



UNITED STATES ENVIRONMENTAL PROTECTION AGENCY  
WASHINGTON, D.C. 20460

OFFICE OF  
AIR AND RADIATION

October 12, 2018

Ms. Katherine Dungey  
Core Energy, LLC  
597 Kubacki Road  
Gaylord, Michigan 49735

Re: Monitoring, Reporting and Verification (MRV) Plan for Northern Niagaran Pinnacle Reef Trend

Dear Ms. Dungey:

The United States Environmental Protection Agency (EPA) has reviewed the Monitoring, Reporting and Verification (MRV) Plan submitted by Core Energy for Northern Niagaran Pinnacle Reef Trend as required by 40 CFR Part 98, Subpart RR of the Greenhouse Gas Reporting Program. The EPA is approving the MRV Plan submitted for Northern Niagaran Pinnacle Reef Trend as the final MRV plan. The MRV Plan Approval Number is 1010117-1. This decision is effective October 17, 2018 and appealable to the EPA's Environmental Appeals Board under 40 CFR Part 78.

If you have any questions regarding this determination, please write to [ghgreporting@epa.gov](mailto:ghgreporting@epa.gov) and a member of the Greenhouse Gas Reporting Program will respond.

Sincerely,

A handwritten signature in black ink that reads "Julius Banks".

Julius Banks, Chief  
Greenhouse Gas Reporting Branch

# **Technical Review of Subpart RR MRV Plan for Core Energy Northern Niagaran Pinnacle Reef Trend**

**October 2018**

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This report summarizes the U.S. Environmental Protection Agency's (EPA's) technical evaluation of the Greenhouse Gas Reporting Program (GHGRP) Subpart RR Monitoring, Reporting, and Verification (MRV) Plan submitted by Core Energy for the Northern Niagaran Pinnacle Reef Trend (NNPRT).

## 1 Overview of Project

Core Energy states in the MRV plan that it operates an integrated carbon dioxide (CO<sub>2</sub>) capture and enhanced oil recovery (EOR) facility in the Northern Niagaran Pinnacle Reef Trend (NNPRT) in northern Michigan. The CO<sub>2</sub> is sourced from gas processing plants servicing production from the Antrim Shale play. The EOR targets are the closely spaced but highly compartmentalized reef complexes in the NNPRT. The reef complexes that are currently active are typically in tertiary production phase through CO<sub>2</sub>-EOR. **Figure 10** in the Core Energy MRV plan shows the depth at which CO<sub>2</sub>-EOR operations will take place in an individual reef and compares the depth of the reef to the Antrim Shale gas producing zone, and source of the CO<sub>2</sub>, which is much shallower than the reef system. **Figure 2** in the MRV plan approximates the geographic location of the reef systems that are operated and currently active under Core Energy. The CO<sub>2</sub>-EOR production phase for the active reefs was initiated in the late 1990s.

### 1.1 Geologic Setting

In their MRV plan, Core Energy provides information on the geologic setting describing the NNPRT as part of an extensive paleo shallow shelf carbonate depositional system. The reef trend forms a circular belt along the platform margin of the Michigan Basin, as shown in **Figure 1** in the MRV plan. A stratigraphic column detailing the Niagara Silurian section is provided in **Figure 4** in the plan. The reef facies developed within the Niagara Group and includes the Lockport and Guelph lithostratigraphic formations, of which the Guelph Formation forms the core of the reservoir rocks associated with the producing reefs. These oil and gas producing reefs along the NNPRT range from 3,500 to 5,500 feet deep. The MRV plan explains that while the reef systems are localized, averaging 50 to 400 acres in area, they may be up to 2,000 acres in areal extent and 150 to 700 feet in vertical relief with steeply dipping flanks.

### 1.2 Geologic Modeling

Core Energy joined the Midwest Regional Carbon Sequestration Partnership (MRCSP) in 2005 and has worked closely with this research consortium to expand the technical understanding of the NNPRT. Core Energy states that the MRSCP determined a potential capacity for the NNPRT estimated at hundreds of millions of tonnes through ancillary CO<sub>2</sub>-EOR storage. Core Energy also worked with MRCSP to model six representative reef reservoirs. The objectives for this work were to develop a detailed understanding of each modeled reef, especially the predictability of internal reef architecture. Core Energy plans to use the models of the six representative reef reservoirs, drawing from the transferability principles from these models, in place of developing detailed models for all of the operating reefs, as well as for each new reef that may be included in future CO<sub>2</sub>-EOR operations. A description of the development of the six representative reef models is given in section 2.2.1 in the MRV plan.



### 1.3 Facility Operations

Core Energy's operations include equipment to capture CO<sub>2</sub> from various sources, dedicated pipelines, injection and production wells, a central processing facility for fluids, compressors, and equipment to process produced oil and associated water and CO<sub>2</sub>. The Dover 36 capture operations and the Chester 10 recycle operations are the two capture units for CO<sub>2</sub> at the Core Energy operations. A description of these operations is provided in section 2.4 of the MRV plan, and a simplified process flow diagram is shown in **Figure 13**.

The injection wells operated by Core Energy are permitted as UIC Class II wells by US EPA and all wells in the operation (production, injection and monitoring wells) are regulated by the Oil, Gas and Mineral Division (OGMD) of the Michigan Department of Environmental Quality (MDEQ). Core Energy has 36 active wells penetrating the Niagaran reefs as of April 2018 (16 injection wells and 20 production/observation wells), with additional wells that are plugged and abandoned.

The injection wells are described in section 2.4.5 of the MRV Plan as geologically suitable for CO<sub>2</sub> storage.

### 1.4 Operation Timeline

Core Energy began its operations in the NNPRT in 2003 with two operating reefs. Their operations have since expanded to 10 active reefs. The NNPRT reefs were originally developed in the 1970s to 1980s, with oil production largely subsiding in the early 1990s. The developed reefs have undergone primary production, with some reefs having secondary recovery through waterflooding and other methods. **Table 1** in the MRV plan lists the active reefs and date of initial flooding for each, and **Figure 12** shows the location of each active reef.

### 1.5 Monitoring and Reporting Timeline

Core Energy plans to report under Subpart RR of the GHGRP for a Specified Period over which Core Energy will have a subsidiary purpose of establishing the long-term containment of a quantifiable quantity of CO<sub>2</sub> in the reefs that it operates. The MRV plan states that Core Energy's primary purpose for injecting CO<sub>2</sub> is to produce oil that would otherwise remain trapped in the reservoir and the Specified Period will be shorter than the planned period of production from the Core Energy facility. When the Specified Period is ended, Core Energy will submit a request for discontinuation of reporting. The MRV plan notes that Core Energy will submit this request when it can provide a demonstration that current monitoring and model(s) show that the cumulative mass of CO<sub>2</sub> reported as sequestered during the Specified Period is not expected to migrate in the future in a manner likely to result in surface leakage. Specifically, the MRV plan states that this demonstration will rely on three principles:

- 1) the amount of CO<sub>2</sub> stored in properly abandoned reefs is considered unlikely to migrate to the surface;

- 2) the continued process of fluid management during the years of CO<sub>2</sub>-EOR operation after the Specified Period will contain injected fluids in the reefs; and
- 3) the cumulative mass reported as sequestered during the Specified Period is a fraction of the theoretical storage capacity of the reefs.

Core Energy anticipates that this can be demonstrated within three years after the Specified Period has ceased.

## **1.6 Facility Modification**

In their MRV plan, Core Energy indicates that future modifications of the CO<sub>2</sub>-EOR operations are very likely and may include capturing and/or securing additional CO<sub>2</sub>; modifying, adding, or closing wells; adding or closing reefs; and adding new equipment and pipelines. The modifications are described in the MRV plan as a continuation of the basic integrated current configuration and not a material change requiring a revised MRV plan. Core Energy would indicate any such changes in their annual monitoring report. The monitoring report, as explained in the MRV plan, would include any new site characterization, risk assessment, monitoring, and mass balance information, with existing provisions for the MRV continuing to apply. These potential changes to Core Energy's operation are explained in Sections 2.5.1 – 2.5.8 in the MRV plan.

The MRV plan provides a description of the facility, including the site setting, processes, operations, and plans for potential future expansion of the CO<sub>2</sub>-EOR into other reefs in the NNPRT. The existing injection wells are permitted as UIC Class II wells and the UIC injection well identification numbers are provided in the MRV plan. Any future injection wells will also be permitted as Class II wells.

The description of the project is determined to be adequate and provides the necessary information to comply with 40 CFR 98.448(a)(6).

## **2 Evaluation of the Delineation of the Maximum Monitoring Area (MMA) and Active Monitoring Area (AMA)**

As part of an MRV Plan, the reporter must identify the maximum monitoring area (MMA) and active monitoring area (AMA), pursuant to 40 CFR 98.448(a)(1). Subpart RR defines the MMA as "the area that must be monitored under this regulation and is defined as equal to or greater than the area expected to contain the free phase CO<sub>2</sub> plume until the CO<sub>2</sub> plume has stabilized plus an all-around buffer zone of at least one-half mile." Subpart RR defines the AMA as "the area that will be monitored over a specific time interval from the first year of the period (n) to the last year in the period (t). The boundary of the AMA is established by superimposing two areas: (1) the area projected to contain the free phase CO<sub>2</sub> plume at the end of year t, plus an all-around buffer zone of one-half mile or greater if known leakage pathways extend laterally more than one-half mile; (2) the area projected to contain the free phase CO<sub>2</sub> plume at the end of year t + 5." See 40 CFR 98.449.

Core Energy worked with MRCSP to develop models of six representative reef reservoirs. To develop the six models, the MRCSP used Static Earth Models (SEMs) to integrate the geologic and geophysical data from five of the reefs. The data utilized in the SEMs include data collected from wells such as location, construction, depth and thickness, lithofacies, core data, well logs, and petrophysical analyses, along with seismic and production data. **Figure 6** in the MRV plan outlines the workflow for the SEMs development.

In the MRV plan, it states that the completed SEMs were used as the basis for input into dynamic models. Dynamic modeling was used to history match with production records, simulate fluid flow and pressure changes, and assist with well design and CO<sub>2</sub>-EOR flood configuration design. History matching is the process of adjusting the model until it reproduces the past behavior of a reservoir as closely as possible. **Figure 9** lists the reefs in Core Energy's operation, and summarizes the analyses completed to date for each reef.

Reservoir models were used to predict the size and location of the plume, as well as a prediction of how the plume extent changes over time. This was performed for each of the reefs modeled.

Core Energy states in the MRV plan that the basic geologic characterization used to define the reef, describe formations, and identify reservoirs and caprocks is similar for all reef structures. Thus, the information based on the reefs modeled, they state, can be transferable to others not undergoing the same detailed level of characterization and modeling. While Core Energy does not do the same level of characterization and modeling for each reef, the lessons learned from their advanced modeling on the five reefs demonstrated the predictability of internal reef architecture for all reefs.

Core Energy plans to continue developing additional reefs for CO<sub>2</sub>-EOR. As new reefs are added, the modeling approach, as explained in the MRV plan, will be to draw on a set of transferable principles from the existing modeling, instead of developing detailed models for each new reef. Core Energy explains that any reef added to the EOR operations would be screened for suitability for EOR and then would be subject to the Michigan unitization process by MEDQ. New wells or well changes would be processed through the MDEQ, as well as through EPA permitting requirements.

From this, Core Energy has defined the MMA based on the anticipated future of expansion to conduct CO<sub>2</sub>-EOR operations in any of the reefs in the NNPRT. **Figure 14** in the MRV plan shows the extent of the MMA. As indicated in Section 3.2, all potential new reefs that could be developed for CO<sub>2</sub>-EOR are in the MMA and would be moved into the AMA as indicated in Section 3.1 if they are developed by Core Energy in the future.

The MMA, as it is defined in the MRV plan, is consistent with subpart RR requirements because the defined MMA accounts for the expected free phase CO<sub>2</sub> plume, based on modeling results, and incorporates the additional 0.5 mile or greater buffer, for all possible reefs that could be developed for CO<sub>2</sub>-EOR.

Core Energy defines the AMA as the sum of the boundaries of the Unit Area of each individual reef/field under development and/or on production. The MRV plan states that the factors used to define the AMA

boundary for each reef are: (1) efficient seals overlying and surrounding each reef that will contain any injected CO<sub>2</sub>; (2) 3D seismic data, analog reef geometry and wells penetrating and near the reef will be used to ensure all CO<sub>2</sub> is injected into the targeted reef system; (3) stored CO<sub>2</sub> will remain in the reef and will not migrate over time, as is demonstrated by the long history of oil and gas production occurring within a reef; (4) free-phase CO<sub>2</sub> is contained in and will remain within the reefs after injection activities cease and the wells are shut-in or closed; and (5) MDEQ rules state that an operator must demonstrate that the reservoir is wholly contained in the Unit Area before any EOR project is authorized.

The rationale used to delineate the MMA, as described in Core Energy's MRV plan, accounts for the existing operational and subsurface conditions at the site along with any possible changes in future operations. The proposed MMA supports a high level of confidence that monitoring over a sufficient area will be performed.

Therefore, the designation of the AMA as each reef system under development and/or production, both existing and potential, and the MMA designation that covers all potential reefs that could be the target for future CO<sub>2</sub>-EOR operations in the NNPRT, plus the 0.5-mile buffer, is reasonable.

The delineation of the MMA and AMA was determined to comply with 40 CFR 98.448(a)(1). The MMA and AMA described in the MRV Plan are clearly and explicitly delineated and are consistent with the definitions in 40 CFR 98.449.

### **3 Identification of Potential Surface Leakage Pathways**

As part of the MRV Plan, the reporter must identify potential surface leakage pathways for CO<sub>2</sub> in the MMA and the likelihood, magnitude, and timing, of surface leakage of CO<sub>2</sub> through these pathways pursuant to 40 CFR 98.448(a)(2). In their MRV plan, Core Energy identified the following as potential leakage pathways that required consideration:

- existing wellbores
- faults and fractures
- natural and induced seismic activity
- lateral migration
- diffuse leakage through the seal
- pipeline and surface equipment.

#### **3.1 Leakage through Existing Wells**

According to Section 4 of the MRV Plan, Core Energy asserts that leakage through wellbores that penetrate a reef, while the most likely pathway for leakage, is still not likely because of the implemented well construction specifications that are employed at their CO<sub>2</sub>-EOR operations. Core Energy's wells are composed of four strings of casing (conductor, surface, intermediate and total depth string), three of which are cemented in place; the surface casing is cemented all the way to the surface. All wells have

tubing strings run near the permitted injection zones. Injection wells require a packer attached to the tubing string, located no more than 100 feet above the permitted zone and mechanical integrity on injection wells must be established and maintained. Additionally, Core Energy complies with all regulatory requirements from state and federal agencies related to well drilling, completion and operation.

The MRV plan describes how previously drilled wells and plugged/abandoned wells are evaluated in an Area of Review, as required by state and federal regulations. **Figure 16** shows wellbore integrity rankings for all wells in Otsego County (green is high integrity), which is the county Core Energy currently has its operations in, and the number of wells that penetrate each reef. Further, it is stated in the MRV plan that all wells in northern Michigan have been ranked based on age, status, and depth, and Core Energy concludes that wells which penetrated the seals were ranked with high integrity because they are more recent wells and, therefore, adhere to the most current regulatory requirements.

In a study performed by MRCSP, cement plugs were also analyzed and ranked based on depth, number of plugs, thickness, and age and Core Energy concluded that plugged wells which penetrated the reefs and nearby off reef locations had sufficient plug placement and thickness to prevent leakage. Core Energy also researched leakage through the wellbore cement in the NNPRT. This research was based on analyzing several cement bond logs in the region and categorizing the bond index. From this work, the wells selected for this research that penetrated the reef were shown to have at least 50 feet of sufficient cement bond within the seal (**Figure 17** in the MRV plan) which is considered sufficient for industry standards. Finally, Core Energy tested several wells for sustained casing pressure after exposure to CO<sub>2</sub>, and no evidence of leakage was observed.

The MRV Plan states that continuous surveillance of injection parameters (particularly bottom hole pressure), routine inspections, and mechanical integrity testing (MIT) will reduce the risk of leakage from the injection wells. Additionally, as applied to other surface equipment, visual inspections of the well sites are performed on a weekly basis, which serves as a proactive and preventative method for identifying leaks in a timely manner. Mechanical integrity testing is conducted every 5 years. If mechanical integrity testing demonstrated a leak, the well would be isolated, and the leak would be mitigated as appropriate to prevent leakage to the atmosphere.

Finally, the highly-compartmentalized nature of the NNPRT reefs and the state requirements for drilling potential new wells in active and new reefs will prevent new wells from posing a threat of leakage. As discussed in section 2.1, the structure of each reef ensures that they are separated from each other and that there is no fluid communication along the wellbore. Moreover, Core Energy controls all the pertinent rights that would preclude (or allow) for a well to be drilled within its unit; thus, any future wells drilled in any of the reef systems of the NNPRT would be through Core Energy's operations and would fall under their previously described process and management strategies.

Based on this, the MRV plan provides an adequate characterization of the likelihood of a CO<sub>2</sub> leakage that could be expected from existing wells and from potential future drilling.

### **3.2 Leakage through Faults and Fractures**

The MRV plan states that while there are basement crustal features that affect formation thickness and may affect the tectonic movement of Paleozoic structures there are fewer identified faults in northern Michigan, the location of Core Energy operations. The faults that are present are deeper and do not influence the integrity of the caprocks/seals for the reefs in the NNPRT.

Thus, the MRV plan provides an adequate characterization of the minimal likelihood and potential volume of a CO<sub>2</sub> leakage that could be expected through faults and fractures.

### **3.3 Leakage from Natural and induced Seismic Activity**

The MRV plan states that there have been no recorded seismic events in northern Michigan, giving it a low risk of seismic activity (0-4%). The MRV plan also states that 2D and 3D seismic data near Core Energy's current location of operations confirm that there are no major structural features in that area.

Thus, the MRV plan provides an adequate characterization of the minimal likelihood of leakage from natural and induced seismic activity.

### **3.4 Leakage through Lateral Migration Outside of a Reef**

In the MRV plan, several factors are listed to demonstrate that lateral leakage of CO<sub>2</sub> outside the boundaries of a reef system is unlikely. First, containment is stated to be provided by the inherent reef geology, which consists of non-porous salts and evaporites along the flanks and overlying the reef structures. Second, Core Energy states that the operational procedures they use include injection and production monitoring from well-managed wells, and that these operational procedures will minimize the potential of any potential leakage. Third, Core Energy's periodic material balance associated with the measured reservoir fluids confirms that no CO<sub>2</sub> appears to have been lost to the surroundings from the reef to date. Finally, Core Energy asserts that containment is also validated by the numerical modelling undertaken for each of the reefs of interest.

Thus, the MRV plan provides adequate characterization of the minimal likelihood of CO<sub>2</sub> leakage that could be expected from lateral migration.

### **3.5 Leakage through the Formation Seal**

The seal for the reefs is the overlying Salina group and is composed of several hundred feet of salt, shale, and tight carbonate. The MRV plan states that leakage through the Salinas group is highly improbable, as it is a proven natural seal due to the containment of oil and gas which has been trapped in the reef structures over geologic time. The MRV plan states that additional pressure and geomechanical modeling of the seals in several reefs confirm the integrity of the confining units. Geomechanical analysis were also conducted using wireline logs and core tests for selected reefs and

the findings indicate the reservoir or caprock were not likely to fracture if the injection pressure is kept below the UIC permit pressure limit.

In fact, the MRV plan states that the fracture gradient in this area is 0.8 psi/ft, which equates to approximately 4,130 psi at a depth of 5,162 feet (the shallowest perforation in Core Energy reefs). The wellhead (surface) pressure equates to 1,761 psi. Most importantly, the maximum pressure the injection well tubing can experience is 1,400 psi, based on the pressure that can be delivered from the injection compressors. Thus, the fracture pressure is higher than can physically be realized within the well, implying little-to-no risk of fracturing the seals. Further, each CO<sub>2</sub> injection well is assigned a maximum surface injection pressure as a part of the EPA injection well permitting process, whose purpose is to ensure that the reservoir fracture pressure is not exceeded.

Thus, the MRV plan provides an adequate characterization of the minimal likelihood of a CO<sub>2</sub> leakage that could be expected through the formation seal.

### **3.6 Leakage from Surface Equipment**

Core Energy will use its routine maintenance and daily inspection procedures to minimize the risk of leakage from the pipelines and surface equipment. Core Energy's maintenance and procedural monitoring as described in the MRV plan provides an adequate characterization of the likelihood of a CO<sub>2</sub> leak that could be expected from surface equipment, with associated response procedures in place to appropriately respond should a leak occur.

## **4 Strategy for Detecting and Quantifying Surface Leakage of CO<sub>2</sub> and for Establishing Expected Baselines for Monitoring**

40 CFR 98.448(a)(3) requires that an MRV Plan contain a strategy for detecting and quantifying any surface leakage of CO<sub>2</sub>, and 40 CFR 98.448(a)(4) requires that an MRV Plan include a strategy for establishing the expected baselines for monitoring CO<sub>2</sub> surface leakage. Section 5 and portions of Section 2 of the MRV plan outlines Core Energy's approach to data collection and strategy for monitoring for CO<sub>2</sub> leakage, and includes monitoring of injection wells, well maintenance, monitoring of surface infrastructure, and field inspections. Section 6 gives Core Energy's approach for establishing baselines against which monitoring results are compared.

Core Energy uses Coriolis mass flow meters for all measurements that are included in the mass balance. Other metered input/output sites include recycled gas processing facilities, injection wells, HP separators, LP separators, and the outlet of the recycle compressor at Dover 36. Vortex flow meters are also used for some operational monitoring.

Core Energy's monitoring approach includes collecting flow, pressure, and gas composition data from each reef, which is then recorded in a central Human Machine Interface (HMI) computer system. Core Energy also uses the HMI computer system to record continuous production and injection data on a per-minute basis daily. Operators record flow rate totalizer readings from injection and production

parameters daily and visit the well sites daily to record well data (tubing pressure, casing pressures, and wellhead temperatures). These monitoring methods provide the basis for an accounting of the CO<sub>2</sub> acquired from the Dover 10 facility, injected into the reefs, and recycled at the Dover 36 facility.

Fluid composition will be determined quarterly to be consistent with Subpart RR specifications in section 98.447(a). The MRV plan states that all meter and composition data are documented, and records will be retained for the Specified Period. Any facilities added during the Specified Period would also be managed and monitored in the same manner.

If any leakage were to occur, Core Energy will use an event-driven process to assess, track and quantify the amount of CO<sub>2</sub> leakage at the surface.

#### **4.1 Injection/Production Zone Leakage**

For potential leakage from the injection/production zone, Core Energy states that it will rely on the continuous monitoring system to flag any anomalous results from general performance behavior and characteristics for a reef and evaluate as necessary. If leakage was detected, the plan states that an appropriate method would be used to quantify the leaked volume of CO<sub>2</sub>, such as using a material balance equation based on the history of injected quantities and monitored pressures. If no leak is detected at the surface, relevant parameters (rate, concentration, and duration) would be used to quantify the leakage volume to the subsurface, if suspected.

#### **4.2 Wellbore Leakage**

In the MRV plan, it is explained that the injection wells are outfitted with a Coriolis meter and receive routine maintenance and inspections. Mechanical integrity for injection wells is monitored through daily readings of casing pressure, quarterly fill-up tests and mandatory mechanical integrity tests (MIT) every five years. If a loss of mechanical integrity were to occur the well would be shut-in and repaired and an MIT would be performed once the workover was finished, all with oversight from the EPA. Any other well workovers would trigger evaluation and, if necessary, repairs. If CO<sub>2</sub> leakage occurs, Core Energy states that an appropriate approach for quantifying the leakage volume will be used and included in an internal Subpart W assessment performed for the Core Energy Facility.

#### **4.3 Equipment Leaks and Vented Emissions of CO<sub>2</sub>**

Core Energy estimates the leaks from surface equipment located between the injection flow meter and the injection wellhead, the surface equipment located between the production flow meter and the production wellhead, the CO<sub>2</sub> content of produced oil, and vented CO<sub>2</sub> according to the procedures in 40 CFR Part 98 Subpart W. Core Energy contracts with a third-party firm to determine Core Energy's emissions using the Subpart W methodology. This results in, an annual internal Subpart W report for Core Energy. Based on the results of this report to date, Core Energy does not meet the threshold for reporting its emissions to EPA under Subpart W; thus, these reports are only used internally, and will be used to report parameters under subpart RR that can use subpart W methodologies.



Core Energy's MRV plan adequately and appropriately describes both a strategy for detecting and quantifying any surface leakage of CO<sub>2</sub> based on the identification of potential leakage risks, as well as establishing baselines for monitoring against which potential suspected leaks can be identified, evaluated, and, if necessary, quantified.

Core Energy describes their use of onsite management and an automatic data system in sections 2.4.4. and 5 to conduct the EOR operations. Section 6 of the MRV plan describes how Core Energy will use data from these efforts to identify and investigate variances from expected performance that could indicate CO<sub>2</sub> leakage. Data that are collected and used as a baseline include visual inspections, injection well surveillance, production well surveillance, and mechanical integrity testing. The approach for the injection/production data is to track the following parameters: injection rate, production rates, tubing pressure, casing pressure, wellhead temperatures, and runtime. Additionally, reservoir pressure will be tracked using episodic surveys on a field and a well-to-well basis. Wellbore data that will be tracked include pressure monitoring in the injection zone, monitoring of the annular pressure in wellheads, routine maintenance and inspection, and MIT results.

**Table 1** provides general information on the leakage pathways, monitoring programs to detect leakage, and location of monitoring.

#### **4.4 Determination of Baselines for Monitoring CO<sub>2</sub> Surface Leakage**

Based on this described strategy, if results of the monitoring activities fall outside their normal predicted ranges, Core Energy will initiate an investigation to determine if a leak has occurred.

Pressure monitoring of injection wells, along with the operational and monitoring data determining the baseline, is an established way to detect leaks in the injection wells. Annular pressures in injection wells should be close to zero in normal operating conditions because the annulus is isolated by the tubing and packer from injection fluids. Any higher pressure would indicate a potential leak in either the tubing or the packer and would trigger further investigation. Mechanical integrity testing is conducted every five years for the injection wells.

Throughout Section 5 of the MRV Plan, Core Energy discusses how leaks will be quantified, using a combination of measurements, mass balance and engineering estimates, as appropriate. Fugitive leakage would be detected and managed as an upset event and calculated for that event based on operating conditions at that time.

The MRV plan provides an acceptable to detecting and quantifying surface leakage of CO<sub>2</sub> and for establishing expected baselines for monitoring and complies with subpart RR.

**Table 1. Leakage Pathways, and Proposed Monitoring Programs and Locations**

<b>Leakage Pathway</b>	<b>Detection Monitoring Program</b>	<b>Monitoring Location</b>
Wells	<ul style="list-style-type: none"> <li>• DCS Surveillance</li> <li>• Daily Inspections</li> <li>• MIT</li> </ul>	Injection well – from wellhead to injection formation
Faults and Fractures	N/A – Leakage pathways are found by the MRV plan to be highly improbable.	N/A
Natural and induced seismic activity	N/A – Seismic activity is found by the MRV plan to be highly improbable.	N/A
Lateral Migration	N/A – Leakage pathways are found by the MRV plan to be highly improbable.	N/A
Formation Seal	N/A – Leakage pathways are found by the MRV plan to be highly improbable.	N/A
Surface Equipment	<ul style="list-style-type: none"> <li>• HMI Computer System</li> <li>• Daily Inspections</li> </ul>	From injection flow meter to injection wellhead and from production flow meter to injection wellhead

## 5 Considerations Used to Calculate Site-Specific Variables for the Mass Balance Equation

Under Subpart RR, a reporter who is actively producing oil or natural gas is required to calculate the amount of CO<sub>2</sub> sequestered using equation RR-11 per 40 CFR 98.443(f)(1). The equation is:

$$CO_2 = CO_{2I} - CO_{2P} - CO_2 - CO_{2 I} - CO_{2 P}$$

where:

CO<sub>2</sub> = Total annual CO<sub>2</sub> mass sequestered in subsurface geologic formations (metric tons) at the facility in the reporting year.

CO<sub>2I</sub> = Total annual CO<sub>2</sub> mass injected (metric tons) in the well or group of wells covered by this source category in the reporting year.

CO<sub>2P</sub> = Total annual CO<sub>2</sub> mass produced (metric tons) net of CO<sub>2</sub> entrained in oil in the reporting year.

$CO_{2E}$  = Total annual  $CO_2$  mass emitted (metric tons) by surface leakage in the reporting year.

$CO_{2FI}$  = Total annual  $CO_2$  mass emitted (metric tons) from equipment leaks and vented emissions of  $CO_2$  from equipment located on the surface, between the flow meter used to measure injection quantity and the injection wellhead in the reporting year, calculated as provided in subpart W.

