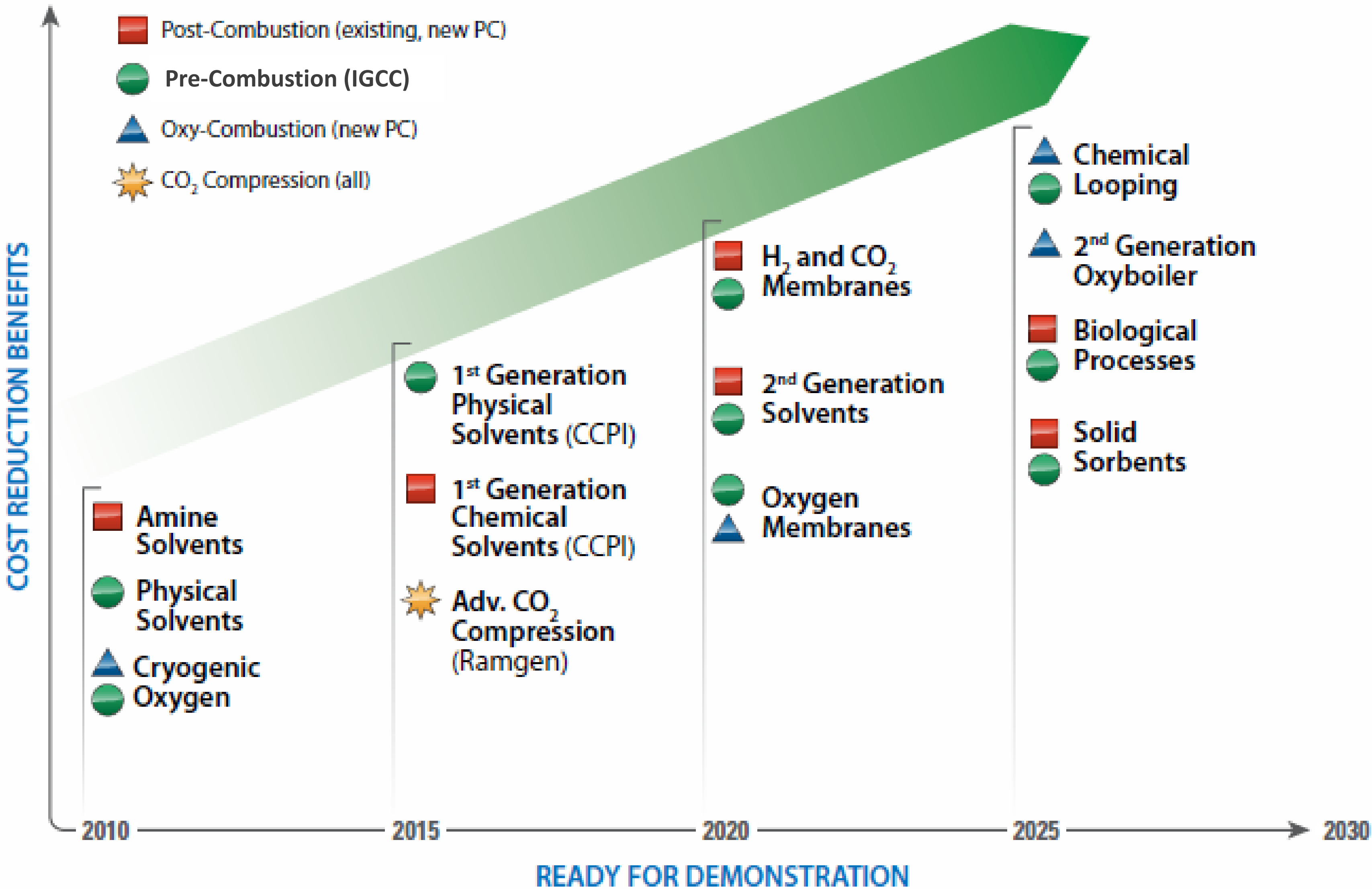

Figure 2-13. DOE/NETL CO_2 Capture Technology Development

What Is Rectisol?