$CO_{2FP}$  = Total annual  $CO_2$  mass emitted (metric tons) from equipment leaks and vented emissions of  $CO_2$  from equipment located on the surface between the production wellhead and the flow meter used to measure production quantity in the reporting year, calculated as in Subpart W and including the metered  $CO_2$  measurements at the wet and dry vents attached to the separators

Core Energy explains its approach to calculating each of these variables in Section 7 of the MRV Plan.<sup>1</sup>

### **5.1 Mass of $CO_2$ Injected into the Subsurface**

The volume of  $CO_2$  injected will be tracked at the injection wells that are active at each of the ten reefs. Core Energy will use equation RR-4 (in §98.443) to calculate the mass of  $CO_2$  injected. Core Energy will calculate " $C_{CO_2,p,u}$ " using a weighted average that accounts for the different  $CO_2$  concentrations in the different sources of  $CO_2$ . This approach is described in Section 7.2 in the MRV Plan.

Core Energy's proposed approach for calculating the mass of  $CO_2$  injected into the subsurface is consistent with the subpart RR requirements.

### **5.2 Mass of $CO_2$ Produced**

The Coriolis mass flow meters are used to measure the  $CO_2$  in produced fluids per Equation RR-7 and  $CO_2$  entrained in oil is accounted for per Equation RR-9. Core Energy will determine a quarterly  $CO_2$  concentration for the recycle gas at Dover 36 Facility flow meter #19 to use in calculating  $CO_2$  produced. Equations RR-7 and RR-9 will be used to calculate the total mass produced for that quarter.

Core Energy's proposed approach for calculating the mass of  $CO_2$  produced is consistent with the subpart RR requirements.

---

<sup>1</sup> Although total annual  $CO_2$  mass received is not an input variable to the mass balance equation for calculating the amount of  $CO_2$  sequestered, the MRV plan explains how Core Energy will calculate the total mass of  $CO_2$  received. Core Energy will track  $CO_2$  received from the Chester 10 capture operations and recycle gas from the Dover 36 capture operations using Coriolis mass flow meters. Core Energy will use equation RR-1 to calculate the mass of  $CO_2$  received for each mass flow meter and will use equation RR-3 to calculate the sum of  $CO_2$  received across all flow meters (per §98.443). To account for the  $CO_2$  currently in inventory within the reef complex, Core Energy will track the current and cumulative volume of  $CO_2$  from the Dover 36 capture operations and will indicate when it has reached the inventory amount of 2,110,000 metric tons. This inventory reflects  $CO_2$  that has previously been injected into Core Energy-operated reefs but has not yet been utilized for  $CO_2$ -EOR operations. After that amount is reached, the mass will continue to be tracked. Core Energy's proposed approach for calculating the total annual mass received is consistent with the subpart RR requirements.

### 5.3 Mass of CO<sub>2</sub> Emitted by Surface Leakage and from Equipment Leaks and Vented Emissions

Core Energy plans to address potential leakage in a manner that is tailored to the leakage event, type and location. Estimates of any leakage will be determined by available measurements, engineering estimates, and emission factors depending on the site-specific factors. The MRV plan describes the potential approaches for quantification of leaks in Sections 5.5 – 5.7. If a leak were to occur, Core Energy would quantify and report the leakage amounts and retain a record of the event with descriptions of actions taken to address the leakage. Core Energy states in the MRV plan that it will reconcile leakage estimates from their internal Subpart W report with the results from any event-driven quantification to assure that surface leaks are consistent. Equation RR-10 would be used to calculate and report the mass of CO<sub>2</sub> emitted by surface leakage.

Subpart RR allows subpart W methods to be used to calculate leaks from equipment between meters used to measure CO<sub>2</sub> injected and produced and the wellheads (i.e., equipment leaks that take place while the CO<sub>2</sub> is being measured, processed, or transported at the surface). Core Energy will reconcile their internal Subpart W report and results from any event-driven quantification to assure that surface leaks are not double-counted.

This approach is consistent with subpart RR requirements for calculating emissions from equipment leakage, vented emissions, and surface leakage.

### 5.4 Mass of CO<sub>2</sub> Sequestered in Subsurface Geologic Formations

Core Energy will use equation RR-11 to determine the mass of CO<sub>2</sub> that is incidentally stored each year. For the cumulative mass of CO<sub>2</sub> sequestered Core Energy will sum the total annual volumes.

## 6 Summary of Findings

The subpart RR MRV Plan for Core Energy’s CO<sub>2</sub> EOR Facility meets the requirements of 40 CFR 98.238. The regulatory provisions of 40 CFR 98.238(a), which specifies the requirements for MRV plans, are summarized below, along with a summary of relevant provisions in Core Energy’s MRV Plan.

Subpart RR MRV Plan Requirement	Core Energy MRV Plan
40 CFR 98.448(a)(1): Delineation of the maximum monitoring area (MMA) and the active monitoring areas (AMA).	Section 3 of the MRV Plan describes the MMA and AMA. The MMA is given in Figure 14 and encompasses most of the NNPRT. The AMA is defined by the boundary of the Unit Area of each individual reef/field as established in the Order by the Supervisor of Wells for the MDEQ authorizing each EOR project.
40 CFR 98.448(a)(2): Identification of potential surface leakage pathways for CO <sub>2</sub> in the MMA	Section 4 of the MRV Plan identifies and evaluates potential surface leakage pathways.

<p>and the likelihood, magnitude, and timing, of surface leakage of CO<sub>2</sub> through these pathways.</p>	<p>The MRV Plan identifies the following most likely potential pathways: leakage from existing wellbores, faults and fractures, natural and induced seismic activity, lateral migration outside of a reef, diffuse leakage through the seal, and pipeline/surface equipment leakage. The MRV Plan analyzes the likelihood, magnitude, and timing of surface leakage through these pathways. Core Energy determined that leakage pathways are highly improbable to minimal at the NNPR CO<sub>2</sub> EOR facility, and it is very unlikely that potential leakage conduits would result in significant loss of CO<sub>2</sub> to the atmosphere.</p>
<p>40 CFR 98.448(a)(3): A strategy for detecting and quantifying any surface leakage of CO<sub>2</sub>.</p>	<p>Section 5 of the MRV Plan describes how the facility would detect CO<sub>2</sub> leakage to the surface, such as monitoring of existing wells, field inspections, and pressure monitoring. Sections 5 and 7 of the MRV Plan describe how surface leakage would be quantified.</p>
<p>40 CFR 98.448(a)(4): A strategy for establishing the expected baselines for monitoring CO<sub>2</sub> surface leakage.</p>	<p>Section 6 describes how historical results from daily monitoring of field conditions and operational data, as well as routine testing and maintenance information, will be used to monitor for possible surface leakage. Part of this data collection will include accruing well pressure survey histories for injection and production wells to determine each well's general performance behavior. In addition, visual inspections, injection well surveillance, production well surveillance, and mechanical integrity testing will also establish a baseline against which monitoring for surface leakage will be based.</p>
<p>40 CFR 98.448(a)(5): A summary of the considerations you intend to use to calculate site-specific variables for the mass balance equation.</p>	<p>Section 7 of the MRV Plan describes Core Energy's approach to determining the amount of CO<sub>2</sub> sequestered using the subpart RR mass balance equation, including as related to calculation of total annual mass injected, and calculation of total annual mass emitted as equipment leakage.</p>
<p>40 CFR 98.448(a)(6): For each injection well, report the well identification number used for the UIC permit (or the permit application) and the UIC permit class.</p>	<p>Appendix I of the MRV plan provides well identification numbers for each well. The MRV Plan specifies that injection wells are permitted as UIC Class II.</p>
<p>40 CFR 98.448(a)(7): Proposed date to begin collecting data for calculating total amount</p>	<p>The MRV Plan states that Core Energy will begin implementing this MRV plan beginning January 1, 2018.</p>

sequestered according to equation RR-11 or RR-12 of this subpart.	
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## **Appendix A: Final MRV Plan**

**Core Energy**

**Northern Niagaran Pinnacle Reef Trend (NNPRT)  
CO<sub>2</sub> Monitoring, Reporting, and Verification (MRV) Plan**

September, 2018



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## Introduction

Core Energy LLC (Core Energy) operates an integrated carbon dioxide (CO<sub>2</sub>) capture and enhanced oil recovery (EOR) facility in the Northern Niagaran Pinnacle Reef Trend (NNPRT) in Michigan. The Core Energy facility includes equipment to capture CO<sub>2</sub> from various sources, dedicated pipelines, a set of subsurface geologic reef formations, and equipment to process oil.

Core Energy joined the Midwest Regional Carbon Sequestration Partnership (MRCSP) in 2005 and has worked closely with the research team to advance the technical understanding of the reefs and the regional geology in the context of ongoing EOR operations. This research demonstrates that CO<sub>2</sub>-EOR results in incidental CO<sub>2</sub> storage in the reefs at the end of the CO<sub>2</sub>-EOR life cycle. Core Energy intends to inject CO<sub>2</sub> with a secondary purpose of establishing long-term containment of a measurable quantity of CO<sub>2</sub> in subsurface geological formations in the NNPRT for a term referred to as the "Specified Period."

The MRCSP regional geologic characterization indicates that there is potential capacity for hundreds of millions tonnes of CO<sub>2</sub> through ancillary CO<sub>2</sub> EOR storage in the NNPRT. This potential far exceeds the amount of CO<sub>2</sub> available for EOR and, ultimately, ancillary storage capacity. This means that Core Energy anticipates being limited by the amount of available CO<sub>2</sub> in the future rather than by the amount of economically viable CO<sub>2</sub> EOR opportunity. In addition, the nature of the reef geology, as described in Section 2, provides operational flexibility that is much like buffer storage capacity. As a result, Core Energy anticipates continuing its business practice of capturing as much CO<sub>2</sub> as it can while the Antrim Shale play is still active and storing it within the reef system to support its EOR operations. Since it began operations, Core Energy has developed an inventory of anthropogenic CO<sub>2</sub> that is in circulation within the existing reef structures. Calculation of this inventory of working CO<sub>2</sub> is discussed further in Section 2.

During the Specified Period, Core Energy will utilize the working inventory of CO<sub>2</sub> through capture at the Dover 36 Facility and combine it with new CO<sub>2</sub> captured through the Chester 10 Facility. Over time, the mass balance calculation of stored CO<sub>2</sub> will reflect the existing inventory of CO<sub>2</sub> plus the new CO<sub>2</sub>, as discussed in Sections 2, 5, and 7. Core Energy plans to further expand the amount of CO<sub>2</sub> introduced to the field if new sources become available. This additional amount would also be reflected in the mass balance calculation of stored CO<sub>2</sub>.

Core Energy developed this monitoring, reporting, and verification (MRV) plan in accordance with 40 CFR §98.440-449 (Subpart RR) to provide for the monitoring, reporting and verification of the quantity of CO<sub>2</sub> sequestered at the Core Energy facility during the Specified Period. This plan describes how CO<sub>2</sub> EOR and ancillary storage take place in the reefs and how Core Energy will apply the requirements in 40 CFR §98.440-449 (Subpart RR) to calculate the annual amount of CO<sub>2</sub> stored throughout the entire Core Energy CO<sub>2</sub> EOR facility

In accordance with Subpart RR, flow meters are used to quantify the mass of CO<sub>2</sub> received, injected, produced, contained in products, and lost through venting or leakage. If leakage is detected, the mass of leaked CO<sub>2</sub> will be quantified using three approaches. First, Core Energy follows the procedures in 40 CFR §98.230-238 (Subpart W) to quantify fugitive emissions, planned and unplanned releases of CO<sub>2</sub>, and other surface releases from equipment. Second,

Core uses orifice type flow meters installed at its Wet and Dry Vent locations to measure the mass of recycle gas that is vented. And finally, Core Energy's risk-based monitoring program uses surveillance techniques in the subsurface and above ground to detect CO<sub>2</sub> leaks from potential subsurface leakage pathways. The CO<sub>2</sub> mass data, including CO<sub>2</sub> mass at different points in the injection and production process, equipment leaks, and surface leaks, will be used in the mass balance equations included in 40 CFR §98.440-449 (Subpart RR) to calculate the mass of CO<sub>2</sub> stored on an annual and cumulative basis.

**This MRV plan contains 12 sections:**

- Section 1 contains general facility information.
- Section 2 presents the project description. This section describes the geologic setting, reservoir modeling of the reefs, the operational history in the area, and the Core Energy facility operations.
- Section 3 describes the monitoring area for the Core Energy facility.
- Section 4 presents the evaluation of potential pathways for CO<sub>2</sub> leakage to the surface and demonstrates that the potential for leakage through pathways other than the man-made well bores and surface equipment is minimal.
- Section 5 describes Core Energy's risk-based monitoring process.
- Section 6 describes the baselines against which monitoring results will be compared to assess whether changes indicate potential leaks.
- Section 7 describes Core Energy's approach to determining the mass of CO<sub>2</sub> stored using the mass balance equations in 40 CFR §98.440-449, Subpart RR of the Environmental Protection Agency's (EPA) Greenhouse Gas Reporting Program (GHGRP).
- Section 8 presents the schedule for implementing the MRV plan.
- Section 9 describes the quality assurance program to ensure data integrity.
- Section 10 describes Core Energy's record retention program.
- Section 11 contains References.
- Section 12 contains Appendices.

**Technical Notes:**

1. Unless otherwise stated, this document uses the term "tonnes" to indicate metric tons (MT).

2. All calculations and reporting will be done on a metric ton basis (1000 kgs to 1 MT). Anytime CO<sub>2</sub> numbers are reported on a volume basis, Core Energy will utilize a conversion factor of 0.019 million cubic feet (MMCF), or 19,000 cubic feet, of CO<sub>2</sub> per metric ton of CO<sub>2</sub>. This translates to approximate conversion between weight basis to volume basis of CO<sub>2</sub> at 60° F, 1 atm (~1.87 kg/m<sup>3</sup> density).

**1. Facility Information**

- i) Reporter number – 545462
- ii) US Environmental Protection Agency (USEPA) (Region V) administers the Underground Injection Control (UIC) program for all classes of injection wells in Michigan. The Michigan Department of Environmental Quality (MDEQ) Oil, Gas and Minerals Division (OGMD) administers the statutes and rules subject to Part 615, Supervisor of Wells, of the Natural Resources and Environmental Protection Act, 1994, PA 451, as amended (NREPA). The injection wells operated by Core Energy are permitted as UIC Class II wells by US EPA and all wells (including production, injection and monitoring wells) are regulated by OGMD.
- iii) As of April 2018, there are 36 active wells penetrating the Niagaran reefs operated by Core Energy and there are additional wells that have been plugged and abandoned. A summary of these wells is included in Appendix I. Table A-1 indicates the active wells and includes the unit (reef), processing facility, API and MDEQ permit numbers, well name, depth and status. Table A-2 lists all wells that penetrate the reefs and includes reef, permit number, well name, well number, completion depth and date, type, and a wireline log inventory. Changes to the well inventory will be included in annual reporting.

**2. Project Description**

Core Energy operates in the upper north portion of Michigan in what is known as the NNPRT. (Figure 1).

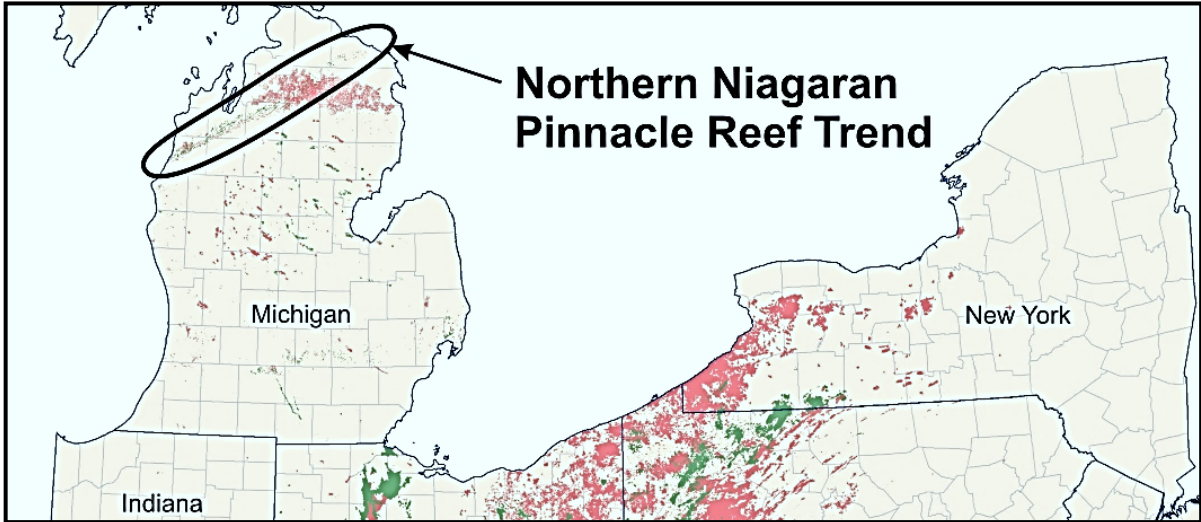


Figure 1 - General location of Core Energy operations

The NNPRT consists of closely spaced but highly-compartmentalized pinnacle reefs located, on average, about 6,000 feet below the ground surface (bgs) but can range from 3,000 to 8,000 feet (Most of the oil- and gas-producing reefs along the NNPRT are at depths of approximately 3500 to 5500 feet). This formation began as a series of coral reefs that formed millions of years ago in a setting similar to what we now observe in the Bahamas or Great Barrier Reef.

Since the reefs formed, sediments and other debris were deposited in layers around and above the reefs, forming hard structures that are excellent for containing the oil and gas that collected in them when the ocean receded and the corals died. It is estimated that in northern Michigan alone, such reefs could sequester several hundred million tonnes of CO<sub>2</sub>.

Data was compiled for all reefs including data from ten cores and covering five Core Energy reefs: Bagley, Chester 16, Dover 33, Chester 2 and Chester 5. Core analyses included descriptions, photographs, porosity and permeability measurements, and advanced analyses in select cores. More than 40 additional Niagaran cores were collected in Otsego County with data available at the Michigan Geologic Repository for Research and Education (MGRRE).

Core Energy also collected 3D seismic data for nine reefs: Chester 16, Dover 33, Dover 35, Dover 36, Chester 2, Chester 5, Charlton 19, Charlton 30/31, and Charlton 6 (Figure 2). The data was used to identify the boundary of the reef edges and verify that there are no structural concerns in the area. Where 3D seismic data is not available, formation tops, thicknesses, and production are used along with nearby reefs to define the boundaries.

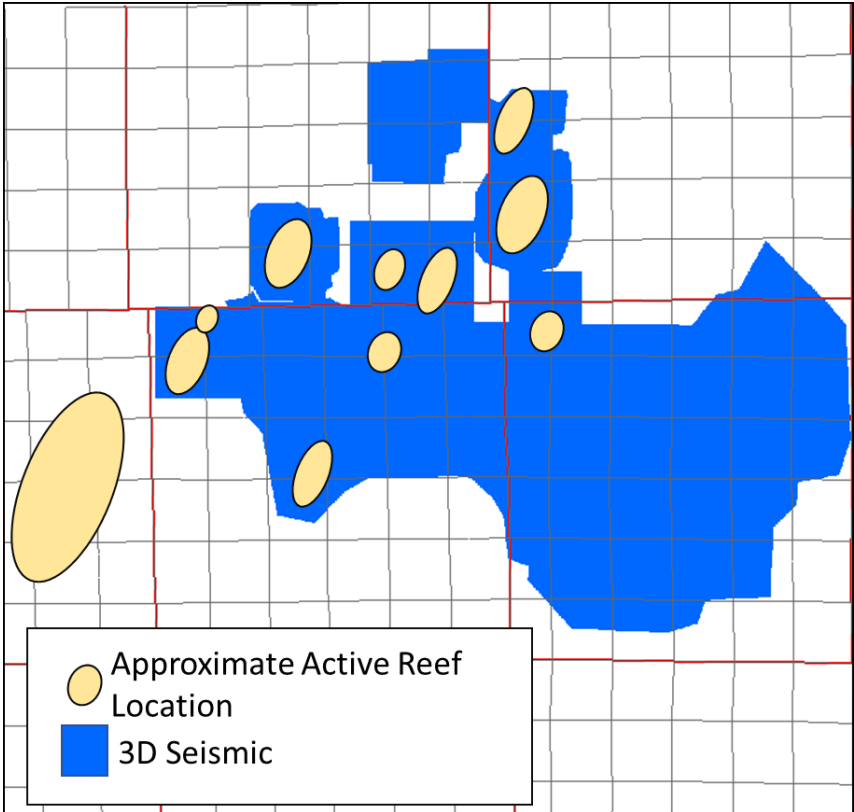
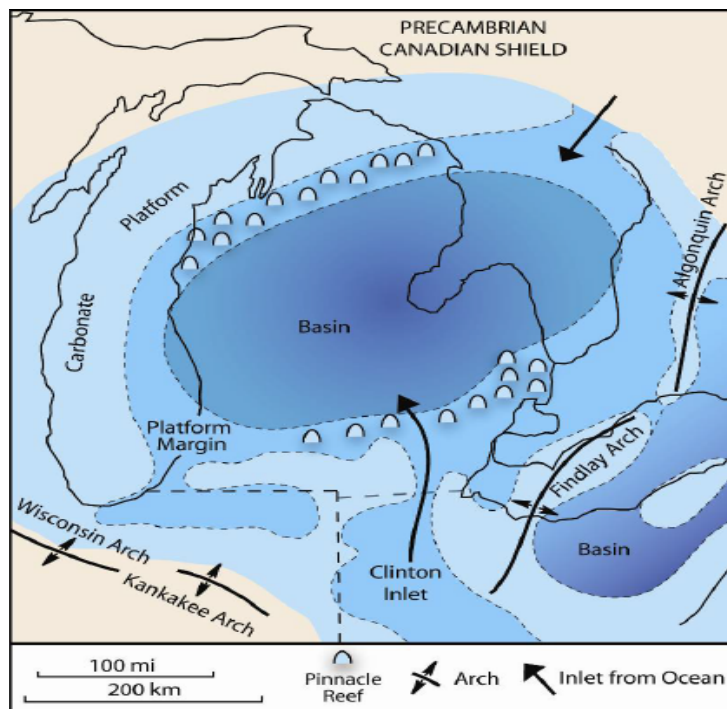


Figure 2: Map of approximate active reef locations (yellow) and 3D seismic (blue).

## 2.1 Geologic Setting

The NNPR is part of an extensive paleo shallow shelf carbonate depositional system. The trend of pinnacle reefs forms a circular belt along the platform margin that rings the Michigan Basin (Figure 3). Most of the oil- and gas-producing reefs along the NNPR are at depths of approximately 3500 to 5500 feet. While individual reef complexes are localized (averaging 50 to 400 acres in area), they may be up to 2000 acres in areal extent and 150 to 700 feet in vertical relief with the steeply dipping flanks. Reef height, pay thickness, burial depth, and reservoir pressure increase towards the basin center (Gill 1979). Currently, there are approximately 800 fields in the NNPR and approximately 400 in the Southern Niagaran Pinnacle Reef Trend (SNPR) of the Michigan Basin.

The NNPR is generally divided in an updip direction into gas, oil, and water-saturated zones (Gill 1979). The reservoir facies primarily consist of porous and permeable dolomite and limestone. Some reefs are completely dolomitized, while others are essentially all limestone. Dolomitization of reefs increases as the reefs become shallower, and salt and anhydrite plugging of porosity occurs in the deeper reefs (Gill 1979). Effective porosity intervals for the reservoir range from only a few feet to several hundred feet from reef to reef. Porosity values extend to 35%, but typically average 3-12%; the best porosity and permeability are associated with dolomitized reef core and flank facies. The best reservoir rocks are characterized by well-developed inter-crystalline and vuggy porosity with average permeability values of 3 to 10 millidarcies. Secondary porosity can significantly enhance permeability within the reservoir.



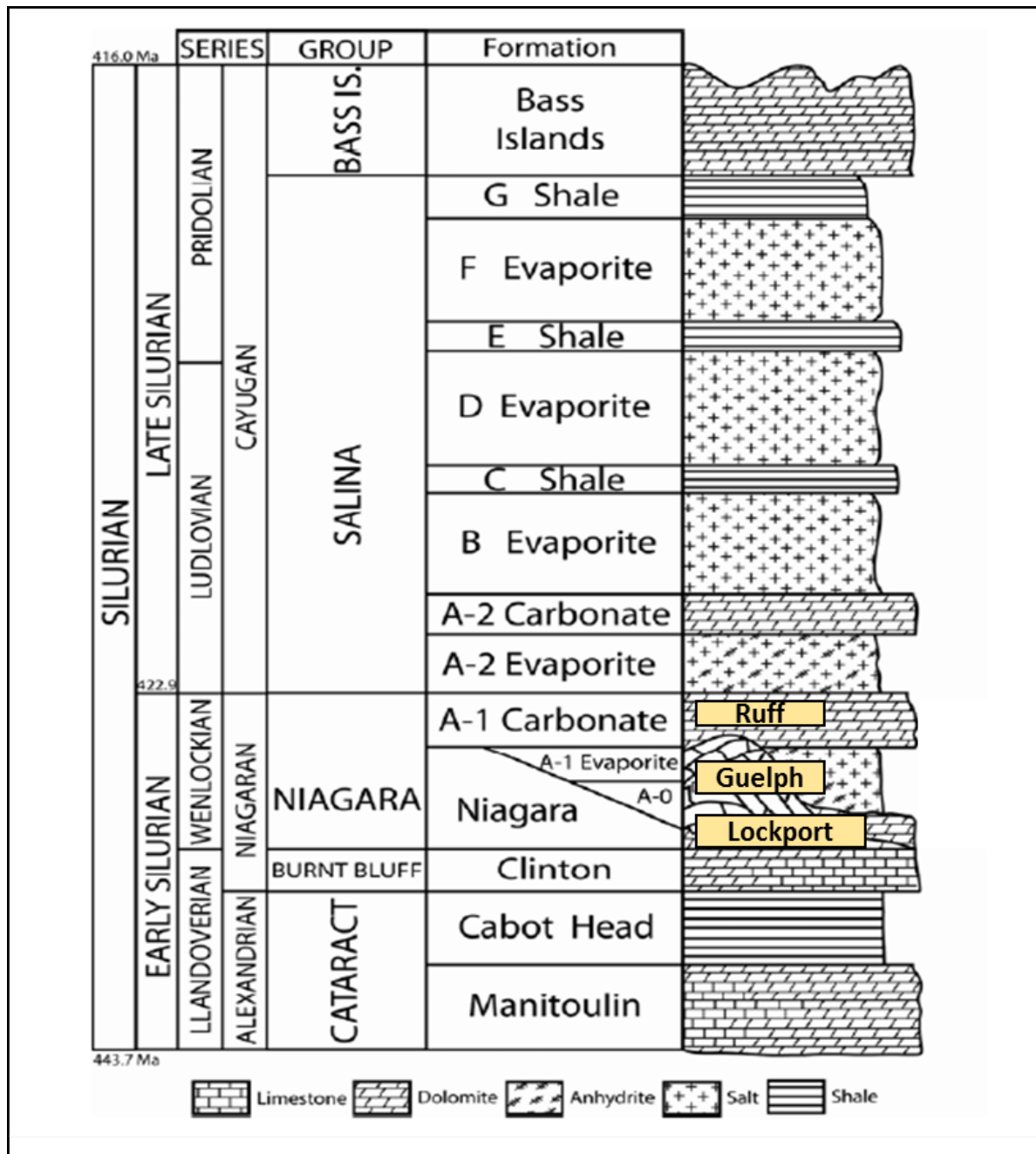
Ritter (2008), modified from Briggs and Briggs (1974)

Figure 3: Carbonate platform and Basin setting during NNPR development in Michigan.



The reef facies developed within the Niagara Group and includes the Lockport and Guelph lithostratigraphic formations (Figure 4). The Lockport Formation is characterized by two types of crinoidal wackestones: dolomitized and low-porosity, undolomitized (Charbonneau 1990). The Lockport reaches a thickness of approximately 500 feet near the basin margins, but thins and has a more reddish color toward the center of the Basin (Huh 1973; Huh et al. 1977; Charbonneau 1990). The Lockport is frequently referred to as the “White Niagaran” but grades upward into a gray argillaceous, nodular crinoidal wackestone. The Guelph Formation contains the informal “Gray Niagaran” and the “Brown Niagaran”. The Guelph “Brown Niagaran” consists of skeletal wackestones, packstones, grainstones, and boundstones/bindstones associated with the carbonate pinnacle reef buildups. It includes thin off-reef carbonate detrital/conglomerate lithofacies below the A-0 carbonate (Huh 1973). The Guelph Formation forms the core of the reservoir rocks associated with producing reefs.





Ritter (2008), modified from Cercone (1984).

Figure 4. Generalized Stratigraphic Column for the Silurian Section noting Niagaran reefs.

The seals for the Niagaran reefs consist of a series of evaporites and salt-plugged carbonates that encase the flanks of the reefs and form regional seals over the entire reef complex (see Figure 4). The A-1 and A-2 evaporites regionally transition from salt off the reefs to anhydrites over the tops of the reef. The A-1 evaporite generally thins or is not present over the tops of the reef but forms restricted seals along the flanks of the reefs. MRCSP studied five representative reefs in detail: Chester 16, Dover 33, Charlton 19, Bagley 11-14-23, and Chester 2. This study included acquiring a full suite of density and acoustic logs in order to characterize the rapid changes in the composition of the evaporites surrounding the reef flanks. These data enabled

the MRCSP to understand and map reservoir porosity, seal integrity, and seismic response and are discussed below.

The A-1 carbonate belongs to the Ruff Formation and overlies the A-1 evaporite. It is a light-brown to tan, fine to medium crystalline, laminated, dolomitic mudstone and stromatolitic or microbial laminated boundstones, which may show truncation surfaces and rip-up clasts (Huh 1973; Gill 1973; Ritter 2008). Laminated, dolomitic mudstones occur in inter-reef deposits and on the reef; dolomitic microbial boundstone facies unconformably overlie the Brown Niagaran skeletal deposits (Gill 1973). The A-1 carbonate generally seals the flanks of the reefs, but some reservoir zones within the carbonate can be developed on the crests of the reefs.

Figure 5 illustrates the internal structure and geometry of reefs as well as their development cycle. This knowledge is important for predicting areas of best reservoir within the reef. The building of a Niagaran reef was initiated by carbonate mud-rich bioherm accumulation in warm, calm, shallow waters. The bioherm grew as sea level rose, following the prime conditions where biohermal organisms thrive (Stage 1). As sea level continued to rise, the reef core developed, dominated by corals and stromatoporoids. The wind direction during time of reef building was important because it created asymmetry within the reef (Rine 2015). The windward direction developed reef rubble where pieces of the reef core broke off and reduced in size by wave water impact. The leeward side developed a muddy detrital grain apron as fine-grained material sloughed off the reef. (Stage 2). When relative sea level stabilized, stromatolitic algal caps formed over top of the reef and created an intertidal, depositional environment. Next, as sea level fell within the Michigan Basin, the reef complex was exposed (Stage 3), and the living reef was killed. Evaporites such as salt and anhydrites were deposited along the flanks of the reefs and diagenesis occurred within the reef core. As post-Niagaran sea level rose and fell, layers of carbonates and evaporites were deposited over the reef complex (Stage 4).

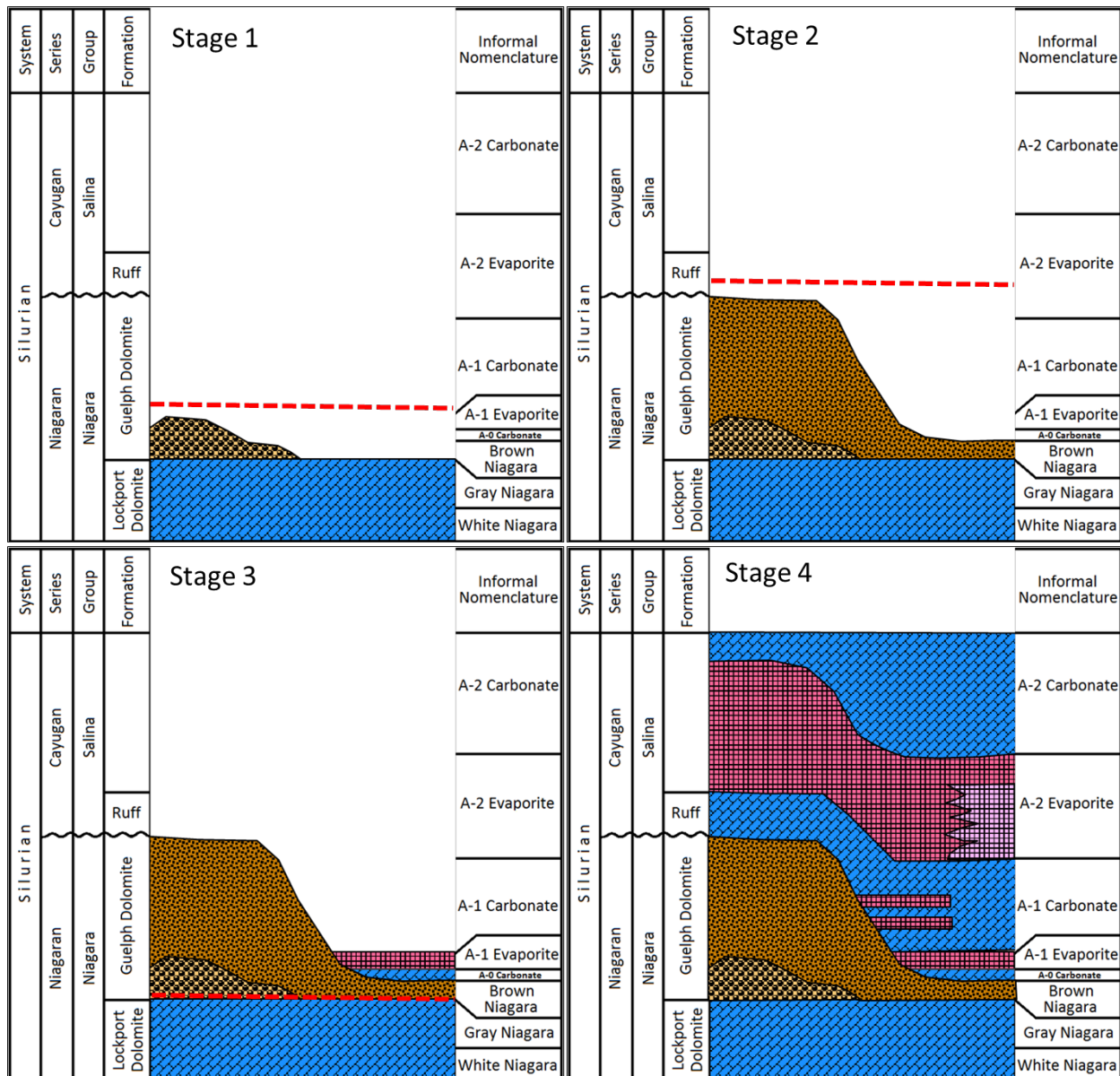


Figure 5: Simplified diagrams of the stages of Niagaran reef development. Red dashed line denotes approximate sea level relative to reef growth.

## 2.2 Reef Reservoir Characterization and Modeling

This subsection of the MRV plan describes the modeling that was developed to characterize the NNPRT reefs operated by Core Energy, Core Energy's understanding of the behavior of EOR operations in the reefs as indicated by the models, and the procedures going forward to use and or expand the modeling to determine which new reefs to include in operations as well as the operations plans for those reefs.

Core Energy worked with MRCSP to model six representative reef reservoirs. The key objectives of this modeling were to develop a detailed understanding of each modeled reef as well as the predictability of internal reef architecture. The modeling was successful in achieving both aims. Going forward, Core Energy does not plan to develop detailed models for each new

reef but will draw on a set of transferable principles from existing modeling that can be applied in operations and improving CO<sub>2</sub> flood performance.

2.2.1 Model Development

MRCSP used Static Earth Models (SEMs) to integrate all available geologic and geophysical information into a single framework used to conceptualize CO<sub>2</sub> migration and retention in the subsurface (Figure 6). The SEMs also provide the basis for incorporating geologic information into dynamic models for the reservoirs. The building of SEMs was an iterative process with multiple stages of quality checks to develop an SEM most representative of geology and reservoir properties. To build SEMS and dynamic models, the following information was integrated by geologists and engineers:

- Reef geometry (seismic and/or production), well locations and construction, formation depth and thickness, and delineation of lithofacies
- Rock properties including porosity, permeability, and fluid saturations from core and wireline log data
- Fluid flow such as density and viscosity of fluids, relative permeability, capillary pressure, and fluid phase

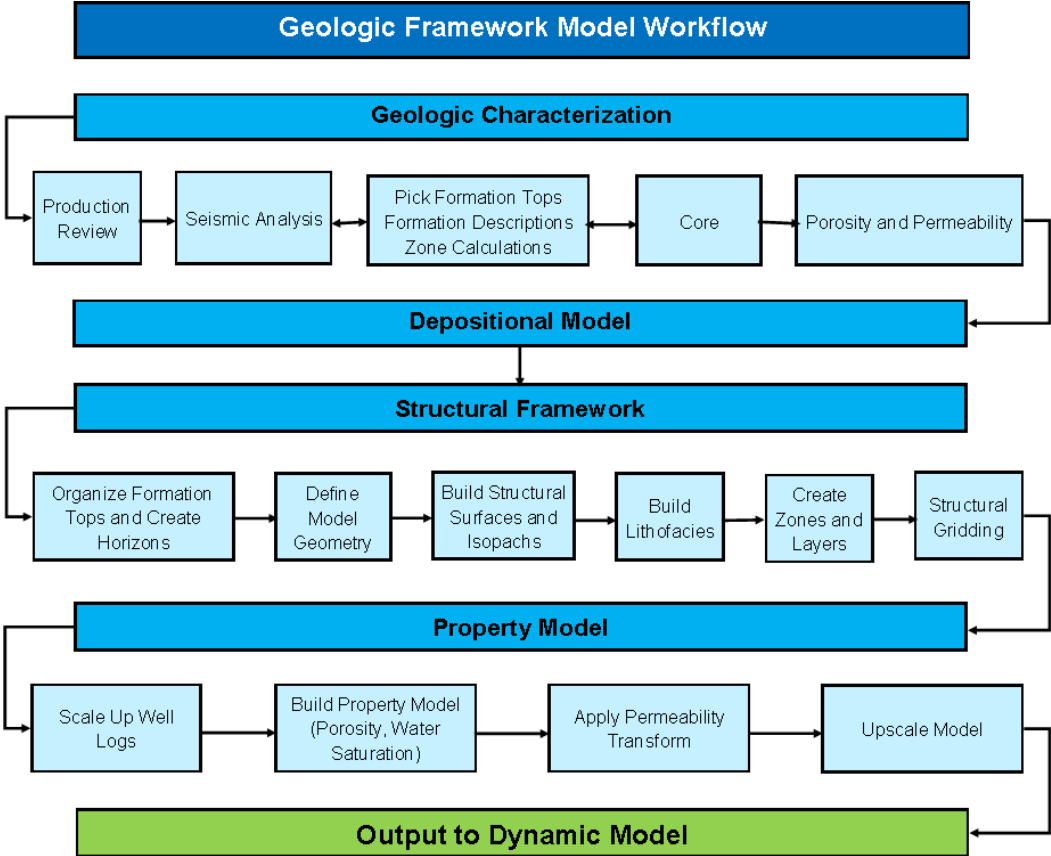


Figure 6: Typical geologic characterization and modeling workflow for reefs.



The modeling workflow began with geologic characterization of a reef which incorporated and integrated all information and data to develop a conceptual/depositional model. Figure 7 illustrates a 2D cross section through one such reef (Chester 16) with formations and reservoir flags. SEMs were then constructed using a conceptual geologic model, which allows for predictability of both vertical and horizontal lithofacies distributions by use of whole core and wireline log data. Figure 8 is an example 2D slice through a 3D SEM of Chester 16 (A) and Dover 33 (B) showing porosity distributions. Once SEMs were complete, they were outputted for dynamic modeling.

Dynamic modeling was used to history match with production records, simulate fluid flow and pressure changes, and assist with well design and CO<sub>2</sub>-EOR flood configuration design.

Basic geologic characterization is used to define the reef, describe formations, and identify reservoir and caprocks. Advanced geologic characterization and modeling are typically used to aid in planning or when a reef does not perform as expected. While Core Energy does not do the same level of characterization and modeling for each reef, lessons learned from advanced modeling show the predictability of internal reef architecture. Core Energy combines the knowledge gained from modeling regarding CO<sub>2</sub> flows within reef architecture along with the feedback from material balance and pressure monitoring and response to develop operational plans for CO<sub>2</sub> EOR.

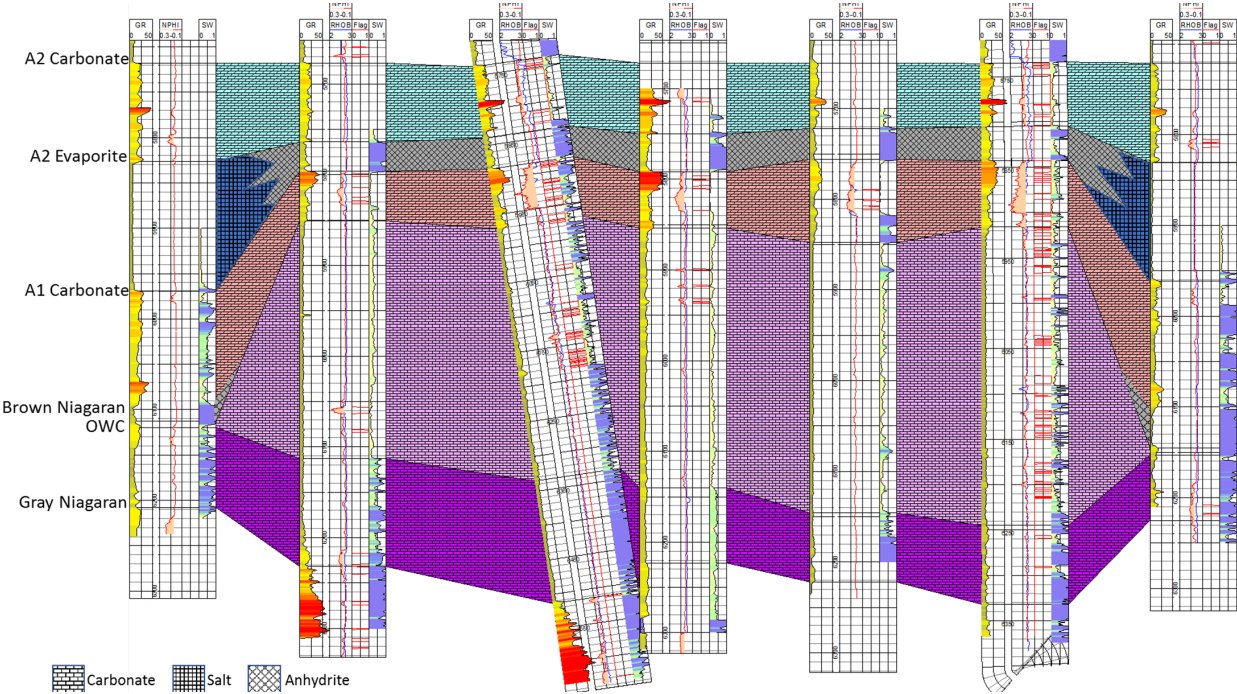


Figure 7: Example 2D conceptual model and geologic characterization of a reef.

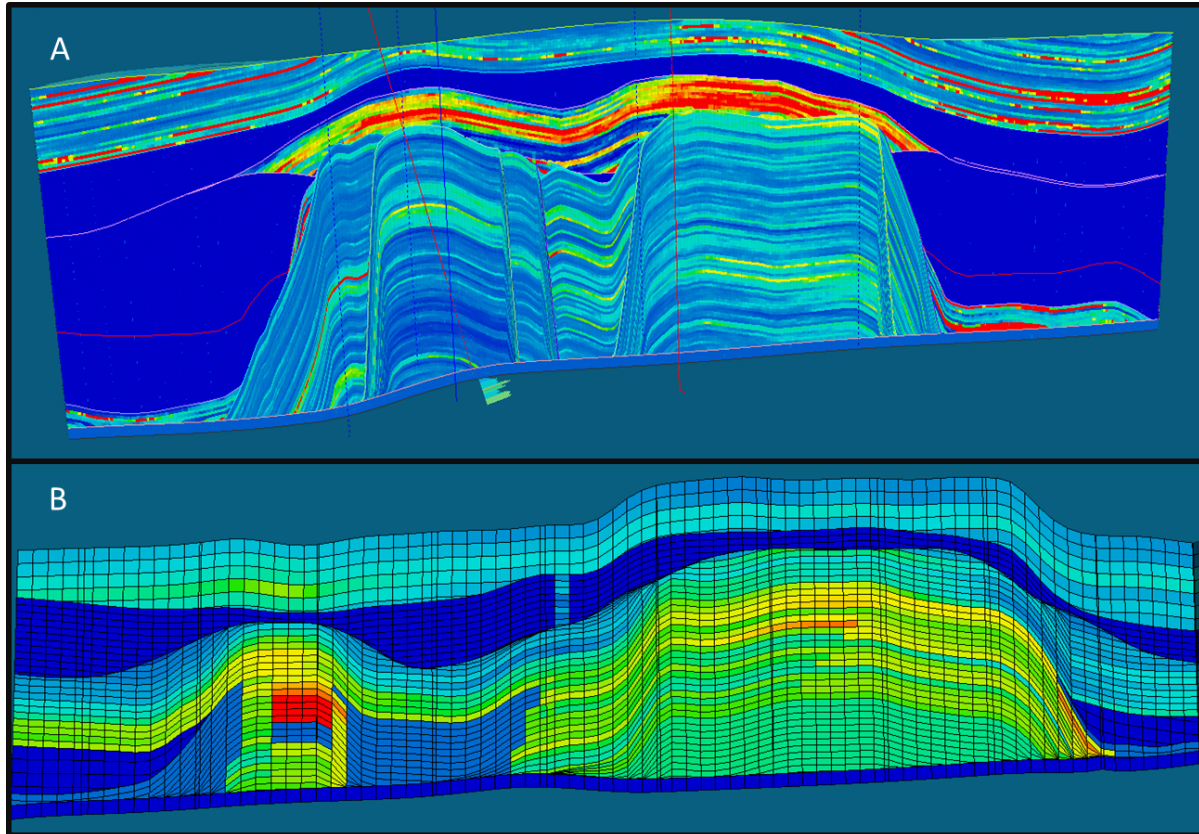


Figure 8. Example slice through a 3D SEM showing porosity distribution through Chester 16 (A) and Dover 33 (B)

Core Energy in collaboration with MRCSP has completed a significant amount of characterization and modeling on select reefs (Figure 9). To date, all 10 reefs have undergone basic geologic characterization to develop a 2D conceptual model of the reef. Five reefs have been developed into SEMs and taken into dynamic modeling. Even though the reefs have variable reservoir properties, there are predictable controls on reservoir performance such as amount of dolomitization, secondary porosity development, and salt plugging which can be identified through geologic characterization. For example, limestone reefs tend to have tighter porosity mid to lower reef with highest porosity and permeability in the upper reef and A1 Carbonate, as illustrated in Figure 8A with hotter colors for higher porosity. Dolomitized reefs tend to have more enhanced porosity throughout the reef due to secondary porosity development as illustrated in Figure 8B with hotter colors for higher porosity. The variability or heterogeneity in rock/facies type is related to a reef's location within the larger Michigan Basin geologic setting.

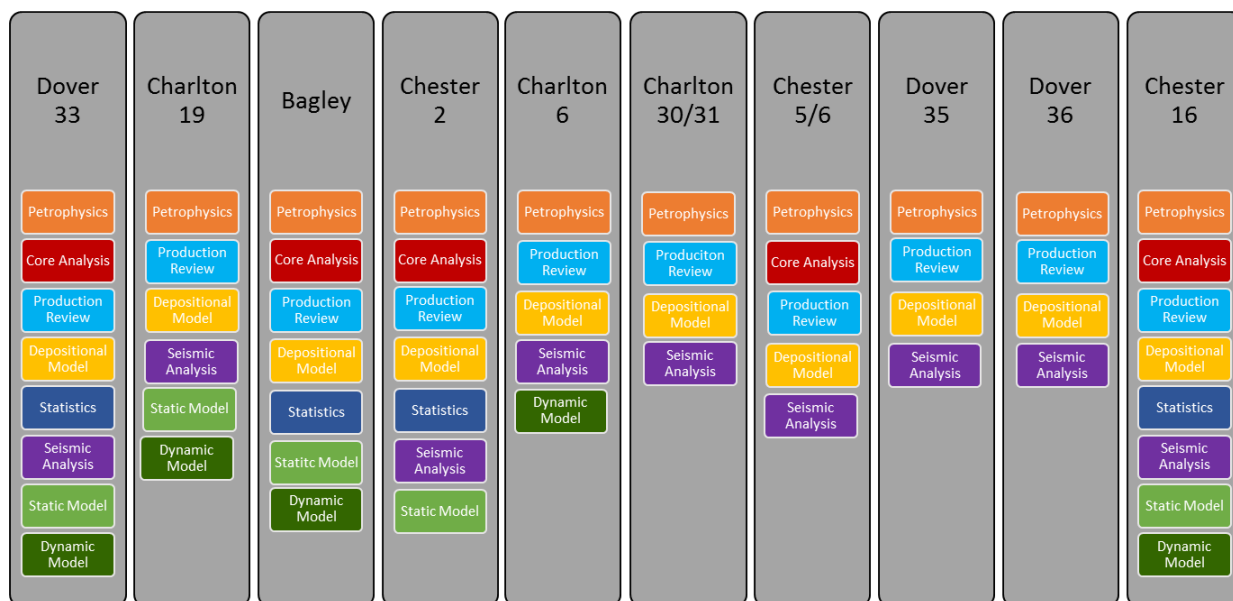


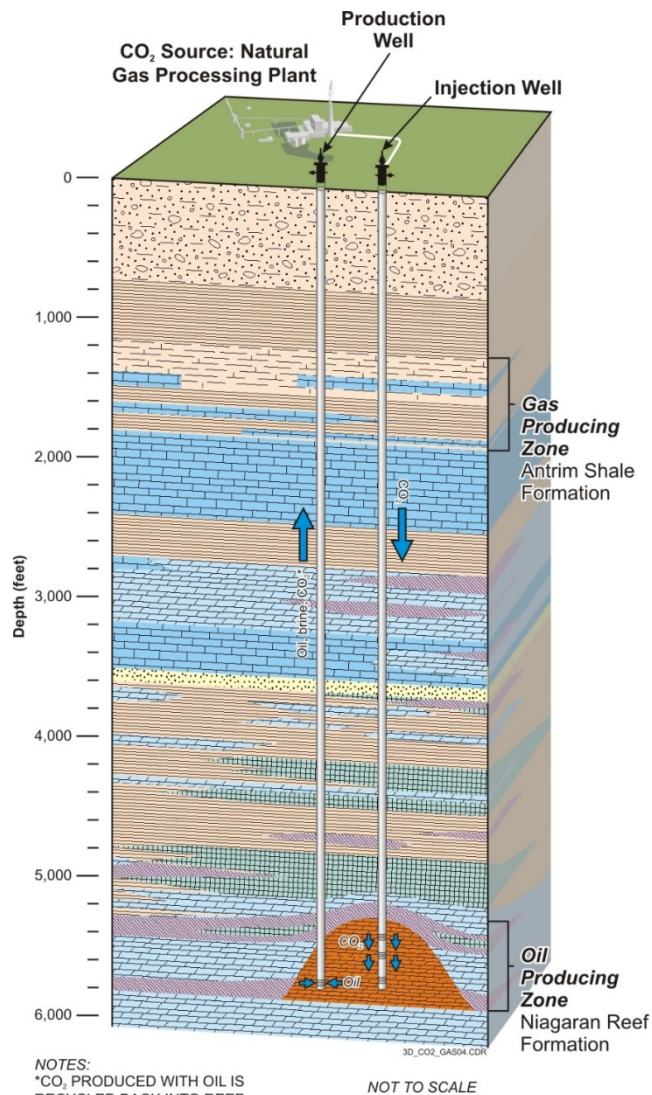
Figure 9: Analyses completed to date by reef.

## 2.2.2 Conceptual Understanding of CO<sub>2</sub> EOR in Reef Structures

The modeling and extensive history of oil and gas production in the NNPR have demonstrated the varying degree of compartmentalization of the reefs and the efficiency of the overlying evaporites and carbonates as seals. The reefs act as a closed reservoir system, which provides excellent conditions for CO<sub>2</sub>-EOR operations.

The discovery pressure in the oil-bearing NNPR reefs averages about 3,000 (psi). Primary production utilized this pressure to flow oil to the surface. Secondary production, using water flooding, was attempted but not widely used. Tertiary production, using CO<sub>2</sub> EOR, was initiated in the late 1990's and expanded by Core Energy as it started operations in 2003.

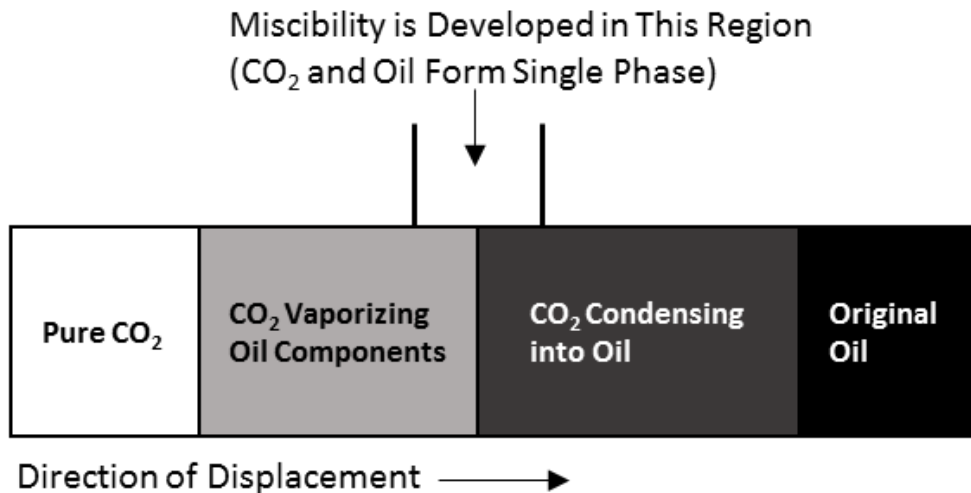
Core Energy typically initiates CO<sub>2</sub> EOR in reefs that have undergone primary and in some cases after secondary production. As CO<sub>2</sub> is injected into the reefs, it contacts the oil trapped in the pore space while it simultaneously increases the reservoir pressure. As contact and pressure increase, the CO<sub>2</sub> eventually becomes miscible with the oil which allows it to flow towards a designed production well. Figure 10 illustrates the CO<sub>2</sub> EOR process in a reef field for a CO<sub>2</sub> injection well and the associated production well. Note that the source of CO<sub>2</sub> is from the gas producing zone indicated at the top of the column.



NOTES:  
 \*CO<sub>2</sub> PRODUCED WITH OIL IS RECYCLED BACK INTO REEF.  
 ALL LOCATIONS ARE APPROXIMATE.  
 Figure 10: Simplified diagram illustrating CO<sub>2</sub>-EOR process in a reef.

Figure 11 shows a graphic representation of how CO<sub>2</sub> and oil become miscible. At either end of the image are pure CO<sub>2</sub> and original oil. As the two come into contact and pressure increases, CO<sub>2</sub> vaporizes oil and also condenses into it, forming a single-phase fluid mixture of CO<sub>2</sub> and oil. This mixture of CO<sub>2</sub> and oil, along with formation brine present in some cases, is then produced from the well.





From Zick, 1986

Figure 11: CO<sub>2</sub> Miscibility Diagram (SPE Monograph 22)

At the end of CO<sub>2</sub> EOR operations, when a project is no longer economically viable and in preparation for closure, Core Energy typically attempts to recover as much CO<sub>2</sub> as it can by producing fluids back through a CPF until such time the reservoir pressure has been reduced to a level whereby wells can no longer flow (approximately 500 psi or less). After the CO<sub>2</sub> recovery effort has been completed, the reservoir pressure has been depleted, and wells will no longer flow; it leaves the reef in a state whereby there is significant voided pore space.

The Core Energy facility has significant operational flexibility due to the modular nature of the reefs and the diversity of their development status. The Core Energy reefs are isolated from each other, and each goes through a phase development maturation process that ranges from new or “fill up”, to operational, onto depleted.

New reefs are in the fill up stage in which the initial volume of CO<sub>2</sub> is being injected to raise reservoir pressure above the minimum miscibility pressure (~1190 psi MMP) of CO<sub>2</sub> in oil. Above this MMP, the CO<sub>2</sub> and oil become a single phase fluid and begin to flow to producer wells depending on the pressure gradient between the injection well and the producer wells. After the reef has been pressurized above the MMP (the fill-up phase), these reefs transition into the operational phase, which can last for many years.

Once a reef is determined to be operational, pipelines will be extended from the producing wells to a central processing facility, if they are not already in place. Based on the oil type and the temperature of the reservoirs, Core Energy found that conducting miscible CO<sub>2</sub> flooding is optimized at roughly 1,300 PSI.