- Developed in the late 1950s by Linde and Lurgi.
- Physical wash process where acid gas compounds are solved in methanol and removed from the syngas.
- Favors low temperatures and high pressures.
- Methanol temperature ranging from −20° to −60°C (−4° to −76°F).
- Removes:
  – CO_2
  – H_2S
  – COS
- Handles:
  – HCN
  – NH_3
  – H_2O

→Basically removes anything that condenses at −60°C.

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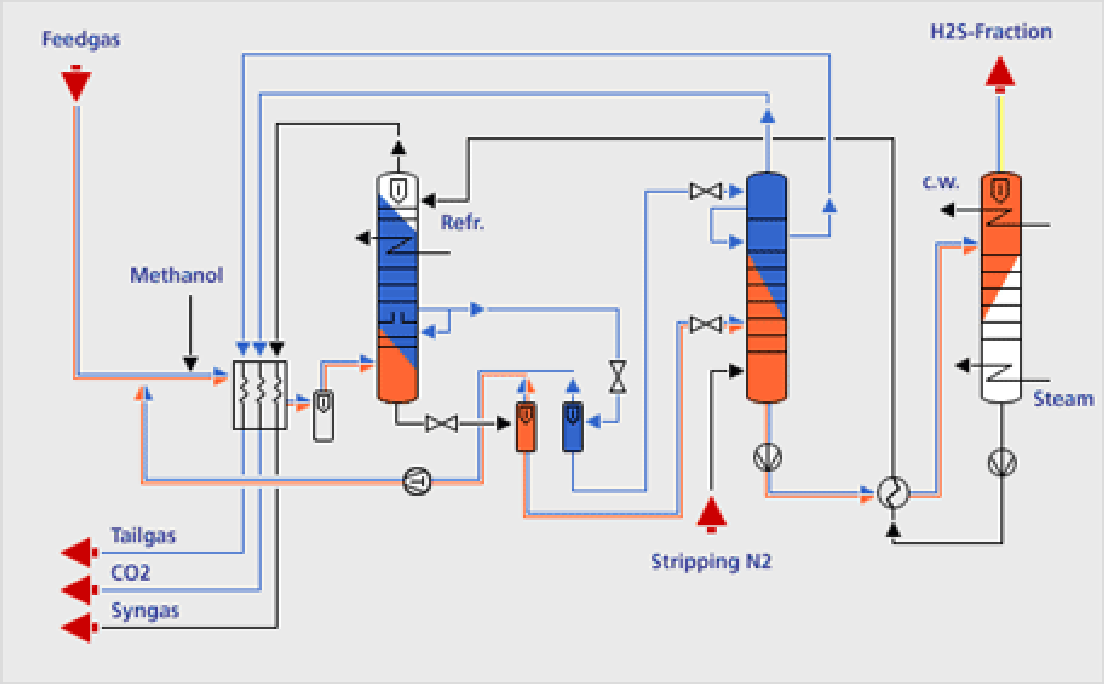
Rectisol



Basic Rectisol® flow diagram

- Rectisol is used when gas cleanliness requirements are very stringent.
- Multiple-stage regeneration for separation of CO_2 and H_2S.
- Produces a high-purity CO_2 stream that can be used for EOR.

What Is Selexol™?

- Licensed by UOP, LLC
- Physical solvent with inert characteristics at ambient or slightly refrigerated temperature.
- Selexol process uses Union Carbide's Selexol solvent—dimethyl ether of polyethylene glycol.
- Uses partial pressure as the driving force for capture, requires pressure above 300 psi.
- Removes:
  - H_2S
  - COS
  - CO_2
  - Ammonia
  - HCN