Core has also tested the capacity to increase pressure above the optimal range and finds that while it has the headroom (available pore space) and ability to increase pressure to well above 1,300 psi, it does not have equipment that could raise pressure to levels near or above the fracture pressure.

When the bulk of economically available oil has been produced via EOR, the reef is considered depleted or nearing depletion. In depleted reefs, the economic return on CO<sub>2</sub> EOR is not as high as in the operational reefs. However, these reefs still have some oil left in place and can also effectively act as short-term storage for CO<sub>2</sub> in the system. When CO<sub>2</sub> EOR operations in a reef end, Core Energy typically recovers as much CO<sub>2</sub> as it can by producing fluids back through a CPF until such a time as the reservoir pressure has been reduced to a level whereby the wells can no longer flow (approximately 500 psi). The amount of CO<sub>2</sub> which remains in the reef below this pressure cannot be recovered and is stored under current conditions.

This development cycle for each reef, combined with operating multiple reefs at once, provides Core Energy with unique operational flexibility. At any time, the number of reefs and the diversity of their status enables Core to accept as much CO<sub>2</sub> as it can capture and then use it over time. This is especially important due to the depleting nature of their anthropogenic source of CO<sub>2</sub> (i.e. gas processing plants servicing the Antrim Shale production).

**2.3 Operational History of the Core Energy Reefs**

The NNPRRT reefs, originally developed in the 1970-1980s, have undergone primary production and, in some cases, secondary recovery through water flood and other methods. Oil operations largely subsided in the early 1990s and then picked up sporadically towards the end of the decade. Core Energy entered the play in 2003, taking over two operating reefs and slowly expanding into eight additional reefs.

**2.3.1 Core Energy EOR Reef Complex Development**

Core Energy currently operates 10 active EOR reefs in Otsego County in northern Michigan. CO<sub>2</sub> EOR was initiated in each of these reefs at different times as indicated in Table 1. Figure 12 shows the location of each reef.

**Table 1: Active CO<sub>2</sub>-EOR reefs and date of initial flooding.**

Reef	Date CO <sub>2</sub> Flooding Initiated
Dover 33	1996
Dover 36	1997
Dover 35	2004
Charlton 30/31	2005
Charlton 6	2006
Chester 2	2009
Chester 5	2011
Charlton 19	2015
Bagley 11-14-23	2015
Chester 16	2017

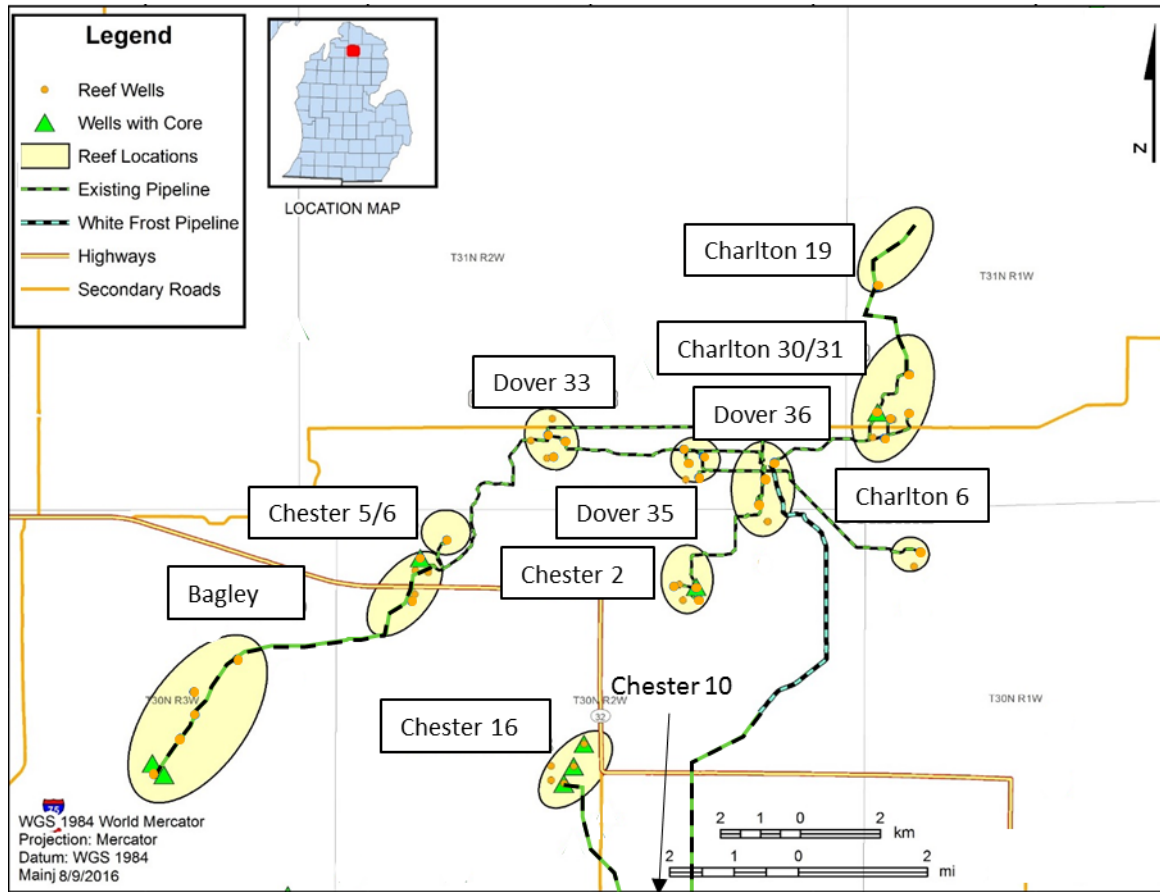


Figure 12: Location of active reefs operated by Core Energy.

### 2.3.2 CO<sub>2</sub> Production and Injection History

All of the active reefs have undergone primary production in the past. Core Energy maintains production records for all wells in the active reefs, including volumes of the following:

- oil produced,
- gas produced (commingled natural gas and CO<sub>2</sub>)
- water produced
- water injected (if applicable), and
- CO<sub>2</sub> injected.

Core Energy worked with Battelle to develop a baseline accounting as of December 31, 2017 of the CO<sub>2</sub> that has been injected since 1996. Since 1996, 2.11 million tonnes of CO<sub>2</sub> has been injected into the Core Energy reefs.

Core Energy is starting its mass balance accounting for CO<sub>2</sub> at zero. This means that the amount of CO<sub>2</sub> already in the system will ultimately be reflected in the mass balance calculation of the amount stored. Over time, the total amount stored will be roughly equal to the sum of CO<sub>2</sub>

from Chester 10 and the inventory of CO<sub>2</sub> produced through Dover 36 less any losses from equipment or subsurface leaks, which are expected to be minimal.

#### 2.4 Description of CORE Energy CO<sub>2</sub>-EOR and Ancillary Storage Project Facilities and the Injection Process

Core Energy operates an integrated facility that includes CO<sub>2</sub> capture, dedicated pipelines, injection and production wells, a central processing facility for fluids, and compressors. Figure 13 is a detailed flow chart with equipment names and meter numbers. The rest of this section will use Figure 13 to review the facilities and processes taking place at the Core Energy facility.

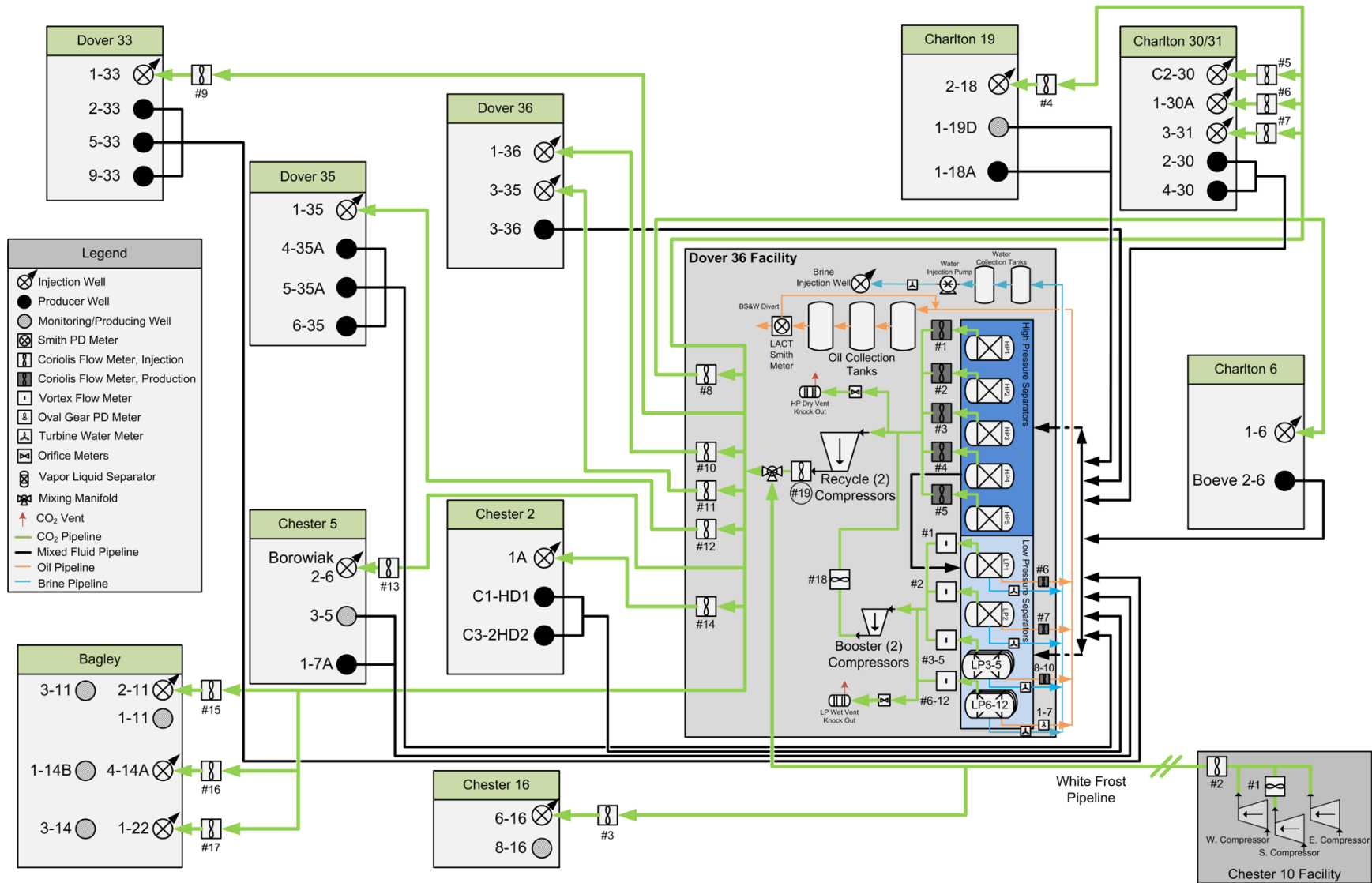


Figure 13 – Simplified Process Flow Diagram of Core Energy's EOR Facility

## 2.4.1 CO<sub>2</sub> Capture

Core Energy captures CO<sub>2</sub> at two locations:

- Chester 10 Facility (shown in bottom right corner of Figure 13): This facility captures CO<sub>2</sub> from a natural gas processing facility that treats gas produced from the Antrim Shale. Core Energy has the right to capture up to 100% of the CO<sub>2</sub> that would normally be vented from the natural gas plant. Core has made investments to expand capture operations over time and plans to make additional investments in the future. It currently captures between 300,000 to 350,000 tonnes of new CO<sub>2</sub> per year. Also, there is potential to capture an additional 100,000 tonnes per year, resulting in net potential 450,000 tonnes of new CO<sub>2</sub> per year. It is expected that the natural gas processing plant will continue operations for at least 10 to 20 years but continued operations depend on market conditions. Core currently has three compressor units at this facility, with the mass of all new CO<sub>2</sub> measured using Coriolis mass flow meter number 2 (Figure 13).
- Dover 36 Facility (large rectangular box in Figure 13): This facility is co-located along with the Dover 36 reef. This facility contains the main Recycle Compressor along with capture equipment which captures CO<sub>2</sub> from various high-pressure (HP) and low-pressure (LP) fluid separators that treat the fluids from the production wells. Core Energy currently captures ~300,000 tonnes of gas per year at the Dover 36 Facility. This gas consists of CO<sub>2</sub> (~95% by wt.) with small quantities of hydrocarbon gas which is recompressed and sent back to various EOR reefs. The mass of this gas is measured using Coriolis mass flow meter number 19.

## 2.4.2 CO<sub>2</sub> Distribution and Injection

Core Energy maintains about 80 miles of pipelines that are used to move CO<sub>2</sub>, produced fluids, and oil. A diagram of the pipeline network and locations of 10 EOR reefs is shown in Appendix II.

A portion of CO<sub>2</sub> from the Chester 10 Facility delivered via the White Frost Pipeline can be withdrawn directly for injection into Chester 16 reef (measured using Coriolis mass flow meter number 3); the remainder of the CO<sub>2</sub> from Chester 10 flows to the Dover 36 Facility, where it mixes with CO<sub>2</sub> from the Recycle Compressor at the Mixing Manifold. From the Mixing Manifold, Core can re-arrange various piping and valves to direct CO<sub>2</sub> to any one of the reefs.

Dedicated Coriolis mass flow meters are attached to each injection well at the EOR reefs. Some of the meters are located at the Dover 36 Facility while others are located directly at the wellhead. These meters are numbered 3 through 17 (Figure 13) for the 15 injection wells at 10 EOR reefs. It is important to note that Core can change the operational configuration of wells whereby an injector well may become a producer or monitoring well, or a producer well may be converted to an injector well. If in future, a producer well is reconfigured to be an injector well, Core will install a Coriolis or other suitable flow meter to measure the quantity of CO<sub>2</sub> being injected into that well and will indicate such changes in the annual reporting.

### 2.4.3 Produced Fluids Handling and Processing

Table A-1 in Appendix I lists the active wells, of which 20 are “producers”. These 20 wells are further indicated by status as a current producer (PR), a shut-in producer (SI-P) or an observation (OBS) well. Generally, at least one production well is located in each reef. For the new reefs, the production wells will be connected to pipelines for produced fluids once they start producing. For the other reefs, all produced fluids from the reefs flow directly to dedicated separators at central processing facilities.

Core Energy currently has a network of 5 HP separators and 12 LP separators at the Dover 36 Facility. Product streams from reefs that are producing oil under high pressure (> 340 psi) are first sent to an HP separator; product streams from reefs that are producing under low pressure (<340psi) are sent to one of the LP separators. The remaining liquid product stream (containing mostly oil and brine) from an HP separator is further sent to an LP separator for separation and stripping of any entrained gas. The produced gas that is separated in the HP separator is sent to the Recycle Compressor, while the gas separated from the LP separator is first sent to a Booster Compressor prior to being sent to the Recycle Compressor.

The produced gas which primarily consists of CO<sub>2</sub> (>95% by wt) is separated from the produced fluid and flows through a Coriolis mass flow meter at each of the HP separators before being sent to the Recycle Compressor (meters numbered 1 through 5). The bulk of the produced gas is captured in the HP separators (> 90% by wt). Meanwhile, the produced gas that is separated at the LP separator, flows through a Vortex type flow meter. The system of Coriolis mass flow meters (attached to the HP separators) and Vortex flow meters (attached to the LP separators) measures the mass of recycle gas produced from each operational reef. Additionally, one Coriolis mass flow meter (number 18) measures the mass of all recycle gas captured at the LP separators while another (number 19) measures the total quantity of produced gas that is produced by all operational EOR reefs.

Brine is separated by the LP separators. The collected brine is sent to a brine disposal well located onsite at the Dover 36 Facility.

Oil is gathered in collection tanks before flowing through a LACT meter for offsite sales. A small amount of CO<sub>2</sub> remains entrained in the oil after the CO<sub>2</sub> separation process, which bleeds off as the oil moves through the LP meters into a temporary storage/gathering tanks. Core hired an external engineering firm to conduct a survey in 2011 to determine the amount of CO<sub>2</sub> entrained in oil. This study indicates that the concentration of CO<sub>2</sub> entrained in oil is 0.7512% by weight. This translates into roughly 150 tons per year at current operations levels. Because the oil is blended in the gathering tank, Core Energy believes this factor applies uniformly to all oil.

While rare, operational outages periodically occur, which forces produced gas to be vented to the atmosphere. Core has orifice type flow meters installed at its Wet and Dry Vent locations to measure the mass of recycle gas that is vented. Looking back for the last 12 months (May 17 to April 18), a small volume of CO<sub>2</sub> was vented during eight (8) of those months (roughly 50 tons). The volume of CO<sub>2</sub> vented represents less 0.0174% of the produced volume.

#### 2.4.4 Data Collection

The system of flow metering at the Dover 36 Facility is centrally tied to a Core Energy HMI computer system. Coriolis mass flow meters that are located at the reef-site locations (at injection wellheads) typically have data-loggers which collect and store injection data. The HMI system records continuous production and injection data files on a per-minute basis for each day of operations. Operators typically record totalizer readings from injection and production parameters at 9 AM each day for the previous operational day. Additionally, there are daily site visits to the wellsites where operators record well data (e.g., tubing pressure, casing pressures, and wellhead temperatures). Together, these data streams provide accurate accounting of all CO<sub>2</sub> being acquired (from the Chester 10 Facility), injected into EOR reefs, and recycled at the Dover 36 Facility.

The method used when estimating the volume of CO<sub>2</sub> “lost” due to an interruption in data collection or mechanical failure of a meter (equipment) is to use the most recent daily volume of CO<sub>2</sub> associated with the meter and calculate the proportionate volume of “lost” CO<sub>2</sub> based on the number of hours involved in the data gap or until the meter was repaired. Core Energy has well and facility data in three forms: 1) Paper copies (scanned to server), 2) Keyed in data from paper copies into database, and 3) Automated capture of limited set of data that was recently instrumented (Fall of 2016).

Subsequent sections of this Plan, Section 5.5 and Section 6, provide a more detailed explanation for how this data and other means will be used as baseline data for comparison to detect possible surface leakage.

#### 2.4.5 Existing Wells

Core Energy operates 16 injection wells (1 of which is a shut-in injector) and 20 production/observation wells. These wells are listed in Appendix I.

Well status is discussed in Section 4.1.

Wells are configured as each EOR project is developed (see Table 1). Mechanical integrity for injection wells is monitored through daily readings of casing pressure, quarterly fill-up tests and mandatory mechanical integrity tests (MIT) every five years. All injection wells utilize a corrosion inhibited packer fluid in the annular space between the tubing string and casing, above the required isolation packer. Corrosion coupons are placed at various nodes in the system as a way to monitor metal loss.

Maps showing the locations of the wells in each reef are provided in Figure 12. In general, the basic open-hole geophysical logs (e.g. gamma ray, density, resistivity, neutron porosity, photoelectric) are available for most of the wells in the active reefs. A sonic log is available for approximately half of the wells. Cement-bond logs are sparingly available.



## 2.5 Core Energy Procedures for CO<sub>2</sub>- EOR Facility Modification

Core Energy plans to continue routine business operations, which may include securing additional CO<sub>2</sub>; modifying, adding, or closing wells; adding or closing reefs, and adding new facility equipment and pipelines. These modifications represent a continuation of the basic integrated current configuration and MRV approach and not a material change that triggers a revised plan (see 40CFR Part 98.448(d)). Therefore, Core Energy intends to indicate such changes in the annual monitoring report rather than submitting new MRV plans. The monitoring report would demonstrate how the change is a continuation of the existing EOR Facility and would also include any new site characterization, risk assessment, monitoring, and mass balance information as is already included for the existing EOR Facility. The existing provisions for the MRV would continue to apply. Each of these potential changes is discussed in more detail below.

### 2.5.1 New Sources of CO<sub>2</sub>

Core Energy is considering the addition of new equipment to capture additional CO<sub>2</sub> from the adjacent natural gas processing plant through its Chester 10 Compression Facility. It is also exploring the potential to obtain additional CO<sub>2</sub> through nearby sources that are in development.

In the event new sources of CO<sub>2</sub> are added, the amount of CO<sub>2</sub> would be measured using flow meters and added to the reported amount of CO<sub>2</sub> received onsite as indicated in Section 7. Injected CO<sub>2</sub> from these sources would be measured using flow meters and added to the reported amount of CO<sub>2</sub> injected as indicated in Section 7.

### 2.5.2 Adding New Wells

In order to add any new injection wells, Core Energy would have to work with the US EPA (or if Michigan gains primacy for Class II, MDEQ/OGMD) to obtain the permits and from MDEQ/OGMD to obtain permits for any new production wells. Such wells would be sited, completed, and operated in the same manner as the existing wells, under the oversight of the US EPA and/or MDEQ. The existing modeling and learned transferable principles would be combined with reef characteristics to determine location and operational plans for such wells. Well numbers and information would be included in the annual statement.

### 2.5.3 Abandoning Existing Wells

Core Energy follows the UIC Class II requirements and/or the MDEQ/OGMD requirements for closing wells. Any wells closed within a reporting year would be noted in the annual statement.

### 2.5.4 Changing the status of Existing Wells

Core Energy may change the status of an existing well from producer to injector or vice versa. In such situations, Core Energy will work with US-EPA and/or MDEQ/OGMD to obtain the necessary permits and will indicate the status change in the annual statement.

### 2.5.5 Acquiring New Reefs

Core Energy is looking to expand into new reefs based on their potential development value, which is a reflection of past operational history and current ownership structures as well as other factors. Based on the modeling and history of reef development in the area, Core Energy does not anticipate that past operations will preclude any reef from being selected as an expansion candidate. As part of the permitting process, Core Energy will conduct a site characterization, determine the boundaries of the reef, and assess the Area of Review (AoR) of at least ¼ mile around the reef to determine if there are any old wellbores that need to be remediated or closed and whether there are any other impediments to the successful implementation of CO<sub>2</sub> EOR on that reef. All potential new reefs are located in the MMA as indicated in Section 3.2 and would be moved into the AMA as indicated in Section 3.1 if they are developed by Core Energy.

### 2.5.6 Abandoning Existing Reefs

Core Energy will follow the requirements for closing wells and will follow any contractual or permit requirements for abandoning a reef. Core Energy will prepare a closure report for any abandoned reefs that assesses the amount of CO<sub>2</sub> that will be incidentally stored in that reef after closure and serving as the foundation for removing that reef and the related CO<sub>2</sub> from the active MRV reporting program.

### 2.5.7 Adding New Facility Equipment

Core Energy may add new equipment that could have an impact on the mass balance. This might include additional compressors, processing equipment, and/or other equipment. These changes would be noted in the annual statement and CO<sub>2</sub> losses from this equipment would be calculated as in Section 7 and the results included in the mass balance.

### 2.5.8 Acquiring New Pipeline Routes

Core Energy may build additional pipelines to connect new wells to the Core Energy Facility or to connect fill up reefs to production facilities. These changes would be noted in the annual statement and CO<sub>2</sub> losses from this pipeline would be calculated as in Section 7 and the results included in the mass balance.

## 3. Delineation of the Monitoring Area

### 3.1 Active Monitoring Area

Due to the highly compartmentalized nature of the Niagaran reefs, the Active Monitoring Area (AMA) is defined by the boundary of the Unit Area of each individual reef/field as established in the Order by the Supervisor of Wells for the MDEQ authorizing each EOR project. The following factors are considered in defining the boundaries:

- CO<sub>2</sub> injected into a reef remains contained in the reef because of the efficient seals along the edges and overlying the reef

- The edge of the reef is typically defined using 3D seismic data. Where 3D seismic data is not available, reef edges are approximated using all wells surrounding and penetrating a reef, along with analog reef geometry.
- Stored CO<sub>2</sub> will remain within a reef and will not migrate over geologic time, as is demonstrated by the long history of oil and gas production occurring within a reef. Just as the oil and/or gas were trapped in and contained by the reef, the same would be true for the CO<sub>2</sub>.
- Free-phase CO<sub>2</sub> is contained within the reefs and will remain there after injection ceases and wells are shut-in or closed
- MDEQ rules state that an operator must demonstrate that the reservoir is wholly contained in the Unit Area before an EOR project is authorized.

### 3.2 Maximum Monitoring Area

The maximum monitoring area (MMA) for the MRV Plan, based on the anticipated future of expansion to conduct CO<sub>2</sub> EOR operations in reefs within the NNPRT, extends geologically along the northern edge of the Michigan Basin. The NNPRT extends as a band of reefs from Lake Huron (Presque Isle County) to Lake Michigan (Manistee County), of which there are prospective CO<sub>2</sub> EOR reefs in every labeled county shown in Figure 14. In accordance with § 98.448-449, the actual MMA will extend for ½ mile beyond the reefs. The red dashed line in Figure 14 encompasses the half mile buffer to the north and south of the reefs in the MMA.

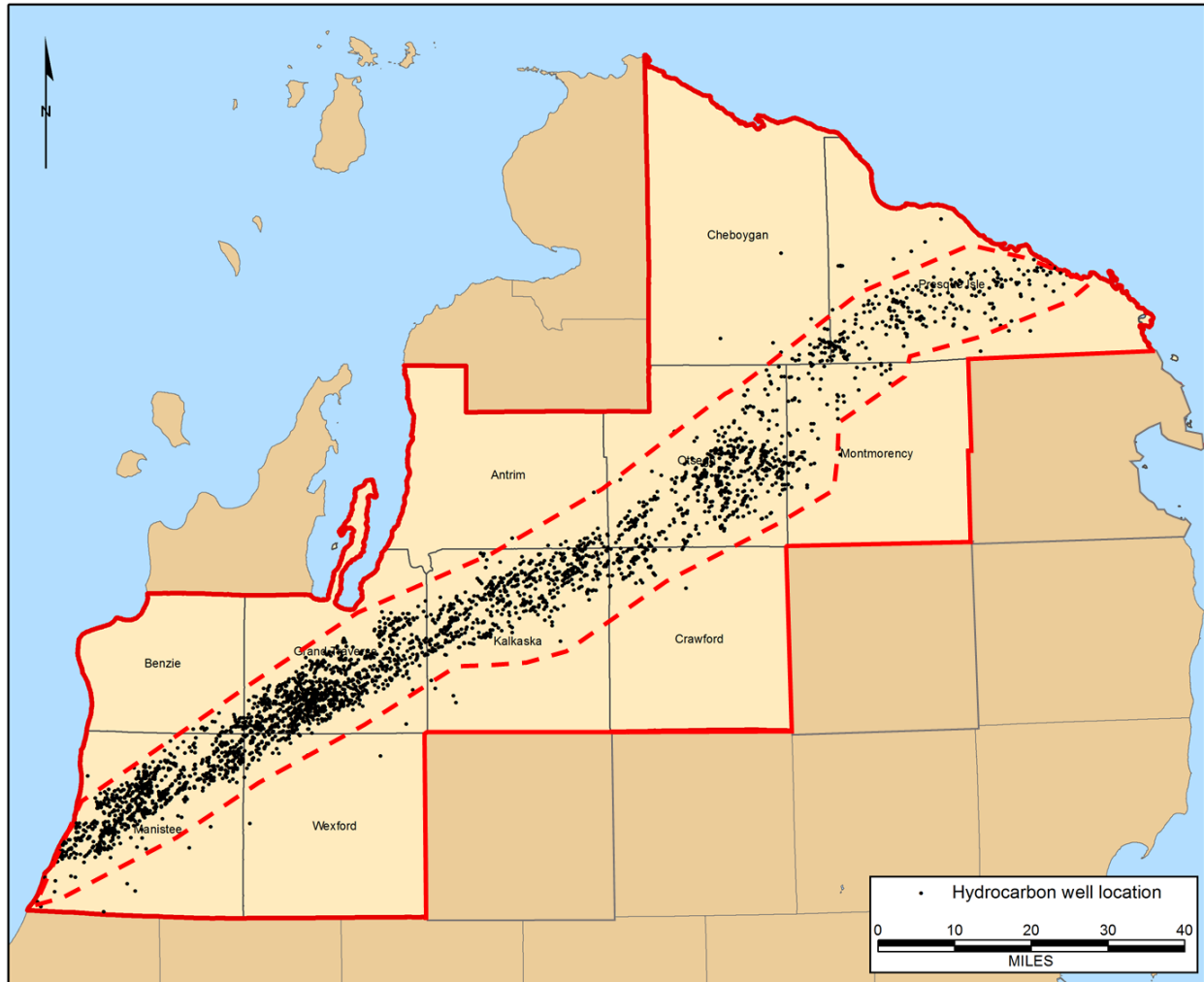


Figure 14 Areal Extent of Maximum Monitoring Area includes the hydrocarbon bearing pinnacle reefs in the NNPRT

The reefs that are currently undergoing CO<sub>2</sub> EOR in Otsego County and all of the reefs in the NNPRT that would be suitable CO<sub>2</sub> EOR targets in the future are found at the same place within Michigan's geological stratigraphic column. The reefs are always contained below the B-Salt and A2-Carbonate and above the White Niagaran (see Figure 15).

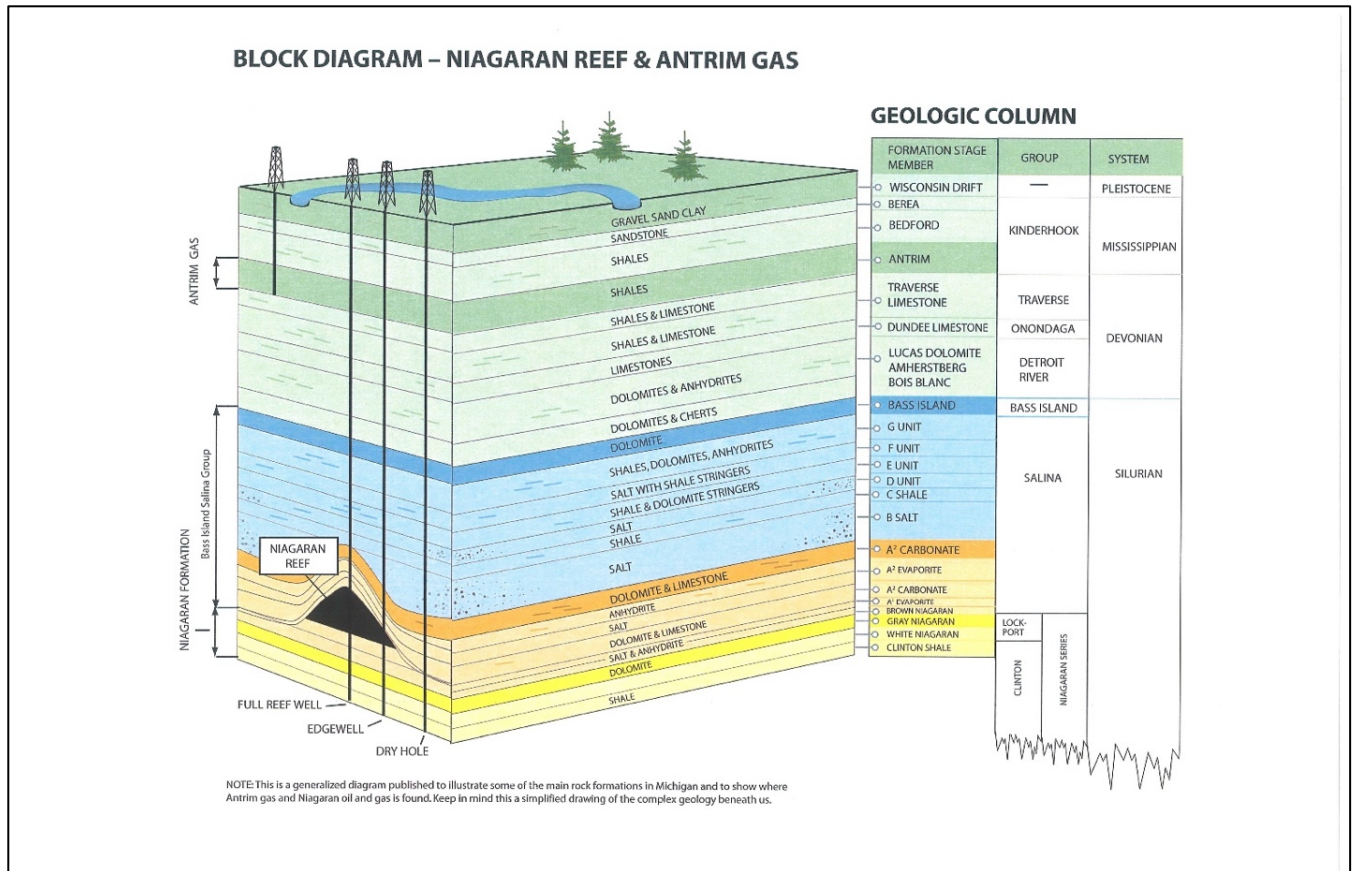


Figure 15 Michigan Stratigraphic Column

The potential risk of leakage is consistent from reef-to-reef in the MMA for several reasons. The hydrocarbon bearing reefs that Core Energy will develop are always found in the same geologic setting within the Michigan Basin. They are isolated, self-contained reservoirs, and the risk associated with leakage pathways are the same from reef-to-reef. Further, any reef added to Core Energy's EOR operations would first be screened for suitability for EOR operations and would then have to undergo the Michigan unitization process by MDEQ. New wells or well changes would go through the state (MDEQ) and federal (US EPA) permitting requirements.

### 3.3 Monitoring Timeframes

Core Energy's primary purpose for injecting CO<sub>2</sub> is to produce oil that would otherwise remain trapped in the reservoir and not, as in UIC Class VI, "specifically for the purpose of geologic storage."<sup>1</sup> During a Specified Period, Core Energy will have a subsidiary purpose of establishing the long-term containment of a measurable quantity of CO<sub>2</sub> in the reefs that it operates. The Specified Period will be shorter than the period of production from the Core Energy facility. At the conclusion of the Specified Period, Core Energy will submit a request for discontinuation of reporting. This request will be submitted when Core Energy can provide a demonstration that current monitoring and model(s) show that the cumulative mass of CO<sub>2</sub> reported as sequestered during the Specified Period is not expected to migrate in the future in a manner likely to result in

<sup>1</sup> EPA UIC Class VI rule, EPA 75 FR 77291, December 10, 2010, section 146.81(b).

surface leakage. It is expected that it will be possible to make this demonstration within three years after injection for the Specified Period ceases. The demonstration will rely on three principles: 1) the amount of CO<sub>2</sub> stored in properly abandoned reefs will be considered unlikely to migrate to the surface, 2) the continued process of fluid management during the years of CO<sub>2</sub> EOR operation after the Specified Period will contain injected fluids in the reefs, and 3) that the cumulative mass reported as sequestered during the Specified Period is a fraction of the theoretical storage capacity of the reefs in the field. See 40 C.F.R. § 98.441(b)(2)(ii).

#### 4. Evaluation of Leakage Pathways

Knowledge gained through the long history of oil and gas production in the Niagaran reefs coupled with the regional geological characterization conducted by Battelle for the MRCSP were used to identify and assess potential pathways for leakage of CO<sub>2</sub> to the surface. The following potential pathways are reviewed:

- Existing wellbores
- Faults and fractures
- Natural and induced seismic activity
- Lateral migration outside of a reef
- Diffuse leakage through the seal
- Pipeline/surface equipment

##### 4.1 Existing Wellbores

Wellbores that penetrate the reef constitute the most likely pathway for leakage, however this risk is assessed as very small because of the well construction specifications implemented by Core Energy. Wells are constructed with four strings of casing (i.e. conductor, surface, intermediate and total depth string), three of which are cemented in place; the surface casing is cemented all the way to the surface. Additionally, all wells have tubing strings run to near the permitted injection zones. Injection wells require a packer attached to the tubing string, located no more than 100 feet (30 m) above the permitted injection zone and mechanical integrity on injection wells must be established and maintained. Core Energy adheres to all regulatory requirements of the state and federal agencies charged with oversight as they relate to well drilling, completion and operation as means to maintain mechanical integrity and prevent wellbore leakage. Though previously drilled wells and plugged/abandoned wells may be thought to have a higher risk for leakage pathways than newly drilled wells, all wells within a defined AoR for a project are evaluated. All wells in northern Michigan have been ranked based on age, status, and depth (penetrating seal). It was concluded that wells which penetrated the seals were ranked with high integrity because they were more recent and adhered to regulatory requirements. Figure 16 shows all the well rankings in Otsego County (green is high integrity) and the number of wells which penetrate each reef.



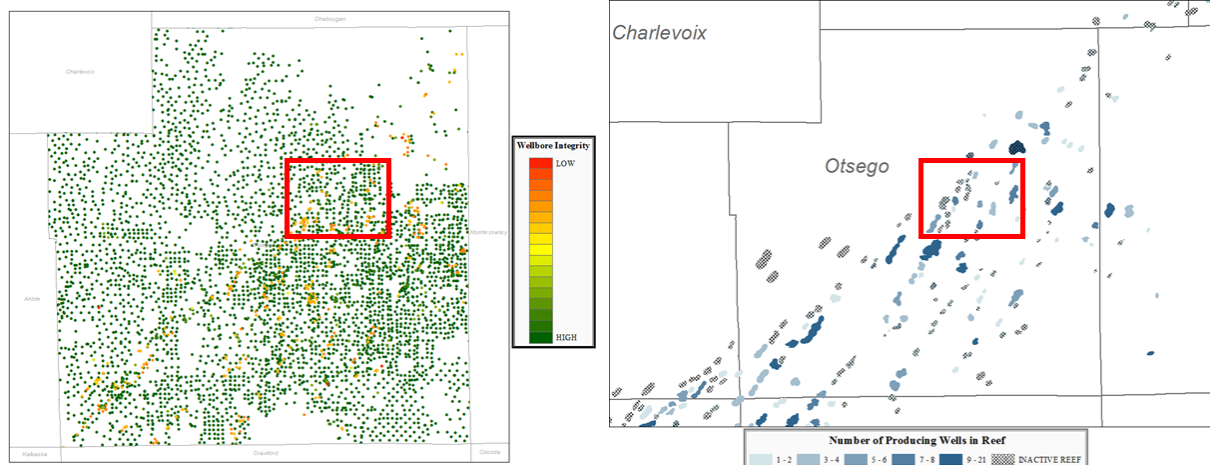


Figure 16: Wellbore integrity ranking (left) of all wells in Otsego County showing dominantly high integrity and the number of wells which penetrate each reef (blue) showing few seal penetrations within the Core Energy reef area (red)

MRCSP's systematic wellbore integrity evaluation in seven fields in the Michigan Basin which were actively being used for CO<sub>2</sub> EOR also included an assessment of cement plugs. In this study, cement plugs were analyzed and ranked based on depth, the number of plugs, thickness, and age. It was concluded that plugged wells which penetrated the reefs and nearby off reef locations had sufficient plug placement and thickness to prevent leakage.<sup>2</sup>

Leakage through wellbore cement was also researched in the NNPRT by analyzing several cement bond logs in the region. Cement was categorized based on the bond index. Cement with 80 to 100% bond was considered sufficient, 60 to 80% was intermediate, and less than 60% was not ideal. Wells which penetrated the reef were shown to have at least 50 feet of sufficient cement bond within the seal, which by industry standards is sufficient (Figure 17). Several wells were also tested for sustained casing pressure after being exposed to CO<sub>2</sub> and did not demonstrate any sustained casing pressure which would be caused by leakage through a cement annulus.

<sup>2</sup> Haagsma, A. , Weber, S. , Moody, M. , Sminchak, J. , Gerst, J. and Gupta, N. (2017), Comparative wellbore integrity evaluation across a complex of oil and gas fields within the Michigan Basin and implications for CO<sub>2</sub> storage. Greenhouse Gas Sci Technol, 7: 828-842. doi:[10.1002/ghg.1620](https://doi.org/10.1002/ghg.1620)

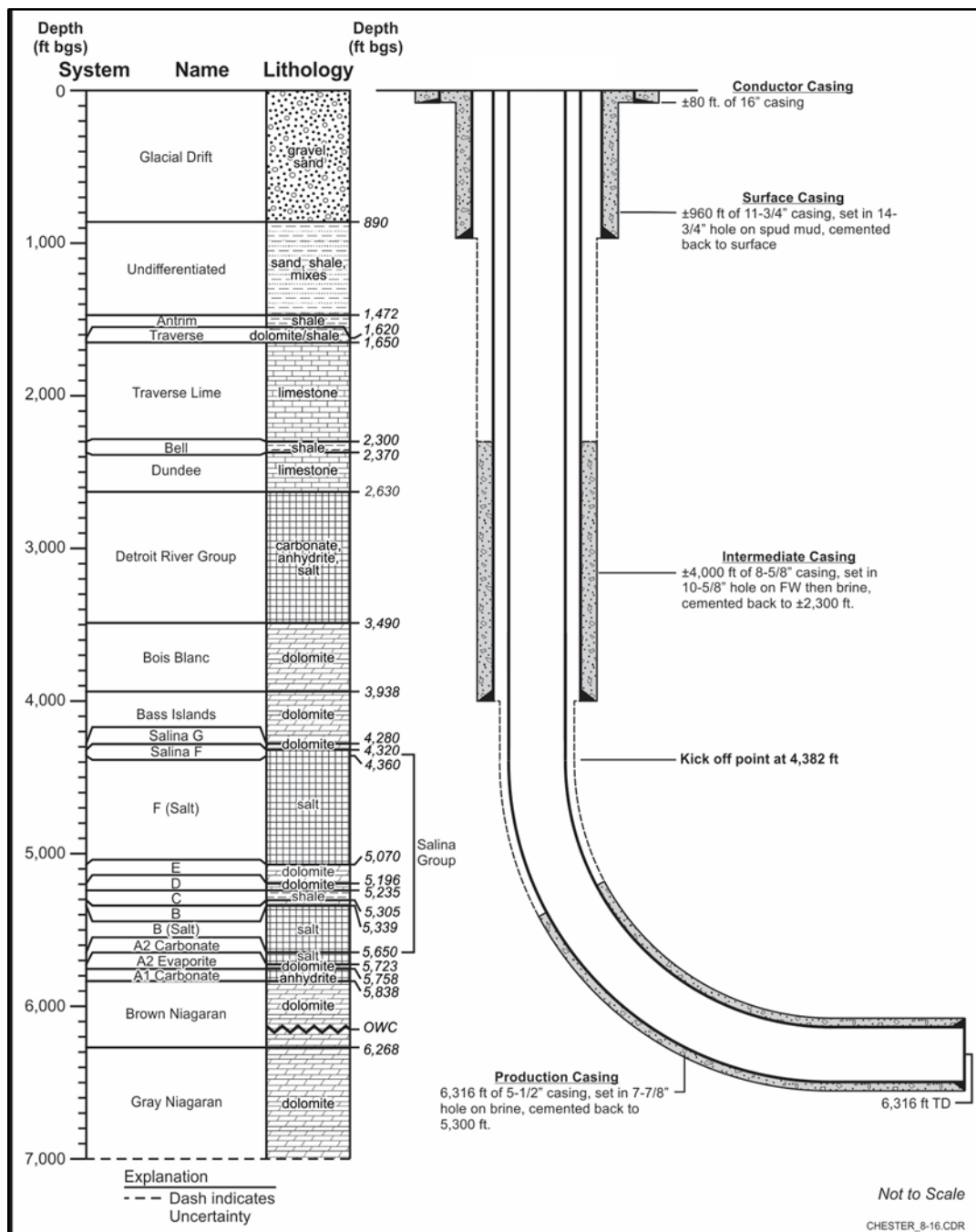


Figure 17: Example of well construction for a Core Energy well showing intervals of cement over crucial formations.

Overall, wellbore integrity studies and the oil and gas history demonstrate that while leakage through a wellbore is possible, the wells have been constructed ideally to prevent such leakage. Core Energy also conducts routine monitoring of active wellbores by performing bottom hole pressure measurements and wellhead inspections.



### 4.1.1 Future Wells

The highly-compartmentalized nature of the NNPRT reefs and the state requirements for drilling wells in active and new reefs will prevent new wells from posing a threat of leakage. As discussed in section 2.1, the structure of each reef ensures that they are separated from each other and that there is no fluid communication. This means that any well drilled in the MMA that does not intersect or pass through a reef, even if drilled to a depth deeper than that of the NNPRT reefs, is not a potential leakage pathway. Additionally, because reefs undergoing CO<sub>2</sub> EOR have to be unitized prior to commencing EOR operations, Core Energy controls all the pertinent rights that would preclude (or allow) for a well to be drilled within its unit, thus, no well could be drilled within the unit boundary of an active EOR project.

### 4.2 Faults and Fractures

Basement crustal features such as the Mid-Michigan Rift/geophysical anomaly and the Grenville Front (Figure 18) may affect formation thickness and the tectonic movement of Paleozoic structures in the sedimentary rock section. Many ancient faults and folds in the Paleozoic section are parallel or perpendicular to the basement features. There are fewer identified faults in the northern most counties of Michigan than there are in southern Michigan, making the NNPRT an ideal location for CO<sub>2</sub>-EOR. The faults in northern Michigan are deeper features and do not influence the integrity of the caprocks for the reefs.

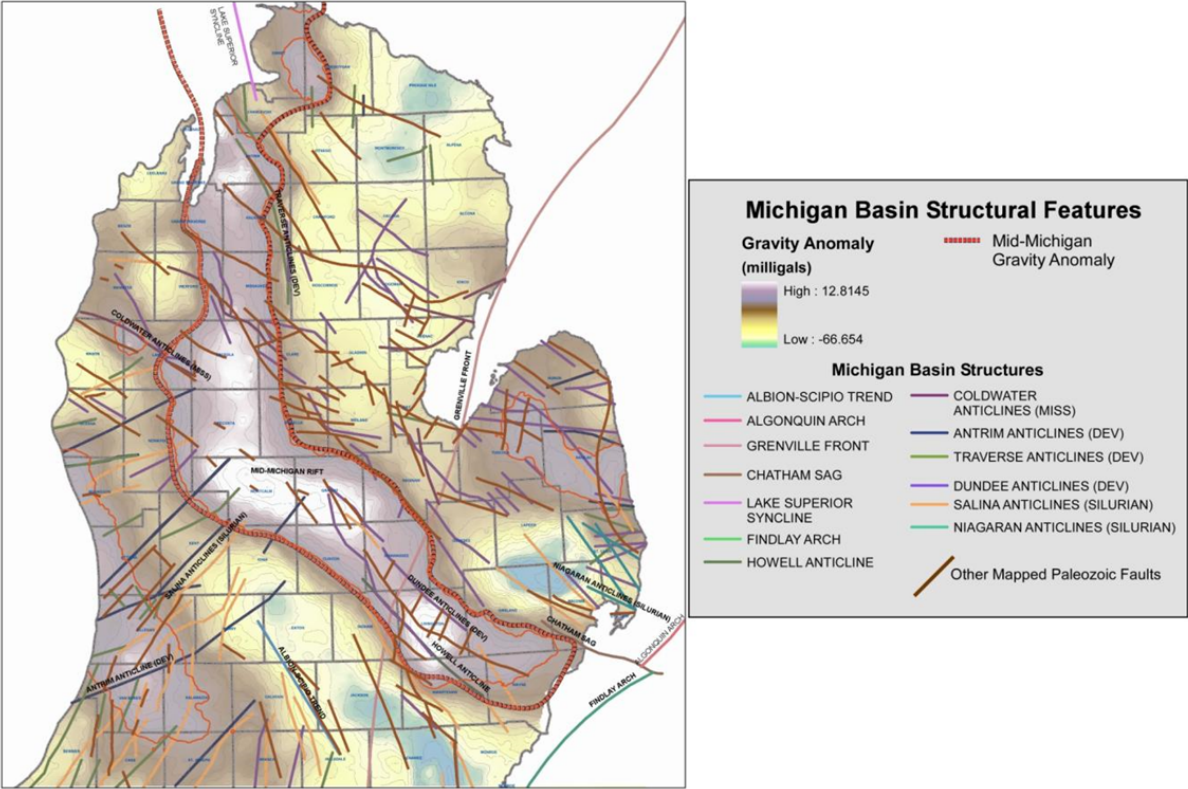


Figure 18: Michigan Basin structural feature

### 4.3 Natural and Induced Seismic Activity

Michigan Basin is structurally stable with few known faults. There are no recorded seismic events in northern Michigan and risk of seismic activity is low with a 0 to 4% chance of a seismic event in northern Michigan and no recorded seismic events (Figure 19A). Nearby 2D and 3D seismic data confirm there are no major structural features around the sites of interest (Figure 19B).

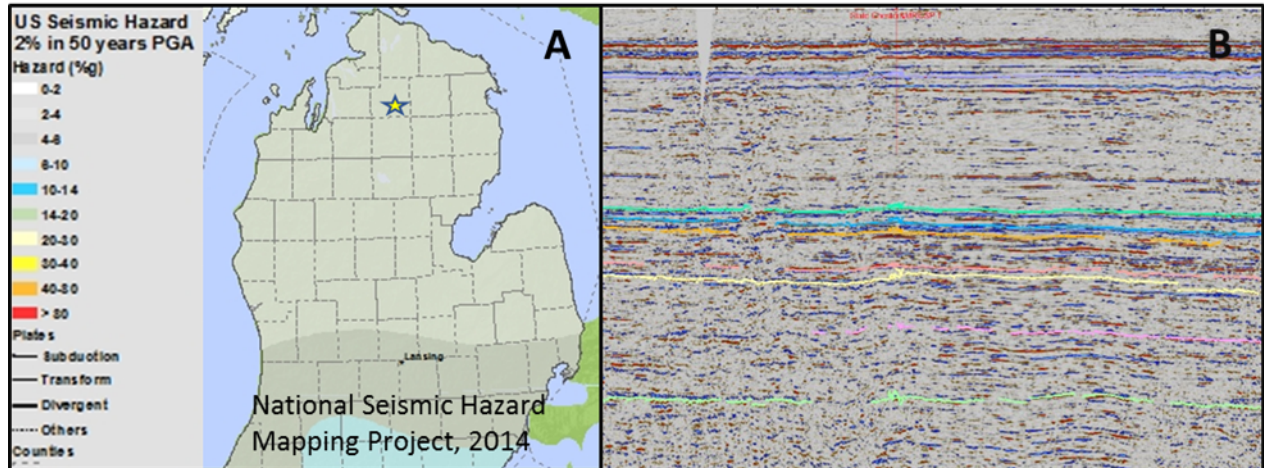


Figure 19: US seismic hazard map (A) with example 2D seismic line (B) showing low risk for seismic activity and no major structural features.

### 4.4 Lateral Migration Outside of a Reef

It is highly unlikely that injected CO<sub>2</sub> will migrate outside of the boundaries of a reef due to the following factors:

- 1) The containment provided by the inherent reef geology consisting of non-porous salts and evaporites along the flanks and overlying the reef structure. This containment is believed to effectively isolate the individual reefs resulting in closed reservoir dynamics observed over the course of MRCSP CO<sub>2</sub> injection (see section 2.1)
- 2) Operational procedures at Core Energy, which monitor injection and production volumes from well-managed wells.
- 3) Periodic material balance associated with the measured reservoir fluid amounts, which has helped correlate and reconfirm that no CO<sub>2</sub> has been lost to the surroundings from the reef thus far.

Containment is also validated by the numerical modeling exercises (both analytical and dynamic numerical models) undertaken for each of the reefs of interest aimed at investigating reef response and CO<sub>2</sub> migration over time.

#### 4.5 Diffuse Leakage through the Seal

Diffuse leakage through the seal, overlying Salina group, is highly unlikely. The seal is composed of several hundred feet of salt, shale, and tight carbonate. Oil and gas production also confirms the successful trapping of fluids in the reefs over geologic time. Additional pressure monitoring and geomechanical modeling of the seals in several reefs confirmed the efficiency and integrity of the confining system.

The fracture gradient is 0.8 psi/ft which is approximately 4130 psi at a depth of 5162 ft (shallowest perforation in Core Energy reefs). The coordinating wellhead (surface) pressure equates to 1761 psi. The maximum pressure tubing can experience is 1400 psi, based on the pressure that can be delivered from the injection compressors. Thus, the fracture pressure is higher than can physically be realized within the well and there is no risk of fracturing the seals. Further, each CO<sub>2</sub> injection well is assigned a maximum surface injection pressure as a part of the US EPA permitting process, whose purpose is to ensure that the reservoir fracture pressure is not exceeded.

Additionally, geomechanical analyses were conducted using wireline logs and core tests for select reefs. Analytical techniques were used to estimate changes in minimum horizontal stress,  $\sigma_h$ , caused by changes in pressure and temperature during CO<sub>2</sub> injection and to determine whether the stress state compromises the ability of reservoirs for safe and effective CO<sub>2</sub> storage. It was found that fracturing of the reservoir or caprock is not likely as long as the injection pressure is maintained below the UIC permit pressure limit.

#### 4.6 Pipeline/surface equipment

Leakage through pipelines and surface equipment is a potential risk. Core Energy uses its routine maintenance and daily inspection procedures to minimize this risk. Further, it will deploy three approaches to calculate the amounts of CO<sub>2</sub> lost through pipelines and surface equipment: 1) following GHGRR Subpart W methods for estimating fugitive and vented emissions, 2) using direct metering to measure specific venting events as discussed in Section 2.4.3, and 3) in the event an extreme event were to occur, using engineering best practices to estimate a loss.

### 5. Monitoring

This section describes the general approach to monitoring at the Core Energy facility and indicates how data will be collected for this MRV plan.

#### 5.1 General Monitoring Procedures

As part of its ongoing operations, Core Energy monitors and collects flow, pressure, and gas composition data from each reef in the central HMI computer system.

As indicated in Figure 13 Core Energy uses Coriolis mass flow meters for all measurements included in the mass balance (Section 7) and also uses Vortex flow meters for some operational monitoring. Fluid composition will be determined, at a minimum, quarterly, consistent with EPA

GHGRP's Subpart RR, section 98.447(a). All meter and composition data are documented, and records will be retained for the Specified Period. Quarterly composition analysis will be done at meter #2 at Chester 10 Facility for pure CO<sub>2</sub> gas and at meter #19 at Dover 36 Facility for combined recycle gas. If any other combined recycle gas processing facilities are added, as indicated in Section 2.5, similar Coriolis mass flow meters will be installed and quarterly composition analyses will be conducted. Such new meters would be included in the monitoring report and Section 7 calculations. If not done on a routine basis, Core will use initial baseline data or last available quarter composition analysis as continuation of reporting quarter, with justification as to why analysis was not done/deemed necessary. All composition analysis will be on % wt. basis of CO<sub>2</sub> in gas stream.

Core Energy has invested in Micro Motion Coriolis Mass Flow Meters throughout its operations. These meters are designed to retain calibration. The meters have no moving parts and a non-intrusive measuring sensor. As a result, there are no probes or detectors that come into direct contact with process fluids. The benefit of this design is that there are no bearings or rotors to wear, turbines to be deformed, electrodes to coat, or degradation of orifices to be concerned about. The manufacturer reports that "It has been our experience, and that of our customers, that Coriolis meters do not shift or lose their calibration during the life of the meter.

When calibration issues arise, the focus of the problem is normally traceable to the flowmeter installation or a characteristic of the process that was not previously taken into consideration." As a result, there are no prevailing industry standard(s) for meter calibration for these meters.

Core Energy observes trend data from the meters and has on occasion sent meters back to the company for recalibration but this does not occur routinely. This type of meter would have to be severely abused (serious mechanical damage, overheating beyond metal plasticity limits) to change calibration. These types of abuses do not happen during normal operations. Therefore, Core Energy considers this approach to be consistent with EPA GHGRP's Subpart RR, section 98.444(e)(3). These meters will be maintained, operated continually, and will feed data directly to the central HMI computer system. The meters meet the industry standard for meter accuracy and calibration frequency. The level of precision and accuracy for these meters currently satisfies the requirements for reporting in existing UIC permits.

Core Energy contracts with a third party firm that specializes in GHG Reporting Rule compliance to determine Core Energy's emissions using the Subpart W methodology. This results in an annual Subpart W report for Core Energy. Based on the results of this report to date, Core Energy does not meet the threshold for reporting its emissions to EPA through the EGRT system. Core Energy tracks its Subpart W emissions internally and will use these calculations, as specified the Subpart RR, for determining the mass of CO<sub>2</sub> stored.

## 5.2 CO<sub>2</sub> Received

Core Energy measures the volume of received CO<sub>2</sub> using Coriolis mass flow meters at the Chester 10 Facility and, as indicated in section 2.4.1, the Dover 36 Facility. As indicated in Section 2.5, any new recycle gas processing would be measured using Coriolis mass flow meters. No CO<sub>2</sub> is received in containers.

### 5.3 CO<sub>2</sub> Injected into the Subsurface

Injected CO<sub>2</sub> will be metered using the Coriolis mass flow meters dedicated to each injection well at a reef.

### 5.4 CO<sub>2</sub> Produced, Entrained in Products, and Recycled

For purposes of reporting under Subpart RR, Core energy will measure the mass of CO<sub>2</sub> produced through separators using Coriolis mass flow meters #19.

For any new production facilities added, as indicated in Section 2.5, the mass of CO<sub>2</sub> produced would similarly be measured using Coriolis mass flow meters.

CO<sub>2</sub> is produced as entrained or dissolved CO<sub>2</sub> in produced oil. As the oil passes through low-pressure separation to a gathering tank, a small amount of CO<sub>2</sub> is released. Core Energy has determined the concentration of CO<sub>2</sub> entrained in oil to be 0.7512% by weight (see Section 2.4.3).