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Amine Scrubbing

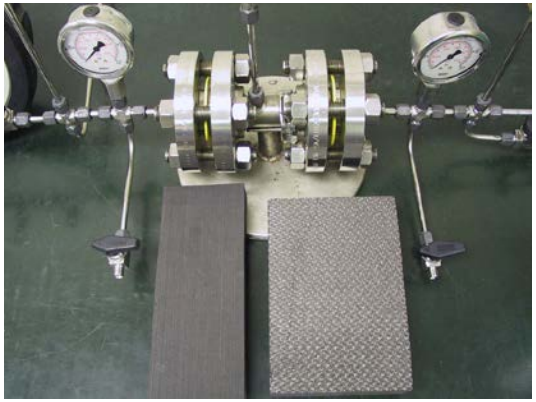
- Used at TECO and Wabash.
- Used for scrubbing CO_2 and H_2S from natural gas-processing plants.
- Several novel amines currently under development for potential application to existing coal-fired power plants for CO_2 capture.
- Process schemes for amine scrubbing are very similar to Rectisol or Selexol.

Swing Adsorption – TSA/PSA

- Adsorbers remove impurities from hydrogen stream.
- Regenerated by dropping pressure, raising temperature, or applying electric current.
- Utilize at least two beds so continuous purification is possible.

- <u>Strengths</u>
  - Pressure swing adsorption (PSA) is commercially available, should be very efficient at higher pressures, no significant hydrogen pressure drop.
  - Multicontaminant removal in one step.

- <u>Weaknesses</u>
  - In a high-pressure system, gas does not expand much during regeneration so a high-density (low-macroporosity) adsorber is required.
  - Typically does not produce ultrahigh-purity hydrogen.



Summary—Advancement of Gasification and Pre Combustion Capture

Efficiency and Cost of Electricity (COE) of IGCC plants with CO_2 capture

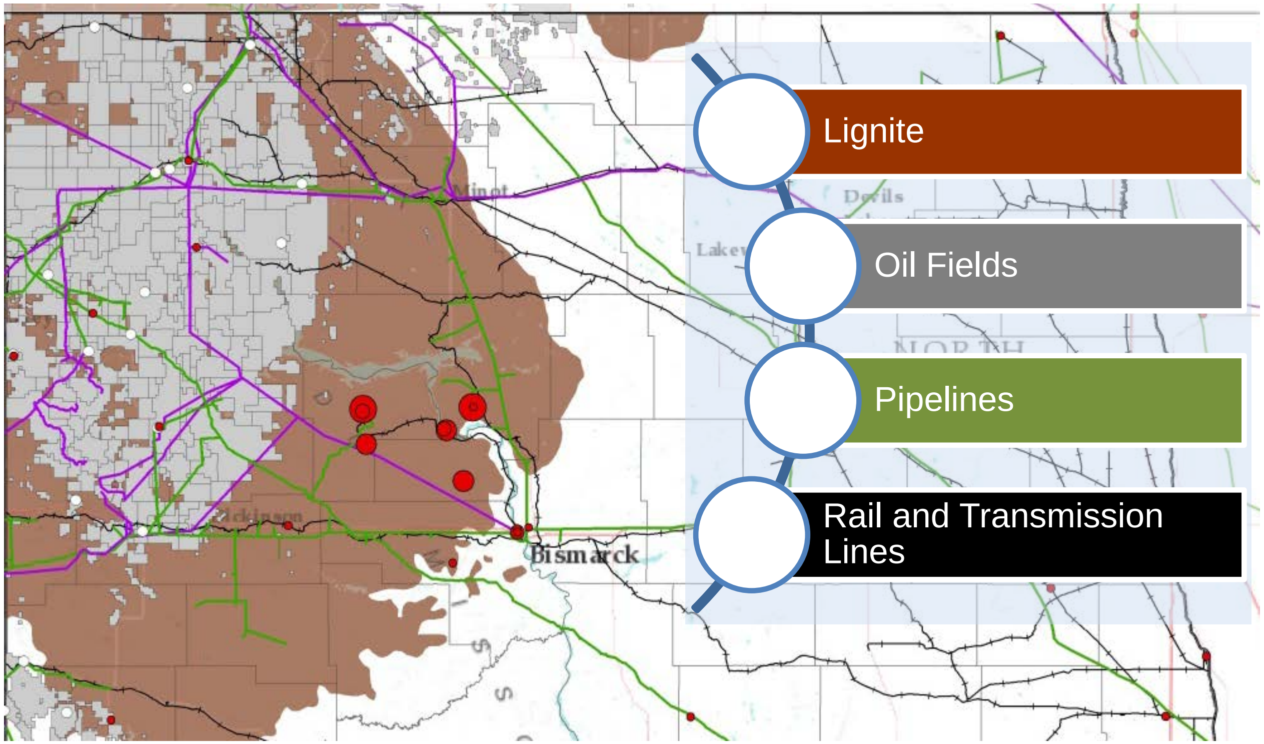
Case Title	Efficiency (% HHV)	Delta* Efficiency (% points)	TPC** ($/kW)	Delta* TPC** ($/kW)	20-yr Levelized COE (¢/kW-hr)	Delta* COE (¢/kW-hr)
Reference IGCC	30.4	0	2,718	0	11.48	0
Adv "F" Turbine	31.7	1.3	2,472	-246	10.64	-0.84
Coal Feed Pump	32.5	0.8	2,465	-7	10.54	-0.10
85% CF	32.5	0.0	2,465	0	10.14	-0.40
WGCU/Selexol	33.3	0.8	2,425	-40	10.00	-0.14
WGCU/H_2Membrane	36.2	2.9	2,047	-378	8.80	-1.20
AHT-1 Turbine	38.0	1.8	1,855	-192	8.14	-0.66
ITM	38.3	0.3	1,724	-131	7.74	-0.40
AHT-2 Turbine	40.0	1.7	1,683	-41	7.61	-0.13
90% CF	40.0	0.0	1,683	0	7.36	-0.25
IGCC Pathway		+9.6%pts (+32%)		-1,035 (-38%)		-4.12 (-36%)
Advanced IGFC	56.3	+26%pts +85%	1,759	-959 (-35%)	7.45	-4.03 (-35%)