### 5.5 CO<sub>2</sub> Emitted by Surface Leakage

Core Energy uses an event-driven process to assess, address, track, and if applicable quantify potential CO<sub>2</sub> leakage to the surface. Core Energy will reconcile the internal Subpart W report and results from any event-driven quantification to assure that surface leaks are not double counted.

The monitoring program for event-driven incidents has been designed to meet two objectives, in accordance with the leakage risk assessment in Section 4: 1) to detect problems before CO<sub>2</sub> leaks to the surface; and 2) to detect and quantify any leaks that do occur. This section discusses how this monitoring will be conducted and used to quantify the volumes of CO<sub>2</sub> leaked to the surface.

#### 5.5.1 Monitoring for potential Leakage from the Injection/Production Zone:

Core Energy routinely tracks and reports on a daily basis, the following surface data for all wells: Injection Rate (MCF), Production Rates (BO, BW, MCF), Tubing Pressure (psig), Casing Pressure (psig), Wellhead Temperatures (°F) and Runtime (Hours). Where there is instrumentation, data are collected more frequently but in the oilfield it is normal and customary for data to be reduced to daily volumes and/or averages. Core utilizes this data primarily for operational oversight and monitoring of EOR projects, but also intends to use this data to determine when further investigation of potential CO<sub>2</sub> leakage is warranted.

Core utilizes modeling, analog performance, operational practice, and historical project performance; bounded by permit conditions that take into account reservoir characteristics (e.g. injection pressure, injectant density, fracture gradient) to develop targeted daily/monthly injection rates, pressures and volumes. If injection rate or pressure significantly deviate from that which is targeted, it generates a flag and alerts operational personnel to investigate and resolve the matter. Operational and engineering personnel will collectively work to resolve these flagged events. Data flags and operational investigations do not mean that leakage of CO<sub>2</sub> has occurred, rather they are an indication that the injection rate and pressure are not conforming to the targeted values. In



most cases, the flagged events result in an easy fix (e.g. pressure gauge failure and subsequent replacement) and pose no threat of CO<sub>2</sub> leakage. However, in those rare cases whereby flagged events cannot be easily resolved, a more thorough and detailed investigation would be initiated, garnering wider Company or industry support as needed. Whenever any investigation identifies that CO<sub>2</sub> leakage has occurred, the volume of CO<sub>2</sub> that has escaped from the closed system will be quantified using operational and engineering judgement and included in the annual RR reporting.

Similarly, Core uses the collected data along with modeling, analogs and project performance to forecast produced volumes (i.e. oil, water, CO<sub>2</sub>) and composition. If producing wells do not have individual separation vessels and meters, they are individually well tested at least quarterly (more frequently if overall project production or individual well pressure data warrant it). The production data is reviewed at least monthly and if there is a significant deviation from past performance or forecast, operational and engineering personnel investigate further. If the cause of the deviation cannot be understood and resolved quickly, a more thorough and detailed investigation would be initiated, garnering wider Company or industry support as needed. Whenever any investigation identifies that CO<sub>2</sub> leakage has occurred, the volume of CO<sub>2</sub> that has escaped from the closed system will be quantified using operational and engineering judgement and included in the annual RR reporting.

Again, because of the unique geology of the NNPRT, to date, there has never been a case whereby leakage was suspected to have occurred in the EOR flood zone. In the very rare event that CO<sub>2</sub> leakage may be suspected in the EOR flood zone, Core would deploy methods to quantify the volume of CO<sub>2</sub> involved. With respect to tracking reservoir pressure, episodic surveys are conducted, on a field-by-field or well-by-well basis to gather information about reservoir pressure and other parameters (e.g. kh, skin). Because of the heterogeneity of these carbonate pinnacle reefs, it is not feasible to let injection wells fall-off or producing wells build-up for periods long enough to reach static conditions, thus, the bottom hole pressure measured in an injection well can be very significantly higher than that measured in a producing well over the typical survey duration (e.g. 3 to 7 days). Therefore, over time, well pressure survey histories are developed for both injection and production wells, that yield general performance behavior and characteristics for each well (field). Then, if a survey is run and its results diverge from this survey history in a statistically significant way, it triggers a deeper evaluation to discern what may be taking place and causing the anomaly. For example if injection wells in a field, over time, yield similar pressure survey results and then suddenly a survey yields an anomalous and lower result, then further evaluation is done to discern what may be causing the change (e.g. net CO<sub>2</sub> in reservoir declined considerably since last survey and/or an injection well was shut-in or its injection rate reduced, then the measured pressure would be expected to be lower than previous surveys).

If leakage in the flood zone were detected, Core Energy would use an appropriate method to quantify the involved volume of CO<sub>2</sub>. This might include use of material balance equations based on known injected quantities and monitored pressures in the injection zone to estimate the volume of CO<sub>2</sub> involved.

A subsurface leak might not lead to a surface leak. In the event of a subsurface leak, Core Energy would determine the appropriate approach for tracking subsurface leakage to determine and quantify leakage to the surface. To quantify leakage to the surface, Core Energy would estimate the relevant parameters (e.g., the rate, concentration, and duration of leakage) to quantify the leak volume. Depending on specific circumstances, these determinations may rely on engineering estimates.

#### 5.5.2 Monitoring of Wellbores:

Core Energy monitors wells through continual pressure monitoring in the injection zone (as described in Section 5.1), monitoring of the annular pressure in wellheads, and routine maintenance and inspection. At any time, in the case of an injection well, where there is a loss of MIT, the well must be and is shut-in until such time the wellbore is repaired. Upon completion of the workover, a new MIT is performed under the oversight of the EPA. The results of the MIT along with workover information are supplied to the EPA and if all is in order, they issue a letter authorizing injection to be resumed. Under no circumstances is injection commenced until such time the letter is in hand.

Leaks from wellbores would be detected through the follow-up investigation of pressure anomalies and visual inspection.

Anomalies in injection zone pressure may not indicate a leak, as discussed above. However, if an investigation leads to a work order, field personnel would inspect the equipment in question and determine the nature of the problem. If it is a simple matter, the repair would be made and the volume of leaked CO<sub>2</sub> would be included in the internal Subpart W report for the Core Energy Facility. If more extensive repair were needed, Core Energy would determine the appropriate approach for quantifying leaked CO<sub>2</sub> using the relevant parameters (e.g., the rate, concentration, and duration of leakage).

Anomalies in annular pressure or other issues detected during routine maintenance inspections would be treated in the same way. Field personnel would inspect the equipment in question and determine the nature of the problem. For simple matters the repair would be made at the time of inspection and the volume of leaked CO<sub>2</sub> would be included in the internal Subpart W report for the Core Energy Facility. If more extensive repairs were needed, the well would be shut in until repairs could be completed and Core Energy would determine the appropriate approach for quantifying leaked CO<sub>2</sub> using the relevant parameters (e.g., the rate, concentration, and duration of leakage).

In the event CO<sub>2</sub> is lost during a repair, the most recent daily volume of CO<sub>2</sub> would be prorated against the number of hours that the failure caused CO<sub>2</sub> to leak from the system. It should be noted that when doing workovers, the wells are always “killed” by using appropriate density fluid and the wells are “dead” (no CO<sub>2</sub> flow), thus, leakage has not occurred during workovers to wells to date. In the rare and unlikely event surface leakage does occur during a workover, an estimate of the volume would be made using engineering and operational judgements.

## 5.6 Mass of CO<sub>2</sub> Emissions from Equipment Leaks and Vented Emissions of CO<sub>2</sub> from Surface Equipment Located Between the Injection Flow Meter and the Injection Wellhead

Core Energy evaluates and estimates leaks from equipment, the CO<sub>2</sub> content of produced oil, and vented CO<sub>2</sub>, using the procedures in 40 CFR Part 98 Subpart W. Core Energy will use this method for reporting under Subpart RR.

## 5.7 Mass of CO<sub>2</sub> Emissions from Equipment Leaks and Vented Emissions of CO<sub>2</sub> from Surface Equipment Located Between the Production Flow Meter and the Production Wellhead

Core Energy evaluates and estimates leaks from equipment, the CO<sub>2</sub> content of produced oil, and vented CO<sub>2</sub>, using the procedures in 40 CFR Part 98 Subpart W. It also measures CO<sub>2</sub> emissions from dry and wet vents attached to the separators. Both of these measurements will be included under Subpart RR.

## 5.8 Demonstration that Injected CO<sub>2</sub> is not expected to Migrate to the Surface

At the end of the Specified Period, Core Energy intends to cease injecting CO<sub>2</sub> for the ancillary purpose of establishing the long-term storage of CO<sub>2</sub> in the Core Energy Facility. After the end of the Specified Period, Core Energy anticipates that it will submit a request to discontinue monitoring and reporting. The request will demonstrate that the amount of CO<sub>2</sub> reported as stored “is not expected to migrate in the future in a manner likely to result in surface leakage” ( §98.441).

At that time, Core Energy will be able to support its request with years of data collected during the Specified Period as well as two to three (or more, if needed) years of data collected after the end of the Specified Period. This demonstration will provide the information necessary for the EPA Administrator to approve the request to discontinue monitoring and reporting including:

- i. An assessment of injection data for each reef indicating the total volume of injected and stored CO<sub>2</sub> as well as the actual surface injection pressures;
- ii. An assessment of the CO<sub>2</sub> leakage detected, if any, including discussion of the estimated amount of CO<sub>2</sub> leaked and the distribution of emissions by leakage pathway; and
- iii. An assessment of reservoir pressure that demonstrates the reservoir pressure in a reef is either too low to enable flow to the surface (i.e., reef has been blown down) or that the reservoir pressure is stable enough to demonstrate that the CO<sub>2</sub> is contained within the reef and not expected to migrate in a manner to create a potential leakage pathway.

## 6. Determination of Baselines for Monitoring CO<sub>2</sub> Surface Leakage

Core Energy will use the results from daily monitoring of field conditions and operational data, as well as routine testing and maintenance information to monitor for surface leakage.

As indicated in sections 2.4.4. and 5, Core Energy uses onsite management and an automatic data system to conduct its EOR operations. Core Energy will use data from these efforts to identify and investigate variances from expected performance that could indicate CO<sub>2</sub> leakage. Below is a description of how this data will be used to determine when further investigation of potential CO<sub>2</sub> leakage is warranted.



- **Visual Inspections:** Operations personnel make daily rounds of the facilities and wells, providing a visual inspection of equipment used in the operations (e.g. vessels, piping, valves, wellheads). Making these rounds provide opportunity to identify issues early and address them proactively, which may preclude leaks from happening and/or minimize any CO<sub>2</sub> leakage. If an identified issue cannot be resolved by the person who first observes it, a work order will be generated to resolve the matter. Each event will be documented, include an estimate of the amount of CO<sub>2</sub> leaked and included in the annual RR reporting. Records for such events will be kept on file for a minimum of three years.
- **Injection Well Surveillance:** Core establishes target rates and pressures for all injection wells based on various parameters (e.g. CO<sub>2</sub> availability, field performance, delivery agreements, permit conditions). When a statistically significant deviation occurs that is outside of the established over or under range of the targeted values, it triggers further investigation to determine if the variance poses a leak threat. If investigation of an event identifies that a leak has occurred, those events will be documented, include an estimate of the amount of CO<sub>2</sub> leaked and included in the annual RR reporting. Records for such events will be kept on file for a minimum of three years.
- **Production Well Surveillance:** Core establishes a forecast for producing wells and projects, estimating the volumes of fluids (e.g. oil, CO<sub>2</sub>, water) that are likely to be produced over a period of time. Evaluation of the produced volumes along with other data (e.g. pressure, composition) informs operational decisions for how to manage a project and aid in identifying possible issues that may involve CO<sub>2</sub> leakage. These evaluations can direct engineering and/or operational personnel to investigate matters further, which can lead to work orders being issued to work on wells and/or surface equipment involved in a CO<sub>2</sub> EOR project. If investigation of an event identifies that a leak has occurred, those events will be documented, include an estimate of the amount of CO<sub>2</sub> leaked and included in the annual RR reporting. Records for such events will be kept on file for a minimum of three years.
- **Mechanical Integrity Testing (MIT):** Each CO<sub>2</sub> injection well has a permit condition whereby mechanical integrity has to be established and maintained. This involves the regular monitoring of the tubing-casing annular pressure and conducting annular fill-up tests. Core operational personnel monitor the pressure and conduct the tests in accordance with the permit conditions. In the event a loss of mechanical integrity occurs, the injection well is immediately shut-in and an investigation is initiated to determine what caused the loss of mechanical integrity. If investigation of an event identifies that a leak has occurred, those events will be documented, include an estimate of the amount of CO<sub>2</sub> leaked and included in the annual RR reporting. Records for such events will be kept on file for a minimum of three years.

## 7. Site Specific Considerations for the Mass Balance Equation

The Core Energy facility is small relative to many other EOR operations. It operates a current total of 15 injection, 14 production, and 7 monitoring/production wells located in 10 reefs. Core Energy also has 2.11 million metric tonnes of CO<sub>2</sub> inventory that will be reflected, over time, in the mass balance equation. Core Energy considers the following site specific conditions for using the equations in Subpart RR §98.443.

### 7.1. Mass of CO<sub>2</sub> Received

Core Energy will use equation RR-1 as indicated in Subpart RR §98.443 to calculate the mass of CO<sub>2</sub> received from the Chester 10 Facility and all recycle gas (currently from Dover 36 Facility but to include other new recycling facilities as indicated in Section 2.5.). In the annual monitoring report, Core Energy will track the current and cumulative volume of Dover 36 Facility CO<sub>2</sub> and indicate when it has reached 2,110,000 metric tonnes of working inventory; at that time, it will stop reporting the amount from Dover 36 under RR-1 / RR-3. In the future, any additional new sources of CO<sub>2</sub> will be added in the same manner.

$$CO_{2T,r} = \sum_{p=1}^4 (Q_{r,p} - S_{r,p}) * C_{CO_2,p,r} \quad \text{Equation RR-1}$$

where:

CO<sub>2T,r</sub> = Net annual mass of CO<sub>2</sub> received through flow meter r (metric tons).

Q<sub>r,p</sub> = Quarterly mass flow through a receiving flow meter r in quarter p at standard conditions (metric tons).

S<sub>r,p</sub> = Quarterly mass flow (metric tons) through a receiving flow meter r that is redelivered to another facility without being injected into a site well in quarter p

C<sub>CO<sub>2</sub>,p,r</sub> = Quarterly CO<sub>2</sub> concentration measurement in flow for flow meter r in quarter p (wt. percent CO<sub>2</sub>, expressed as a decimal fraction).

p = Quarter of the year.

r = Receiving flow meters.

Core Energy will sum to total Mass of CO<sub>2</sub> Received using equation RR-3 in §98.443

$$CO_2 = \sum_{r=1}^R CO_{2T,r} \quad \text{Equation RR-3}$$

where:

CO<sub>2</sub> = Total net annual mass of CO<sub>2</sub> received (metric tons).

CO<sub>2T,r</sub> = Net annual mass of CO<sub>2</sub> received (metric tons) as calculated in Equation RR-1 for flow meter r.

r = Receiving flow meter.

## 7.2 Mass of CO<sub>2</sub> Injected into the Subsurface

Core Energy will use equation RR-4 as indicated in Subpart RR §98.443 to calculate the mass of CO<sub>2</sub> injected into the subsurface at each of the ten reefs. Core proposes to use a method to calculate “C<sub>CO<sub>2</sub>,p,u</sub>” that uses a weighted average concentration that reflects the different CO<sub>2</sub> concentrations in the different sources of CO<sub>2</sub> as explained below.

$$CO_{2,u} = \sum_{p=1}^4 Q_{p,u} * C_{CO_2,p,u}$$

Equation RR-4

where:

CO<sub>2,u</sub> = Annual CO<sub>2</sub> mass injected (metric tons) as measured by flow meter u.

Q<sub>p,u</sub> = Quarterly mass flow rate measurement for flow meter u in quarter p (metric tons per quarter).

C<sub>CO<sub>2</sub>,p,u</sub> = Quarterly CO<sub>2</sub> concentration average measurement in flow for all injection flow meters (wt. percent CO<sub>2</sub>, expressed as a decimal fraction) as determined from Equation A below.

p = Quarter of the year.

u = Injection Flow meter.

For the weighted average concentration, C<sub>CO<sub>2</sub></sub>, Equation A indicates the current calculation using CO<sub>2</sub> from Chester 10 Facility and Dover 36 Facility. If new facilities are added, the weighted concentration average would be modified to include them in the same manner.

Equation A

$$Concentration\ Average = \frac{Q_{p,CH10} * C_{CO_2,p,CH10} + Q_{p,D36} * C_{CO_2,p,D36}}{Q_{p,CH10} + Q_{p,D36}}$$

Where:

Q<sub>p,CH10</sub> = Quarterly mass flow rate measurement of pure CO<sub>2</sub> (from Chester 10 Facility at flow meter #2) in quarter p (metric tons per quarter).

Q<sub>p,D36</sub> = Quarterly mass flow rate measurement of recycle gas (from Dover 36 Facility at flow meter #19) in quarter p (metric tons per quarter).

C<sub>CO<sub>2</sub>,p,CH10</sub> = Quarterly CO<sub>2</sub> concentration of pure CO<sub>2</sub> (from Chester 10 Facility at flow meter #2) in quarter p (wt. percent CO<sub>2</sub>, expressed as a decimal fraction).

C<sub>CO<sub>2</sub>,p,D36</sub> = Quarterly CO<sub>2</sub> concentration of recycle gas (from Dover 36 Facility at flow meter #19) in quarter p (wt. percent CO<sub>2</sub>, expressed as a decimal fraction).

Core Energy will aggregate injection data using equation RR-6:

$$CO_{2i} = \sum_{u=1}^U CO_{2,u} \quad \text{Equation RR-6}$$

where:

$CO_{2i}$  = Total annual  $CO_2$  mass injected (metric tons) through all injection wells.

$CO_{2,u}$  = Annual  $CO_2$  mass injected (metric tons) as measured by flow meter u.

### 7.3 Mass of $CO_2$ Produced

Core Energy uses Coriolis mass flow meters to measure  $CO_2$  in produced fluids as follows. If new production facilities are added, as indicated in Section 2.5, the same approach will be applied.

$$CO_{2,w} = \sum_{p=1}^4 Q_{p,w} * C_{CO_2,p,w} \quad \text{Equation RR-7}$$

Where:

$CO_{2,w}$  = Annual  $CO_2$  mass produced (metric tons) through separator w.

$Q_{p,w}$  = Quarterly gas mass flow rate measurement for separator w in quarter p (metric tons).

$C_{CO_2,p,w}$  = Quarterly  $CO_2$  concentration of recycle gas (currently at Dover 36 Facility flow meter #19) for separator w in quarter p (wt. percent  $CO_2$ , expressed as a decimal fraction).

p = Quarter of the year.

w = Separator.

Core will aggregate production data using equation RR-9 net of the mass of  $CO_2$  entrained in oil as follows:

$$CO_{2P} = \sum_{w=1}^W CO_{2,w} + X \quad \text{Equation RR-9}$$

Where:

$CO_{2P}$  = Total annual  $CO_2$  mass produced (metric tons) through all separators in the reporting year.

$CO_{2,w}$  = Annual  $CO_2$  mass produced (metric tons) through separator w in the reporting year.

w = Separator flow meter.

X= Mass of entrained  $CO_2$  in oil in the reporting year measured utilizing commercial meters and electronic flow-measurement devices at each point of custody transfer. The mass of  $CO_2$  will be calculated by multiplying the total volumetric rate by the  $CO_2$  concentration.

## 7.4 Mass of CO<sub>2</sub> emitted by Surface Leakage

Core Energy will calculate and report the total annual Mass of CO<sub>2</sub> emitted by Surface Leakage using an approach that is tailored to specific leakage events. As described in Sections 4 and 5.1.5-5.1.7, Core Energy is prepared to address the potential for leakage in a variety of settings. Estimates of the amount of CO<sub>2</sub> leaked to the surface will likely depend on a number of site-specific factors including measurements, engineering estimates, and emission factors, depending on the source and nature of the leakage.

Core Energy's process for quantifying leakage will entail using best engineering principles or emission factors. While it is not possible to predict in advance the types of leaks that will occur, Core Energy describes some approaches for quantification in Section 5.1.5-5.1.7. In the event leakage to the surface occurs, Core Energy would quantify and report leakage amounts, and retain records that describe the methods used to estimate or measure the volume leaked as reported in the Annual Subpart RR Report. Further, Core Energy will reconcile the internal Subpart W report and results from any event-driven quantification to assure that surface leaks are not double counted.

Equation RR-10 in 48.433 will be used to calculate and report the Mass of CO<sub>2</sub> emitted by Surface Leakage:

$$CO_{2E} = \sum_{x=1}^X CO_{2,x} \quad \text{Equation RR-10}$$

where:

CO<sub>2E</sub> = Total annual CO<sub>2</sub> mass emitted by surface leakage (metric tons) in the reporting year.

CO<sub>2,x</sub> = Annual CO<sub>2</sub> mass emitted (metric tons) at leakage pathway x in the reporting year.

x = Leakage pathway.

## 7.5 Mass of CO<sub>2</sub> sequestered in subsurface geologic formations.

Core Energy will use equation RR-11 to determine the mass of CO<sub>2</sub> that is incidentally stored each year.

$$CO_2 = CO_{2I} - CO_{2P} - CO_{2E} - CO_{2FI} - CO_{2FP} \quad \text{Equation RR-11}$$

where:

CO<sub>2</sub> = Total annual CO<sub>2</sub> mass sequestered in subsurface geologic formations (metric tons) at the facility in the reporting year.

CO<sub>2I</sub> = Total annual CO<sub>2</sub> mass injected (metric tons) in the well or group of wells covered by this source category in the reporting year.

CO<sub>2P</sub> = Total annual CO<sub>2</sub> mass produced (metric tons) net of CO<sub>2</sub> entrained in oil in the reporting year.

CO<sub>2E</sub> = Total annual CO<sub>2</sub> mass emitted (metric tons) by surface leakage in the reporting year.

CO<sub>2FI</sub> = Total annual CO<sub>2</sub> mass emitted (metric tons) from equipment leaks and vented emissions of CO<sub>2</sub> from equipment located on the surface, between the flow meter

used to measure injection quantity and the injection wellhead in the reporting year, calculated as provided in subpart W.

$CO_{2FP}$  = Total annual CO<sub>2</sub> mass emitted (metric tons) from equipment leaks and vented emissions of CO<sub>2</sub> from equipment located on the surface between the production wellhead and the flow meter used to measure production quantity in the reporting year, calculated as in Subpart W and including the metered CO<sub>2</sub> measurements at the wet and dry vents attached to the separators.

## 7.6 Cumulative mass of CO<sub>2</sub> reported as sequestered in subsurface geologic formations

Core Energy will sum up the total annual volumes obtained using equation RR-11 in 98.443 to calculate the Cumulative Mass of CO<sub>2</sub> Sequestered in Subsurface Geologic Formations.

## 8. Estimated Schedule for Implementation of MRV Plan

This plan will be effective as of January 1, 2018.

## 9. Quality Assurance Program

### 9.1 Monitoring

Core Energy will follow the requirements in 40 CFR part 98.444 as indicated in Sections 2, 5 and 7. As indicated in Section 5.1, Core Energy has invested in Micro Motion Coriolis Mass Flow Meters throughout its operations. These meters are designed to retain calibration. The meters have no moving parts and a non-intrusive measuring sensor. As a result, there are no probes or detectors that come into direct contact with process fluids. The benefit of this design is that there are no bearings or rotors to wear, turbines to be deformed, electrodes to coat, or degradation of orifices to be concerned about. The manufacturer reports that “It has been our experience, and that of our customers, that Coriolis meters do not shift or lose their calibration during the life of the meter. When calibration issues arise, the focus of the problem is normally traceable to the flow meter installation or a characteristic of the process that was not previously taken into consideration.” As a result, there are no prevailing industry standard(s) for meter calibration for these meters. Core Energy observes trend data from the meters and has on occasion sent meters back to the company for recalibration but this does not occur routinely. Core Energy considers this approach to be consistent with EPA GHGRP’s Subpart RR, section 98.444(e)(3). These meters will be maintained, operated continually, and will feed data directly to the central HMI computer system. The meters meet the industry standard for meter accuracy and calibration frequency. The level of precision and accuracy for these meters currently satisfies the requirements for reporting in existing UIC permits.

### 9.2 Procedures for estimating missing data.

In the event Core Energy is not able to collect data for the mass balance equations, it will follow the requirements in 40 CFR part 98.445 to provide missing data.

When estimating the volume of missing CO<sub>2</sub> data due to an interruption in data collection or mechanical failure of a meter (equipment) is to use the most recent daily volume of CO<sub>2</sub>

associated with the meter and calculate the proportionate volume of “lost” CO<sub>2</sub> based on the number of hours involved in the data gap or until meter repaired.

### 9.3 MRV Plan Revisions

In the event there is a material change to the monitoring and/or operational parameters of the Core Energy CO<sub>2</sub> EOR operations that is not anticipated in this MRV plan, the MRV plan will be revised and submitted to the EPA Administrator within 180 days as required in §98.448(d).

## 10. Records Retention

Core Energy will maintain and submit records required under 40 CFR Part 98.3(g) and 40 CFR Part 98.447. Records will be maintained by Core Energy in electronic format at the Core Energy headquarters. In addition, Core Energy has well and facility data in three forms; A.) Paper copies (scanned to server), B.) Keyed in data from paper copies into database, and C.) Automated capture of limited set of data that was recently instrumented (Fall of 2016).

## 11. References

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# Appendix



## Appendix I: List of Wells

Table A-1. Core Energy Wells used for Monitoring and Accounting

Unit	Facility	API Permit	DEQ Permit	Well Name	Well Type	Well Status
<b>Dover 33 EOR Unit</b>	Dover 36 CPF	21-137-29565-00-00	29565	Lawnichak & Myszkier 1-33	Injection	INJ
<b>Dover 33 EOR Unit</b>	Dover 36 CPF	21-137-00652-00-00	61209	Lawnichak 9-33	Oil	PR
<b>Dover 33 EOR Unit</b>	Dover 36 CPF	21-137-51603-00-00	51603	Lawnichak & Myszkier 5-33 HD1	Oil	PR
<b>Dover 33 EOR Unit</b>	Dover 36 CPF	21-137-50985-04-00	55942	Lawnichak & Myszkier 2-33 HD4	Oil	PR
<b>Bagley 11-14-23 EOR</b>	Dover 36 CPF	21-137-39758-01-00	39866	Wrubel 4-14A	Injection	INJ
<b>Bagley 11-14-23 EOR</b>	Dover 36 CPF	21-137-30536-00-00	30536	MBM 1-22	Injection	INJ
<b>Bagley 11-14-23 EOR</b>	Dover 36 CPF	21-137-38240-00-00	38240	Daughters of Friel 2-11	Injection	INJ
<b>Bagley 11-14-23 EOR</b>	Dover 36 CPF	21-137-37794-00-00	37794	Janik Mackowiac 1-11	Oil	OBS
<b>Bagley 11-14-23 EOR</b>	Dover 36 CPF	21-137-38286-00-00	38286	Janik Stevens 3-11	Oil	OBS
<b>Bagley 11-14-23 EOR</b>	Dover 36 CPF	21-137-39748-00-00	39748	Janik Strappazon 3-14	Oil	OBS
<b>Bagley 11-14-23 EOR</b>	Dover 36 CPF	21-137-38859-02-00	39897	Glasser 1-14B	Oil	OBS
<b>Charlton 19 Unit (EOR)</b>	Dover 36 CPF	21-137-42766-00-00	42766	El Mac Hills 2-18	Injection	INJ
<b>Charlton 19 Unit (EOR)</b>	Dover 36 CPF	21-137-40911-04-00	57261	El Mac Hills 1-19D	Oil	SI-P
<b>Charlton 19 Unit (EOR)</b>	Dover 36 CPF	21-137-41801-01-00	61197	El Mac Hills 1-18A	Oil	PR
<b>Charlton 30/31 EOR Unit</b>	Dover 36 CPF	21-137-30203-00-00	30203	State Charlton C2-30	Injection	INJ
<b>Charlton 30/31 EOR Unit</b>	Dover 36 CPF	21-137-59048-00-00	59048	State Charlton & Larsen 3-31	Injection	INJ
<b>Charlton 30/31 EOR Unit</b>	Dover 36 CPF	21-137-29989-00-00	29989	State Charlton 1-30A	Injection	INJ
<b>Charlton 30/31 EOR Unit</b>	Dover 36 CPF	21-137-57916-00-00	57916	State Charlton 4-30	Oil	PR
<b>Charlton 30/31 EOR Unit</b>	Dover 36 CPF	21-137-31287-00-00	31287	State Charlton 2-30	Oil	PR
<b>Charlton 6 EOR Unit</b>	Dover 36 CPF	21-137-35209-00-00	35209	Zeimet-Higgins & St Charlton 1-6	Injection	INJ
<b>Charlton 6 EOR Unit</b>	Dover 36 CPF	21-137-59086-00-00	59086	State Charlton & Boeve 2-6	Oil	PR
<b>Chester 2 EOR Unit</b>	Dover 36 CPF	21-137-29430-00-00	29430	Wolf, Carl 1A	Injection	INJ
<b>Chester 2 EOR Unit</b>	Dover 36 CPF	21-137-29958-01-00	29958	Wolf, Carl et al C1-HD1	Oil	PR

<b>Chester 2 EOR Unit</b>	Dover 36 CPF	21-137- 60596-01-00	60596	Cargas 3-2 HD2	Oil	PR
<b>Chester 5 EOR Unit</b>	Dover 36 CPF	21-137- 59237-00-00	59237	Borowiak 2-6	Injection	INJ
<b>Chester 5 EOR Unit</b>	Dover 36 CPF	21-137- 58926-00-00	58926	Butler 3-5	Injection	SI-I
<b>Chester 5 EOR Unit</b>	Dover 36 CPF	21-137- 29265-01-00	60833	Piasecki 1-7A	Oil	PR
<b>Dover 35 EOR Unit</b>	Dover 36 CPF	21-137- 29236-00-00	29236	Salling Hanson Trust 1-35	Injection	INJ
<b>Dover 35 EOR Unit</b>	Dover 36 CPF	21-137- 37324-01-00	59238	Pomarzynski et al 5-35A	Oil	SI-P
<b>Dover 35 EOR Unit</b>	Dover 36 CPF	21-137- 29947-01-00	29995	Salling Hanson Trust 4-35A	Oil	PR
<b>Dover 35 EOR Unit</b>	Dover 36 CPF	21-137- 57787-00-00	57787	Pomarzynski et al 6-35	Oil	PR
<b>Dover 36 EOR Unit</b>	Dover 36 CPF	21-137- 29348-00-00	29348	Kubacki State 3-35	Injection	INJ
<b>Dover 36 EOR Unit</b>	Dover 36 CPF	21-137- 29235-00-00	29235	Kubacki State 1-36	Injection	INJ
<b>Dover 36 EOR Unit</b>	Dover 36 CPF	21-137- 52719-00-00	52719	Dover State 36 Unit 3-36	Oil	PR
<b>Chester 16 EOR Unit</b>	Dover 36 CPF	21-137- 61189-00-00	61189	Chester 16 Unit 6-16 Pilot	Injection	INJ
<b>Chester 16 EOR Unit</b>	Dover 36 CPF	21-137- 61186-00-00	61186	Chester 16 Unit 8-16	Oil	OBS

Table A-2. Summary of Niagaran Wells by Reef With Listing of Depth, Completion Date, and Wireline Log Inventory used for Geologic Characterization

Source: [Michigan DEQ Oil and Gas Well Database](#)

Note: CAL=CALIPER; GR=GAMMA RAY; NPFI=NEUTRON POROSITY; RHOB=DENSITY; PE=PHOTOELECTRIC; SON=SONIC; RES=RESISTIVITY; CBL=CEMENT BOND LOG; CBIL= circumferential borehole image log (acoustic image log); NEUTRON= neutron log reported in neutron units; PNC=Pulsed Neutron Capture log.

(a) Indicates currently active (not plugged/abandoned) producing well.

(b) Indicates currently active (not plugged/abandoned) injection well.

(c) Deviated well; total depth amsl will be determined after acquiring deviation survey.

Reef	Well Permit No.	Well Name	Well No.	Total Depth, ft		Date Completed	Wireline Logs
				bgs	amsl		
Bagley	29074	Yule King Tree	1-15	6135	- 4815	1/14/1973	CAL,GR,NPFI,RHOB,RES
	29085	Alan Gornick	1-23	6177	- 4867	1/18/1973	CAL,GR,NPFI,RHOB
	29249	Alan Gornick	1-14	6165	- 4869	11/23/1973	CAL,GR,NPFI,RHOB
	30536 <sup>(a)</sup>	MBM	1-22	6013	- 4689	10/24/1975	CAL,GR,NPFI,RHOB,RES
	37794 <sup>(a)</sup>	Janik & Mackowiac	1-11	6326	- 5021	9/11/1984	CAL,GR,NPFI,RHOB,RES,PNC
	38240 <sup>(b)</sup>	Daughters of Friel	2-11	6250	- 4739	10/30/1984	CAL,GR,NPFI,RHOB,RES
	38286 <sup>(a)</sup>	Janik & Stevens	3-11	6045	- 4676	11/2/1984	CAL,GR,NPFI,RHOB,RES
	38859	Glasser	1-14A	6115	- 4811	3/2/1986	CAL,GR,NPFI,RES
	38923	Yule King Tree	1-14	6024	- 4725	10/17/1985	CAL,GR,NPFI,RES,PNC

Reef	Well Permit No.	Well Name	Well No.	Total Depth, ft		Date Completed	Wireline Logs
				bgs	amsl		
	39554	Stevens and State Bagley	1-22	6295	- 4975	1/13/1986	CAL,GR,NPHI,RHOB,RES
	39748 <sup>(a)</sup>	Janik & Strappazon	3-14	6000	- 4706	2/24/1986	CAL,GR,NPHI,RHOB,RES
	39758	Wrubel	4-14	6140	(c)	3/9/1986	CAL,GR,NPHI,RHOB,RES
	39850	Glasser	1-14A	6367	- 4839	3/12/1986	CAL,GR,NPHI,RHOB,RES
	39866 <sup>(a)</sup>	Wrubel	4-14A	6191	- 4822	4/21/1986	CAL,GR,NPHI,RHOB,RES
	39897 <sup>(a)</sup>	Glasser	1-14B	6130	- 4752	5/7/1986	CAL,GR,NPHI,RES,PNC
	55307	Stevens and State Bagley	1-22A	6270	- 4910	1/9/2003	CAL,GR,NPHI,RHOB,RES
Charlton 6	28895	Zeimet & Higgins	1-6	6008	- 4724	6/21/1972	CAL,GR,NPHI,RHOB,RES
	35209 <sup>(b)</sup>	Zeimet, Higgins & State Charlton	1-6	5975	- 4745	12/10/1981	CAL,GR,NPHI,RHOB,PE,RES
	59086 <sup>(a)</sup>	State Charlton & Boeve	2-6	6202	- 4796	6/19/2008	CAL,GR,NPHI,RHOB,RES,PE
Charlton 19	40911	El Mac Hills	1-19	5675	- 4552	3/9/1988	CAL,GR,NPHI,RHOB,RES,SON
	41801	El Mac Hills	1-18A	5466	- 4341	2/24/1989	CAL,GR,NPHI,RHOB,RES,PNC
	42766 <sup>(b)</sup>	El Mac Hills	2-18	5555	(c)	2/5/1990	CAL,GR,NPHI,RHOB,RES,PNC
	54416	El Mac Hills	1-19A	5433	- 4297	6/22/2001	Not Logged
	54582	El Mac Hills	1-19B	5421	(c)	6/27/2001	Not Logged
	54583	El Mac Hills	1-19C	5321	- 4246	7/1/2001	Not Logged
	57261 <sup>(a)</sup>	El Mac Hills	1-19D	5495	- 4335	12/21/2005	CAL,GR,NPHI,RHOB,RES,SON,PNC
Charlton 30-31	29073	Salling Hanson et al	1-31	5770	- 4645	1/9/1973	CAL,GR,NPHI,RHOB,SON,RES
	30195	State Charlton "C"	1-30	5679	- 4497	3/21/1975	CAL,GR,NPHI,RHOB,RES

Reef	Well Permit No.	Well Name	Well No.	Total Depth, ft		Date Completed	Wireline Logs
				bgs	amsl		
	32605	State Charlton "C"	3-30	5746	- 4563	12/16/1978	CAL,GR,NPHI,RHOB,RES
	29989 <sup>(b)</sup>	State Charlton	1-30A	5650	- 4582	12/24/1974	CAL,GR,NPHI,SON,RES
	30203 <sup>(b)</sup>	State Charlton "C"	2-30	6255	- 4588	4/22/1975	CAL,GR,NPHI,RHOB,RES
	31287 <sup>(a)</sup>	State Charlton	2-30	5660	- 4517	12/7/1976	CAL,GR,NPHI,SON,RES
	57916 <sup>(a)</sup>	State Charlton	4-30	5800	- 4599	11/30/2006	CAL,GR,NPHI,RHOB,PE,RES
	59048 <sup>(b)</sup>	State Charlton & Larsen	3-31	5800	- 4689	7/7/2008	CAL,GR,NPHI,RHOB,PE,RES
Chester 2	28459	Cargas, Perry J	1	6005	- 4762	10/4/1971	CAL,GR,NPHI,RHOB,SON,RES
	28706	Finnegan, Bernard et al	1	6051	- 4818	1/6/1972	CAL,GR,NPHI,RES
	29677	Wolf, Carl	1-B	5847	- 4568	6/27/1974	CAL,GR,NPHI,RHOB,RES
	31646	Cargas, Perry J	1-2A	5990	- 4745	9/9/1977	CAL,GR,NPHI,RHOB,RES
	29430 <sup>(b)</sup>	Wolf, Carl	1-A	5973	- 4710	12/2/1973	CAL,GR,NPHI,RHOB,RES
	29958 <sup>(a)</sup>	Wolf, Carl et al "C"	1	5806	- 4536	12/9/1974	CAL,GR,NPHI,RHOB,RES
	29958-01 <sup>(a)</sup>	Wolf, Carl et al "C"	1 HD1	6570	- 4509	10/9/2001	CAL,GR,CBL
	60596 <sup>(a)</sup>	Cargas, Perry J	3-2 HD-1	6962	- 4556	10/9/2012	CAL,GR,NPHI,RHOB,RES,SON,PNC
Chester 5-6	29067	Borowiak	1-6	6022	- 4673	1/11/1973	CAL,GR,NPHI,SON,RES
	29234	Borowiak	1-5	5725	- 4409	4/13/1973	CAL,GR,NPHI,SON,RES
	29254	Kosiara	2-7	5750	- 4398	5/24/1973	CAL,GR,SON,RES
	29265	Piasecki	1-7	5770	- 4416	5/4/1973	CAL,GR,NPHI,SON,RES,PNC

Reef	Well Permit No.	Well Name	Well No.	Total Depth, ft		Date Completed	Wireline Logs
				bgs	amsl		
	31515	Piasecki, John State Chester	1-7	5800	- 4462	6/1/1977	CAL,GR,NPHI,RHOB,RES
	32207	Kosiara, Josephine	2-7A	5881	(c)	3/20/1978	CAL,GR,NPHI,RHOB,RES
	38424	Gottloeb	1-8	6080	(c)	11/21/1984	CAL,GR,NPHI,RHOB,PE,RES
	40169	Nienaber	2-5	5985	- 4633	12/16/1986	CAL,GR,NPHI,RHOB,PE,RES
	58926 <sup>(b)</sup>	Butler	3-5	5897	- 4585	5/1/2008	CAL,GR,NPHI,RHOB,RES,CBIL,CRA
	59237 <sup>(b)</sup>	Borowiak	2-6	6100	- 4751	7/25/2008	CAL,GR,NPHI,RHOB,PE,RES,CBIL,CBL
Chester 16	28159	Gaylord Mortgage	1-16	6210	- 4873	1/4/1971	CAL,GR,NPHI,RHOB,RES,SNP
	28433	Veraghen, Martin G	4-21	6303	- 4972	8/13/1971	CAL,GR,NPHI,RHOB,RES,SNP,SON
	28511	Gaylord Mortgage	2-16	6250	- 4907	9/4/1971	CAL,GR,NPHI,RES,SNP,SON
	28743	Veraghen & Rypkowski	5-21	6350	- 5037	3/29/1972	CAL,GR,NPHI,RES,SNP,SON
	28796	Gaylord Mortgage	3-16	6222	- 4896	8/22/1972	CAL,GR,NPHI,RES,SNP
	28798	Dreffi	4-16	6265	- 4913	3/13/1972	RES,SNP, SON
	28918	Veraghen & Dreffi	6-21	6318	- 4995	7/20/1972	CAL,GR,RES,SNP,SON
	61186	Chester	8-16	6455	- 5020	2/26/2017	CAL,GR,NPHI,RES,RHOB,SON
	61189***	Chester	6-16	6697	- 5061	12/23/2016	CAL,GR,NPHI,RES,RHOB,SON,PNC
Dover 33	29565 <sup>(b)</sup>	Lawnichak & Myszkier	1-33	5675	- 4528	5/20/1974	CAL,GR,NPHI,RES,RHOB,SON,PNC
	29781	Lawnichak & Myszkier	3-33	5625	- 4404	8/16/1974	CAL,GR,NPHI,RES
	29809	Koblinski & Fisher	1-28	5514	- 4397	8/22/1974	CAL,GR,NPHI,RES,SNP

Reef	Well Permit No.	Well Name	Well No.	Total Depth, ft		Date Completed	Wireline Logs
				bgs	amsl		
	29840	Kirt House	2-28	5475	- 4290	8/7/1974	CAL,GR,NPHI,RES,SON
	30392	Winter	2-33	5840	- 4560	8/9/1975	CAL,GR,NPHI,RES,SON
	31108	Amejka	2-34	5886	- 4657	9/5/1976	CAL,GR,NPHI,SON
	31228	Boughner State Dover	3-28	5520	- 4401	7/23/1977	CAL,GR,NPHI,SON
	31303	Thompson	1-33	5690	- 4540	11/22/1976	CAL,GR,NPHI,RES,RHOB
	32298	Boughner State Dover	4-28	5505	(c)	7/7/1978	CAL,GR,NPHI
	33830	Lawnichak & Myszkier	5-33	5775	- 4565	7/28/1980	CAL,GR,NPHI,RES,SON
	33937	Lawnichak & Myszkier	5-33A	5746	- 4536	8/4/1980	CAL,GR,NPHI,RES,SON
	35195	Winter	1-33	5740	- 4457	12/31/1982	CAL,GR,NPHI,RES,RHOB
	35584	Lawnichak & Morey	1-33	5703	- 4539	8/24/1982	CAL,GR,NPHI,RHOB
	50985	Lawnichak & Myszkier	2-33	5763	- 4597	11/22/1996	CAL,GR,NPHI,RHOB,PNC
	51601	Lawnichak & Myszkier	2-33 HD1	6990	- 4315	12/30/1996	CAL,GR,TDT
	51603	Lawnichak & Myszkier	5-33 HD1	6456	- 4354	2/2/1997	CAL,GR,PNC
	55479	Lawnichak & Myszkier	2-33 HD2	6138	(c)	8/21/2003	Not Logged
	55845	Lawnichak & Myszkier	2-33 HD3	7335	- 4368	9/23/2003	Not Logged
	55942	Lawnichak & Myszkier	2-33 HD4	7134	- 4348	12/29/2003	Not Logged
	61209	Lawnichak	9-33	6085	- 4677	12/3/2016	CAL,GR,NPHI,RES,RHOB,SON
□ ○ ☹	29374	Pomerzynski	2-35	5760	- 4619	9/27/1973	CAL,GR,NPHI,SON,RES

Reef	Well Permit No.	Well Name	Well No.	Total Depth, ft		Date Completed	Wireline Logs
				bgs	amsl		
	29947	Salling Hanson Trust	4-35	5564	- 4450	10/18/1974	CAL,GR,SON
	35941	Tinsey	1-35	5792	(c)	8/23/1982	CAL,GR,NPHI,RHOB,PE,RES
	37324	Pomerzynski et al	5-35	5715	- 4575	12/22/1983	CAL,GR,NPHI,RHOB,PE,RES
	37381	Taskey & Saddler Estate	1-35	5768	- 4615	2/14/1984	CAL,GR,NPHI,RHOB,RES
	29236 <sup>(b)</sup>	Salling & Hanson	1-35	5780	- 4656	5/25/1973	CAL,GR,NPHI,SON,RES
	29995 <sup>(b)</sup>	Salling Hanson Trust	4-35A	5715	- 4504	11/4/1974	CAL,GR,NPHI,SON,RES
	57787 <sup>(a)</sup>	"Pomarzynski"	6-35	5950	- 4688	11/30/2006	CAL,GR,NPHI,RHOB,PE,RES
	(59238) <sup>(a)</sup>	"Pomarzynski"	5-35A	5864	- 4437	8/24/2008	CAL,GR,NPHI
Dover 36	29303	Kubacki Cole	2-36	5765	- 4592	6/14/1973	CAL,GR,NPHI,SON,RES
	29664	Freese, Charles E III et al	1-2	5830	- 4614	4/8/1974	CAL,GR,NPHI,SON,RES
	29235 <sup>(b)</sup>	Kubacki & State Dover	1-36	5835	- 4683	4/29/1973	CAL,GR,NPHI,SON,RES
	29348 <sup>(b)</sup>	Kubacki State	3-35	6431	(c)	7/6/1973	CAL,GR,NPHI,SON,RES
	52719 <sup>(a)</sup>	Dover 36 Unit	3-36	5700	- 4533	7/31/1998	CAL,GR,NPHI,RHOB,PE,RES

Source: [Michigan DEQ Oil and Gas Well Database](#)

Note: CAL=CALIPER; GR=GAMMA RAY; NPHI=NEUTRON POROSITY; RHOB=DENSITY; PE=PHOTOELECTRIC; SON=SONIC; RES=RESISTIVITY; CBL=CEMENT BOND LOG; CBIL= circumferential borehole image log (acoustic image log); NEUTRON= neutron log reported in neutron units; PNC=Pulsed Neutron Capture log.

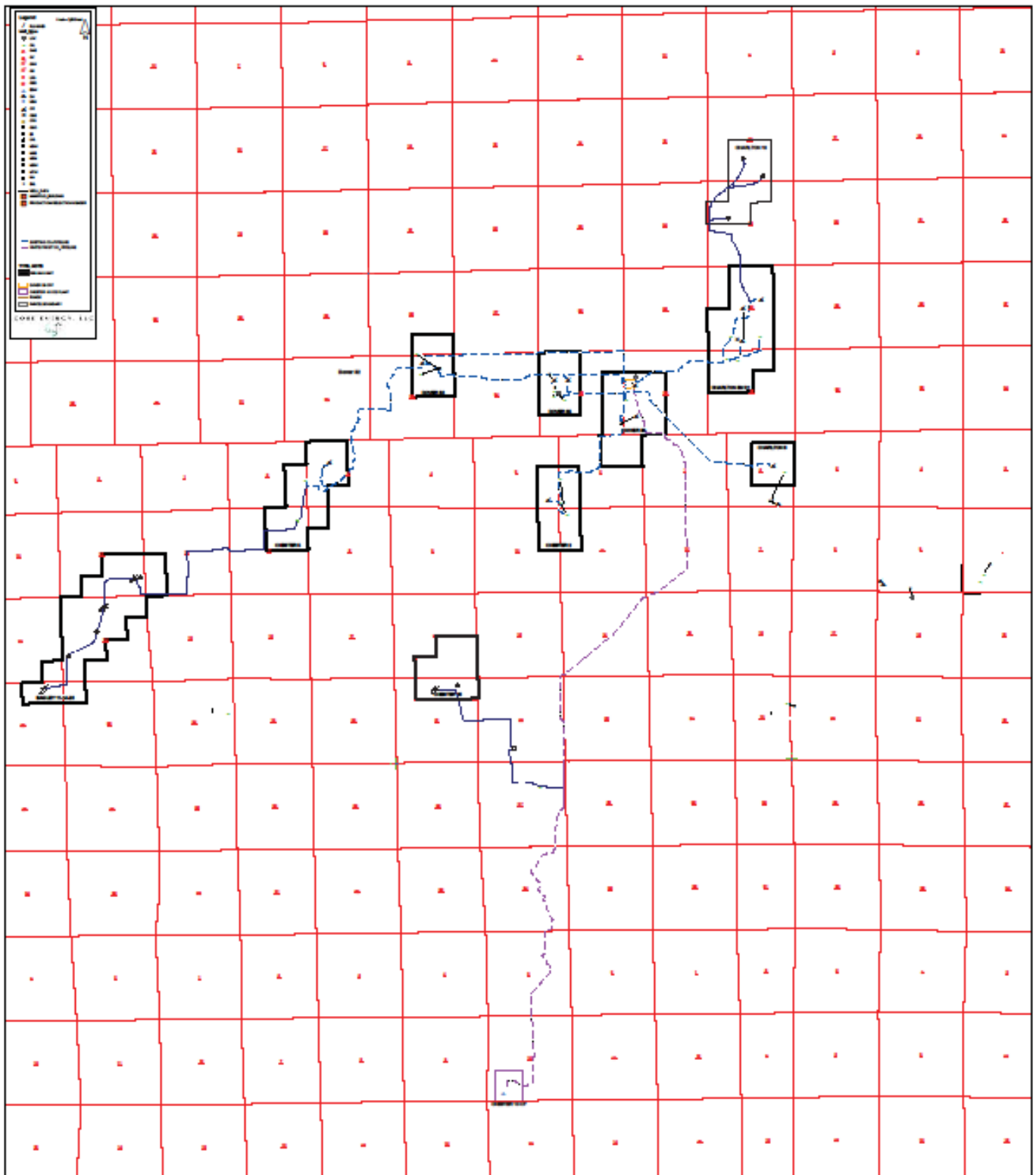
(a) Indicates currently active (not plugged/abandoned) producing well.

(b) Indicates currently active (not plugged/abandoned) injection well.

(c) Deviated well; total depth amsl will be determined after acquiring deviation survey.



## Appendix II: Map of Core Energy pipelines



## **Appendix B: Submissions and Responses to Requests for Additional Information**

**Core Energy**

**Northern Niagaran Pinnacle Reef Trend (NNPRT)  
CO<sub>2</sub> Monitoring, Reporting, and Verification (MRV) Plan**

September, 2018

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## Introduction

Core Energy LLC (Core Energy) operates an integrated carbon dioxide (CO<sub>2</sub>) capture and enhanced oil recovery (EOR) facility in the Northern Niagaran Pinnacle Reef Trend (NNPRT) in Michigan. The Core Energy facility includes equipment to capture CO<sub>2</sub> from various sources, dedicated pipelines, a set of subsurface geologic reef formations, and equipment to process oil.

Core Energy joined the Midwest Regional Carbon Sequestration Partnership (MRCSP) in 2005 and has worked closely with the research team to advance the technical understanding of the reefs and the regional geology in the context of ongoing EOR operations. This research demonstrates that CO<sub>2</sub>-EOR results in incidental CO<sub>2</sub> storage in the reefs at the end of the CO<sub>2</sub>-EOR life cycle. Core Energy intends to inject CO<sub>2</sub> with a secondary purpose of establishing long-term containment of a measurable quantity of CO<sub>2</sub> in subsurface geological formations in the NNPRT for a term referred to as the "Specified Period."

The MRCSP regional geologic characterization indicates that there is potential capacity for hundreds of millions tonnes of CO<sub>2</sub> through ancillary CO<sub>2</sub> EOR storage in the NNPRT. This potential far exceeds the amount of CO<sub>2</sub> available for EOR and, ultimately, ancillary storage capacity. This means that Core Energy anticipates being limited by the amount of available CO<sub>2</sub> in the future rather than by the amount of economically viable CO<sub>2</sub> EOR opportunity. In addition, the nature of the reef geology, as described in Section 2, provides operational flexibility that is much like buffer storage capacity. As a result, Core Energy anticipates continuing its business practice of capturing as much CO<sub>2</sub> as it can while the Antrim Shale play is still active and storing it within the reef system to support its EOR operations. Since it began operations, Core Energy has developed an inventory of anthropogenic CO<sub>2</sub> that is in circulation within the existing reef structures. Calculation of this inventory of working CO<sub>2</sub> is discussed further in Section 2.

During the Specified Period, Core Energy will utilize the working inventory of CO<sub>2</sub> through capture at the Dover 36 Facility and combine it with new CO<sub>2</sub> captured through the Chester 10 Facility. Over time, the mass balance calculation of stored CO<sub>2</sub> will reflect the existing inventory of CO<sub>2</sub> plus the new CO<sub>2</sub>, as discussed in Sections 2, 5, and 7. Core Energy plans to further expand the amount of CO<sub>2</sub> introduced to the field if new sources become available. This additional amount would also be reflected in the mass balance calculation of stored CO<sub>2</sub>.

Core Energy developed this monitoring, reporting, and verification (MRV) plan in accordance with 40 CFR §98.440-449 (Subpart RR) to provide for the monitoring, reporting and verification of the quantity of CO<sub>2</sub> sequestered at the Core Energy facility during the Specified Period. This plan describes how CO<sub>2</sub> EOR and ancillary storage take place in the reefs and how Core Energy will apply the requirements in 40 CFR §98.440-449 (Subpart RR) to calculate the annual amount of CO<sub>2</sub> stored throughout the entire Core Energy CO<sub>2</sub> EOR facility

In accordance with Subpart RR, flow meters are used to quantify the mass of CO<sub>2</sub> received, injected, produced, contained in products, and lost through venting or leakage. If leakage is detected, the mass of leaked CO<sub>2</sub> will be quantified using three approaches. First, Core Energy follows the procedures in 40 CFR §98.230-238 (Subpart W) to quantify fugitive emissions, planned and unplanned releases of CO<sub>2</sub>, and other surface releases from equipment. Second,

Core uses orifice type flow meters installed at its Wet and Dry Vent locations to measure the mass of recycle gas that is vented. And finally, Core Energy's risk-based monitoring program uses surveillance techniques in the subsurface and above ground to detect CO<sub>2</sub> leaks from potential subsurface leakage pathways. The CO<sub>2</sub> mass data, including CO<sub>2</sub> mass at different points in the injection and production process, equipment leaks, and surface leaks, will be used in the mass balance equations included in 40 CFR §98.440-449 (Subpart RR) to calculate the mass of CO<sub>2</sub> stored on an annual and cumulative basis.

**This MRV plan contains 12 sections:**

- Section 1 contains general facility information.
- Section 2 presents the project description. This section describes the geologic setting, reservoir modeling of the reefs, the operational history in the area, and the Core Energy facility operations.
- Section 3 describes the monitoring area for the Core Energy facility.
- Section 4 presents the evaluation of potential pathways for CO<sub>2</sub> leakage to the surface and demonstrates that the potential for leakage through pathways other than the man-made well bores and surface equipment is minimal.
- Section 5 describes Core Energy's risk-based monitoring process.
- Section 6 describes the baselines against which monitoring results will be compared to assess whether changes indicate potential leaks.
- Section 7 describes Core Energy's approach to determining the mass of CO<sub>2</sub> stored using the mass balance equations in 40 CFR §98.440-449, Subpart RR of the Environmental Protection Agency's (EPA) Greenhouse Gas Reporting Program (GHGRP).
- Section 8 presents the schedule for implementing the MRV plan.
- Section 9 describes the quality assurance program to ensure data integrity.
- Section 10 describes Core Energy's record retention program.
- Section 11 contains References.
- Section 12 contains Appendices.

**Technical Notes:**

1. Unless otherwise stated, this document uses the term "tonnes" to indicate metric tons (MT).

2. All calculations and reporting will be done on a metric ton basis (1000 kgs to 1 MT). Anytime CO<sub>2</sub> numbers are reported on a volume basis, Core Energy will utilize a conversion factor of 0.019 million cubic feet (MMCF), or 19,000 cubic feet, of CO<sub>2</sub> per metric ton of CO<sub>2</sub>. This translates to approximate conversion between weight basis to volume basis of CO<sub>2</sub> at 60° F, 1 atm (~1.87 kg/m<sup>3</sup> density).

**1. Facility Information**

- i) Reporter number – 545462
- ii) US Environmental Protection Agency (USEPA) (Region V) administers the Underground Injection Control (UIC) program for all classes of injection wells in Michigan. The Michigan Department of Environmental Quality (MDEQ) Oil, Gas and Minerals Division (OGMD) administers the statutes and rules subject to Part 615, Supervisor of Wells, of the Natural Resources and Environmental Protection Act, 1994, PA 451, as amended (NREPA). The injection wells operated by Core Energy are permitted as UIC Class II wells by US EPA and all wells (including production, injection and monitoring wells) are regulated by OGMD.
- iii) As of April 2018, there are 36 active wells penetrating the Niagaran reefs operated by Core Energy and there are additional wells that have been plugged and abandoned. A summary of these wells is included in Appendix I. Table A-1 indicates the active wells and includes the unit (reef), processing facility, API and MDEQ permit numbers, well name, depth and status. Table A-2 lists all wells that penetrate the reefs and includes reef, permit number, well name, well number, completion depth and date, type, and a wireline log inventory. Changes to the well inventory will be included in annual reporting.