* Delta shown is the incremental change as each new technology is added to previous case configuration

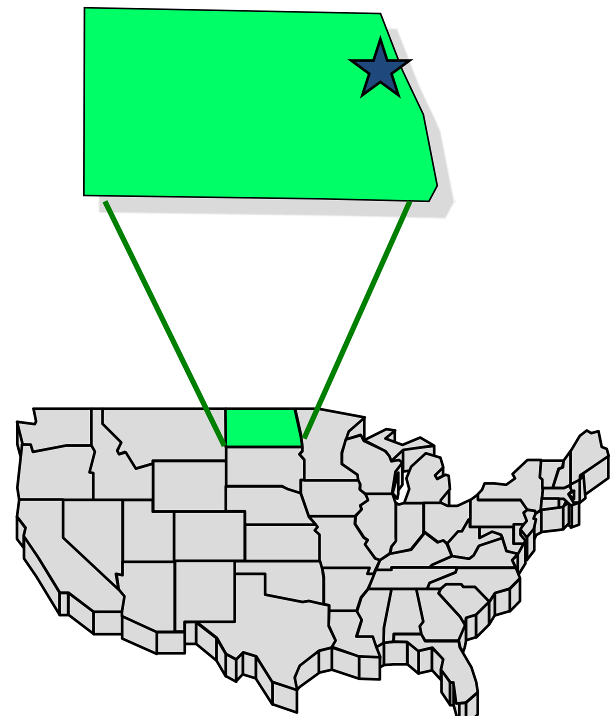
** TPC is reported in January 2007 dollars and excludes owner's costs

Gerdes et al. Current and Future Technologies for Gasification Based Power Generation; NETL, Vol. 2, Revision 1, Oct 7, 2010.

West-Central North Dakota Synergies



- Lignite
- Oil Fields
- Pipelines
- Rail and Transmission Lines



Thank you!

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