**2. Project Description**

Core Energy operates in the upper north portion of Michigan in what is known as the NNPRT. (Figure 1).

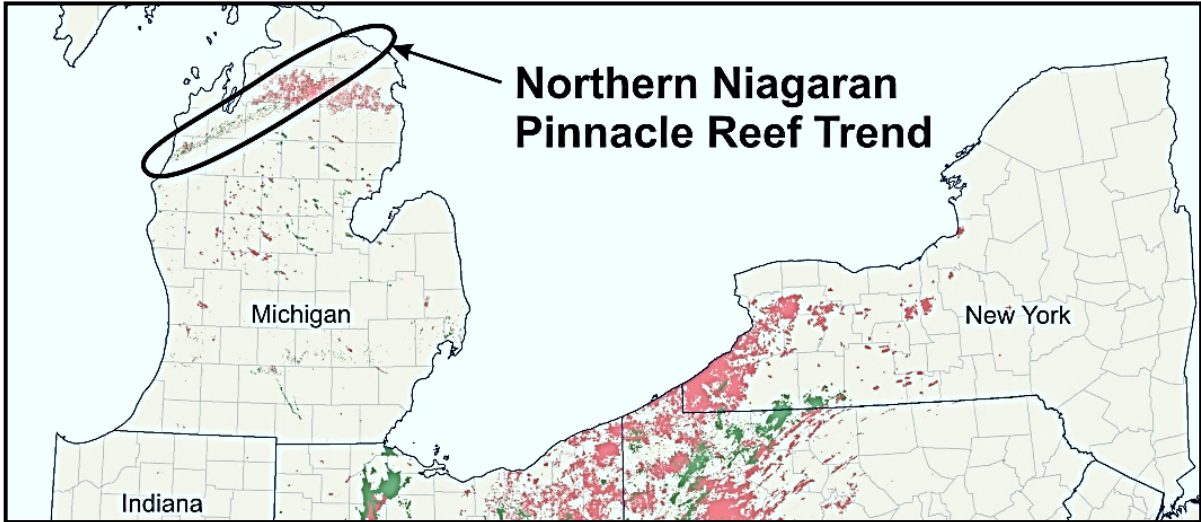


Figure 1 - General location of Core Energy operations



The NNPRT consists of closely spaced but highly-compartmentalized pinnacle reefs located, on average, about 6,000 feet below the ground surface (bgs) but can range from 3,000 to 8,000 feet (Most of the oil- and gas-producing reefs along the NNPRT are at depths of approximately 3500 to 5500 feet). This formation began as a series of coral reefs that formed millions of years ago in a setting similar to what we now observe in the Bahamas or Great Barrier Reef.

Since the reefs formed, sediments and other debris were deposited in layers around and above the reefs, forming hard structures that are excellent for containing the oil and gas that collected in them when the ocean receded and the corals died. It is estimated that in northern Michigan alone, such reefs could sequester several hundred million tonnes of CO<sub>2</sub>.

Data was compiled for all reefs including data from ten cores and covering five Core Energy reefs: Bagley, Chester 16, Dover 33, Chester 2 and Chester 5. Core analyses included descriptions, photographs, porosity and permeability measurements, and advanced analyses in select cores. More than 40 additional Niagaran cores were collected in Otsego County with data available at the Michigan Geologic Repository for Research and Education (MGRRE).

Core Energy also collected 3D seismic data for nine reefs: Chester 16, Dover 33, Dover 35, Dover 36, Chester 2, Chester 5, Charlton 19, Charlton 30/31, and Charlton 6 (Figure 2). The data was used to identify the boundary of the reef edges and verify that there are no structural concerns in the area. Where 3D seismic data is not available, formation tops, thicknesses, and production are used along with nearby reefs to define the boundaries.

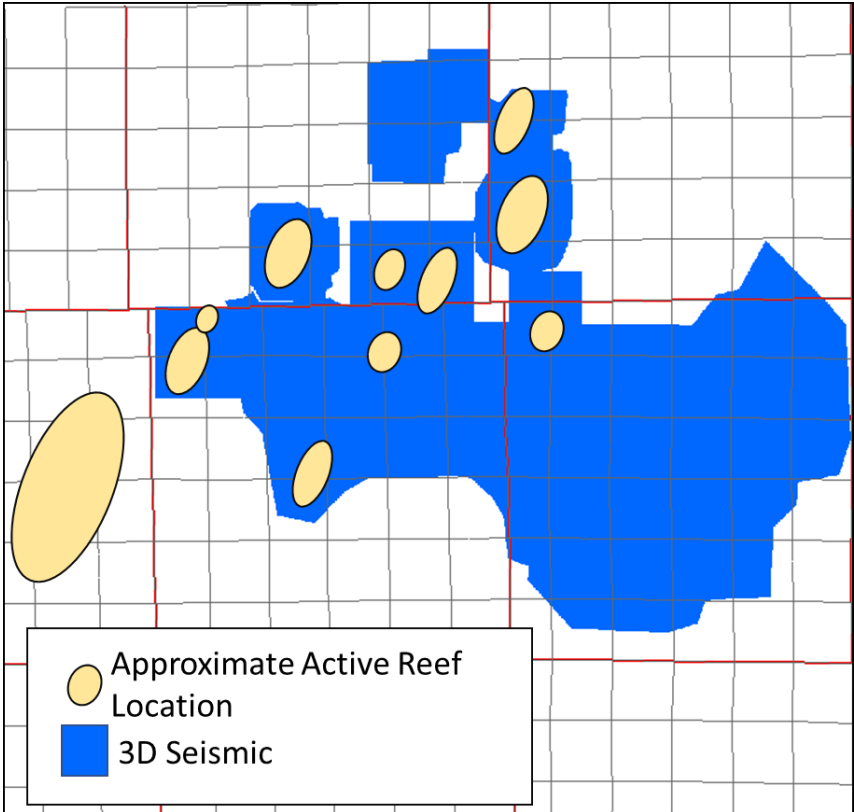
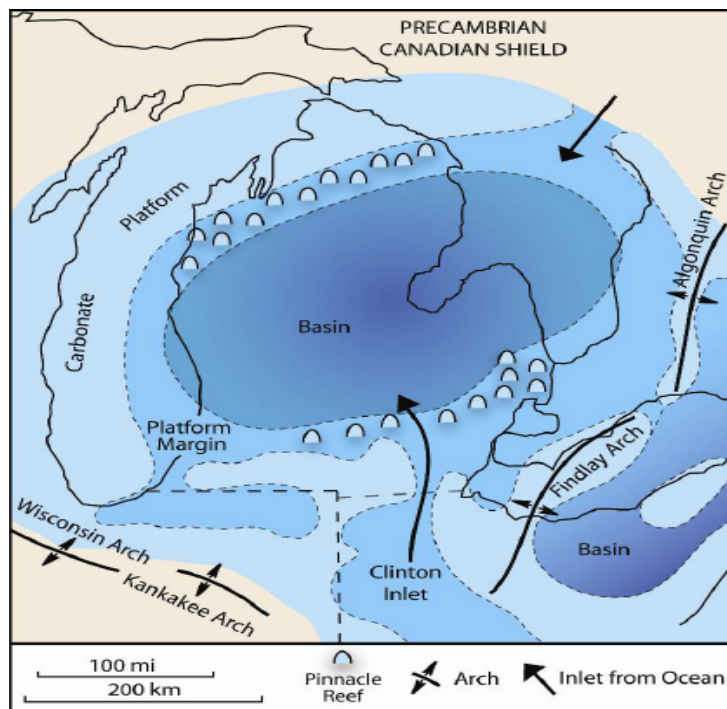


Figure 2: Map of approximate active reef locations (yellow) and 3D seismic (blue).

## 2.1 Geologic Setting

The NNPR is part of an extensive paleo shallow shelf carbonate depositional system. The trend of pinnacle reefs forms a circular belt along the platform margin that rings the Michigan Basin (Figure 3). Most of the oil- and gas-producing reefs along the NNPR are at depths of approximately 3500 to 5500 feet. While individual reef complexes are localized (averaging 50 to 400 acres in area), they may be up to 2000 acres in areal extent and 150 to 700 feet in vertical relief with the steeply dipping flanks. Reef height, pay thickness, burial depth, and reservoir pressure increase towards the basin center (Gill 1979). Currently, there are approximately 800 fields in the NNPR and approximately 400 in the Southern Niagaran Pinnacle Reef Trend (SNPR) of the Michigan Basin.

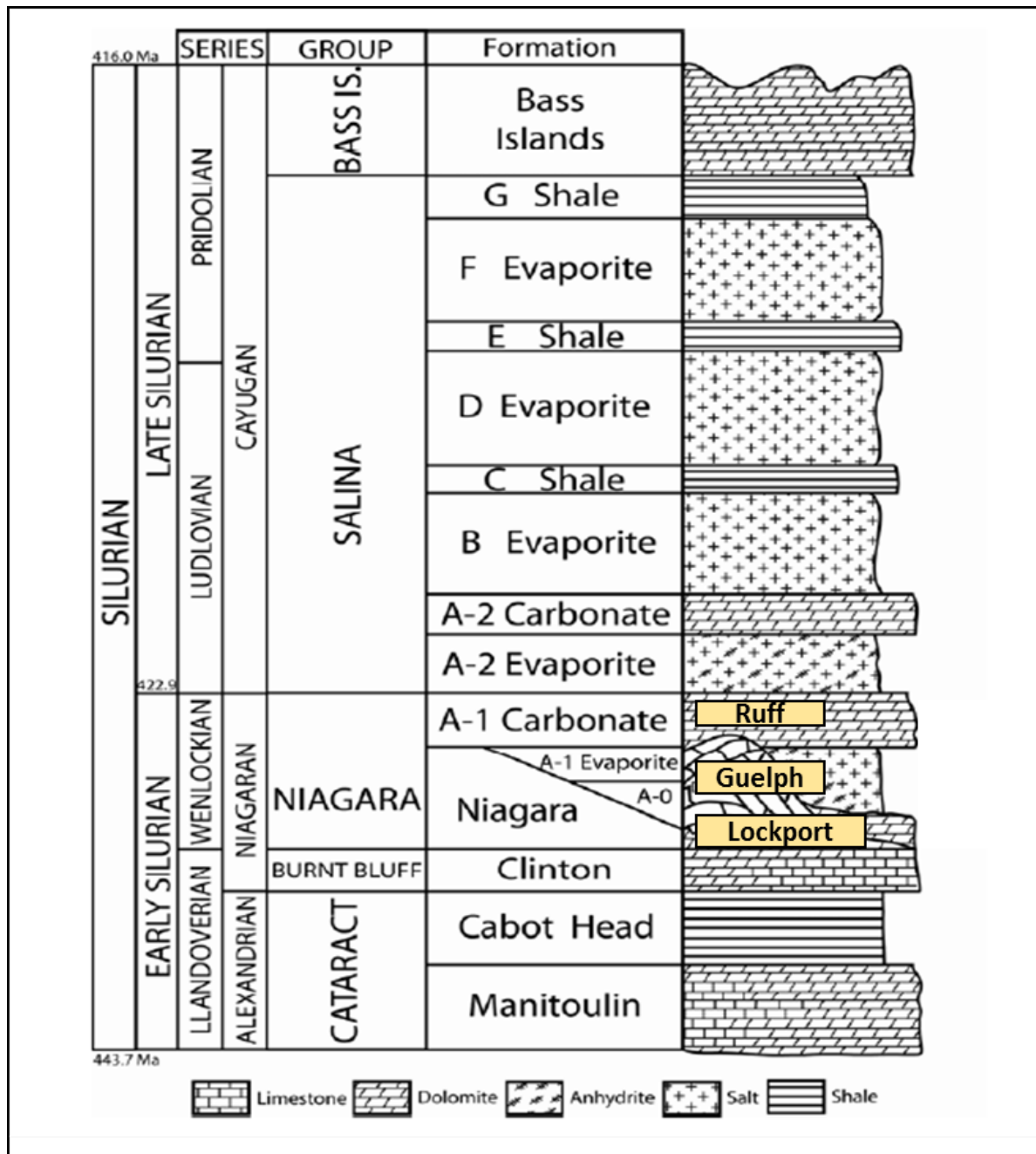
The NNPR is generally divided in an updip direction into gas, oil, and water-saturated zones (Gill 1979). The reservoir facies primarily consist of porous and permeable dolomite and limestone. Some reefs are completely dolomitized, while others are essentially all limestone. Dolomitization of reefs increases as the reefs become shallower, and salt and anhydrite plugging of porosity occurs in the deeper reefs (Gill 1979). Effective porosity intervals for the reservoir range from only a few feet to several hundred feet from reef to reef. Porosity values extend to 35%, but typically average 3-12%; the best porosity and permeability are associated with dolomitized reef core and flank facies. The best reservoir rocks are characterized by well-developed inter-crystalline and vuggy porosity with average permeability values of 3 to 10 millidarcies. Secondary porosity can significantly enhance permeability within the reservoir.



Ritter (2008), modified from Briggs and Briggs (1974)

Figure 3: Carbonate platform and Basin setting during NNPR development in Michigan.

The reef facies developed within the Niagara Group and includes the Lockport and Guelph lithostratigraphic formations (Figure 4). The Lockport Formation is characterized by two types of crinoidal wackestones: dolomitized and low-porosity, undolomitized (Charbonneau 1990). The Lockport reaches a thickness of approximately 500 feet near the basin margins, but thins and has a more reddish color toward the center of the Basin (Huh 1973; Huh et al. 1977; Charbonneau 1990). The Lockport is frequently referred to as the “White Niagaran” but grades upward into a gray argillaceous, nodular crinoidal wackestone. The Guelph Formation contains the informal “Gray Niagaran” and the “Brown Niagaran”. The Guelph “Brown Niagaran” consists of skeletal wackestones, packstones, grainstones, and boundstones/bindstones associated with the carbonate pinnacle reef buildups. It includes thin off-reef carbonate detrital/conglomerate lithofacies below the A-0 carbonate (Huh 1973). The Guelph Formation forms the core of the reservoir rocks associated with producing reefs.



Ritter (2008), modified from Cercone (1984).

Figure 4. Generalized Stratigraphic Column for the Silurian Section noting Niagaran reefs.

The seals for the Niagaran reefs consist of a series of evaporites and salt-plugged carbonates that encase the flanks of the reefs and form regional seals over the entire reef complex (see Figure 4). The A-1 and A-2 evaporites regionally transition from salt off the reefs to anhydrites over the tops of the reef. The A-1 evaporite generally thins or is not present over the tops of the reef but forms restricted seals along the flanks of the reefs. MRCSP studied five representative reefs in detail: Chester 16, Dover 33, Charlton 19, Bagley 11-14-23, and Chester 2. This study included acquiring a full suite of density and acoustic logs in order to characterize the rapid changes in the composition of the evaporites surrounding the reef flanks. These data enabled

the MRCSP to understand and map reservoir porosity, seal integrity, and seismic response and are discussed below.

The A-1 carbonate belongs to the Ruff Formation and overlies the A-1 evaporite. It is a light-brown to tan, fine to medium crystalline, laminated, dolomitic mudstone and stromatolitic or microbial laminated boundstones, which may show truncation surfaces and rip-up clasts (Huh 1973; Gill 1973; Ritter 2008). Laminated, dolomitic mudstones occur in inter-reef deposits and on the reef; dolomitic microbial boundstone facies unconformably overlie the Brown Niagaran skeletal deposits (Gill 1973). The A-1 carbonate generally seals the flanks of the reefs, but some reservoir zones within the carbonate can be developed on the crests of the reefs.

Figure 5 illustrates the internal structure and geometry of reefs as well as their development cycle. This knowledge is important for predicting areas of best reservoir within the reef. The building of a Niagaran reef was initiated by carbonate mud-rich bioherm accumulation in warm, calm, shallow waters. The bioherm grew as sea level rose, following the prime conditions where biohermal organisms thrive (Stage 1). As sea level continued to rise, the reef core developed, dominated by corals and stromatoporoids. The wind direction during time of reef building was important because it created asymmetry within the reef (Rine 2015). The windward direction developed reef rubble where pieces of the reef core broke off and reduced in size by wave water impact. The leeward side developed a muddy detrital grain apron as fine-grained material sloughed off the reef. (Stage 2). When relative sea level stabilized, stromatolitic algal caps formed over top of the reef and created an intertidal, depositional environment. Next, as sea level fell within the Michigan Basin, the reef complex was exposed (Stage 3), and the living reef was killed. Evaporites such as salt and anhydrites were deposited along the flanks of the reefs and diagenesis occurred within the reef core. As post-Niagaran sea level rose and fell, layers of carbonates and evaporites were deposited over the reef complex (Stage 4).

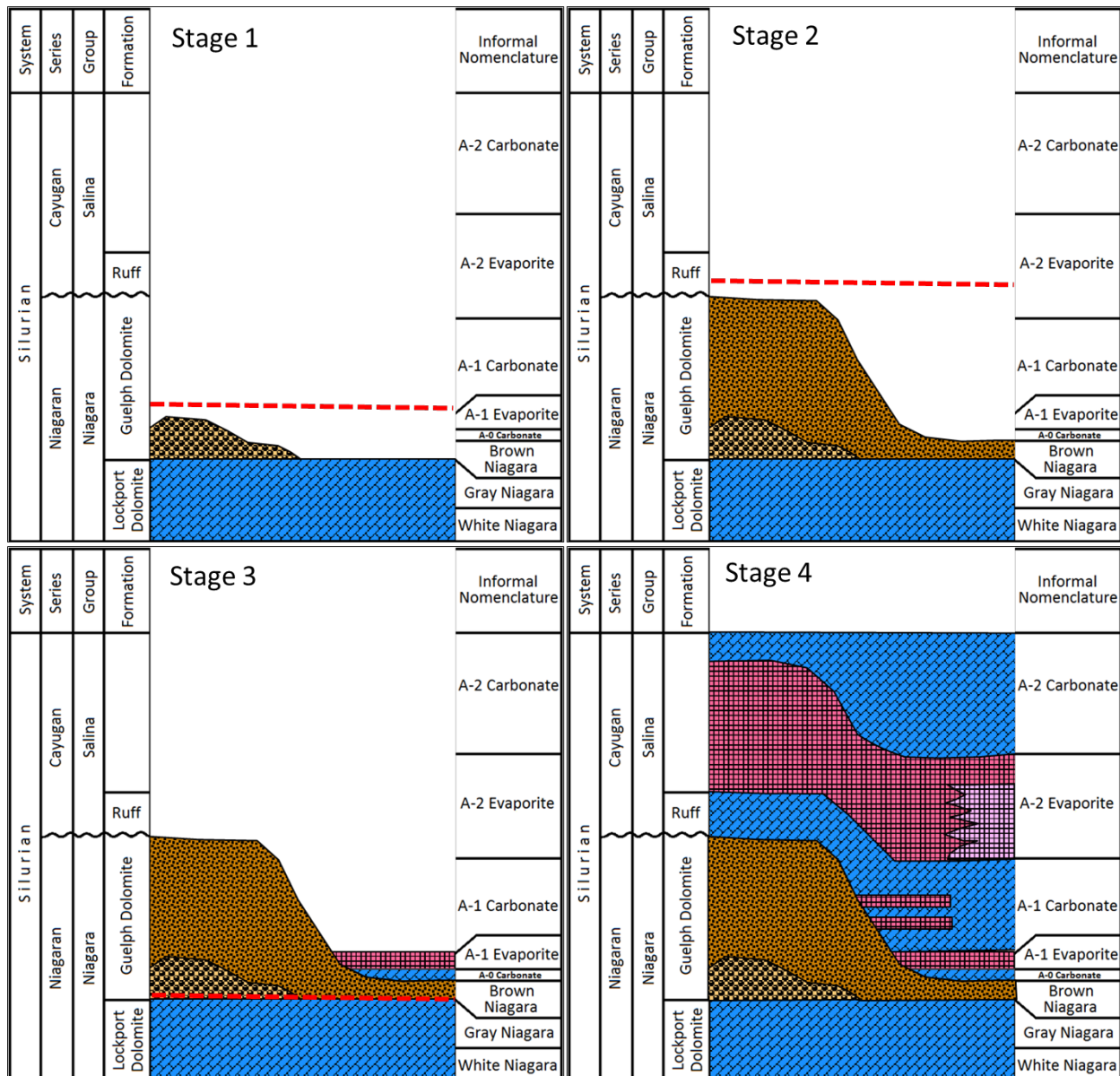


Figure 5: Simplified diagrams of the stages of Niagaran reef development. Red dashed line denotes approximate sea level relative to reef growth.

## 2.2 Reef Reservoir Characterization and Modeling

This subsection of the MRV plan describes the modeling that was developed to characterize the NNPR reefs operated by Core Energy, Core Energy’s understanding of the behavior of EOR operations in the reefs as indicated by the models, and the procedures going forward to use and or expand the modeling to determine which new reefs to include in operations as well as the operations plans for those reefs.

Core Energy worked with MRCSP to model six representative reef reservoirs. The key objectives of this modeling were to develop a detailed understanding of each modeled reef as well as the predictability of internal reef architecture. The modeling was successful in achieving both aims. Going forward, Core Energy does not plan to develop detailed models for each new



reef but will draw on a set of transferable principles from existing modeling that can be applied in operations and improving CO<sub>2</sub> flood performance.

2.2.1 Model Development

MRCSP used Static Earth Models (SEMs) to integrate all available geologic and geophysical information into a single framework used to conceptualize CO<sub>2</sub> migration and retention in the subsurface (Figure 6). The SEMs also provide the basis for incorporating geologic information into dynamic models for the reservoirs. The building of SEMs was an iterative process with multiple stages of quality checks to develop an SEM most representative of geology and reservoir properties. To build SEMs and dynamic models, the following information was integrated by geologists and engineers:

- Reef geometry (seismic and/or production), well locations and construction, formation depth and thickness, and delineation of lithofacies
- Rock properties including porosity, permeability, and fluid saturations from core and wireline log data
- Fluid flow such as density and viscosity of fluids, relative permeability, capillary pressure, and fluid phase

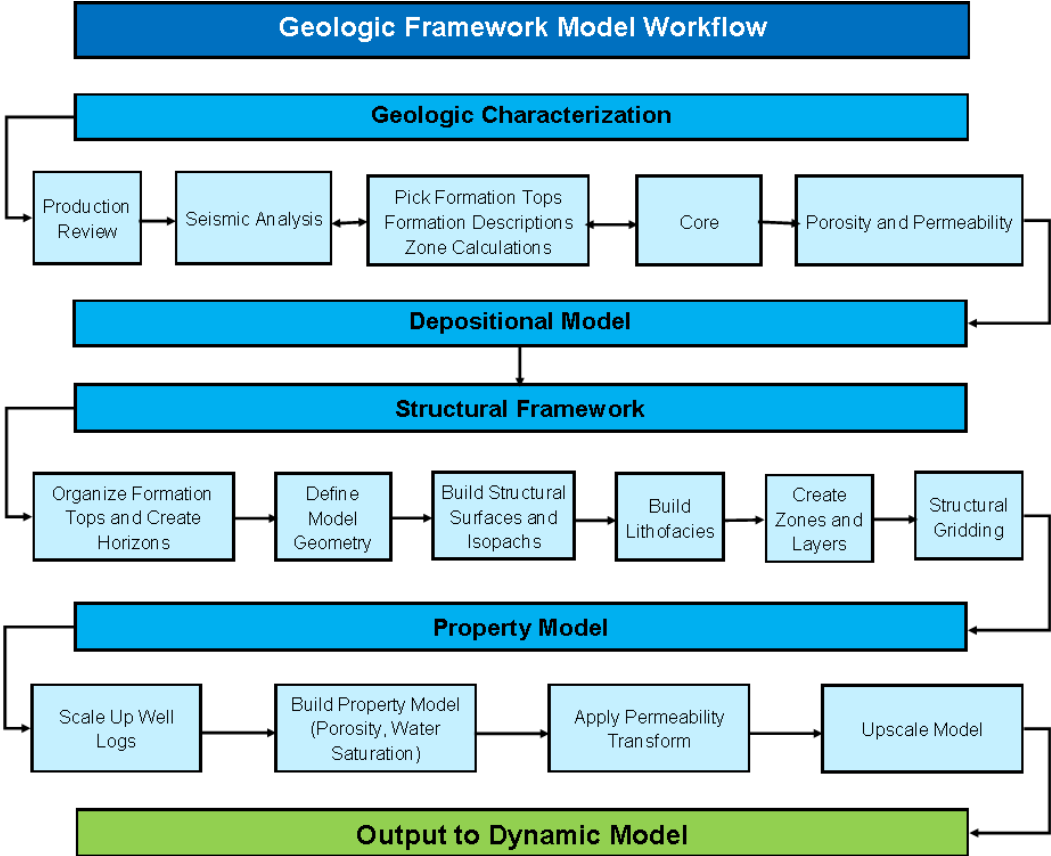


Figure 6: Typical geologic characterization and modeling workflow for reefs.

The modeling workflow began with geologic characterization of a reef which incorporated and integrated all information and data to develop a conceptual/depositional model. Figure 7 illustrates a 2D cross section through one such reef (Chester 16) with formations and reservoir flags. SEMs were then constructed using a conceptual geologic model, which allows for predictability of both vertical and horizontal lithofacies distributions by use of whole core and wireline log data. Figure 8 is an example 2D slice through a 3D SEM of Chester 16 (A) and Dover 33 (B) showing porosity distributions. Once SEMs were complete, they were outputted for dynamic modeling.

Dynamic modeling was used to history match with production records, simulate fluid flow and pressure changes, and assist with well design and CO<sub>2</sub>-EOR flood configuration design.

Basic geologic characterization is used to define the reef, describe formations, and identify reservoir and caprocks. Advanced geologic characterization and modeling are typically used to aid in planning or when a reef does not perform as expected. While Core Energy does not do the same level of characterization and modeling for each reef, lessons learned from advanced modeling show the predictability of internal reef architecture. Core Energy combines the knowledge gained from modeling regarding CO<sub>2</sub> flows within reef architecture along with the feedback from material balance and pressure monitoring and response to develop operational plans for CO<sub>2</sub> EOR.

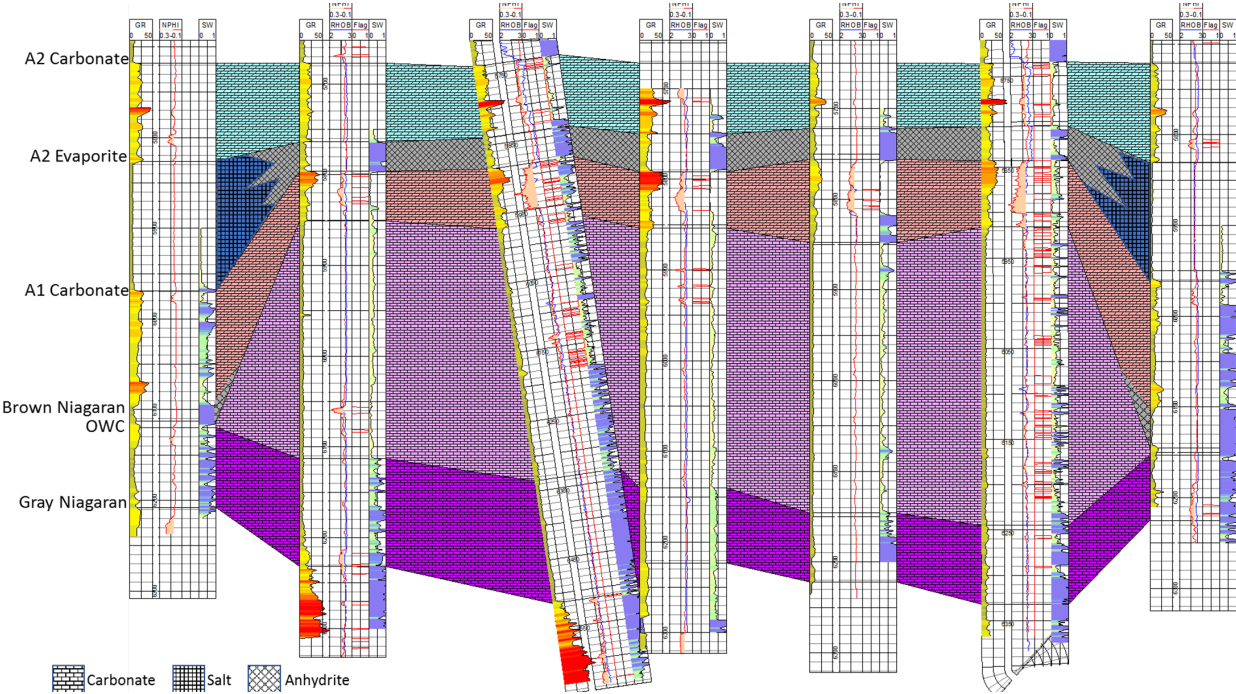


Figure 7: Example 2D conceptual model and geologic characterization of a reef.



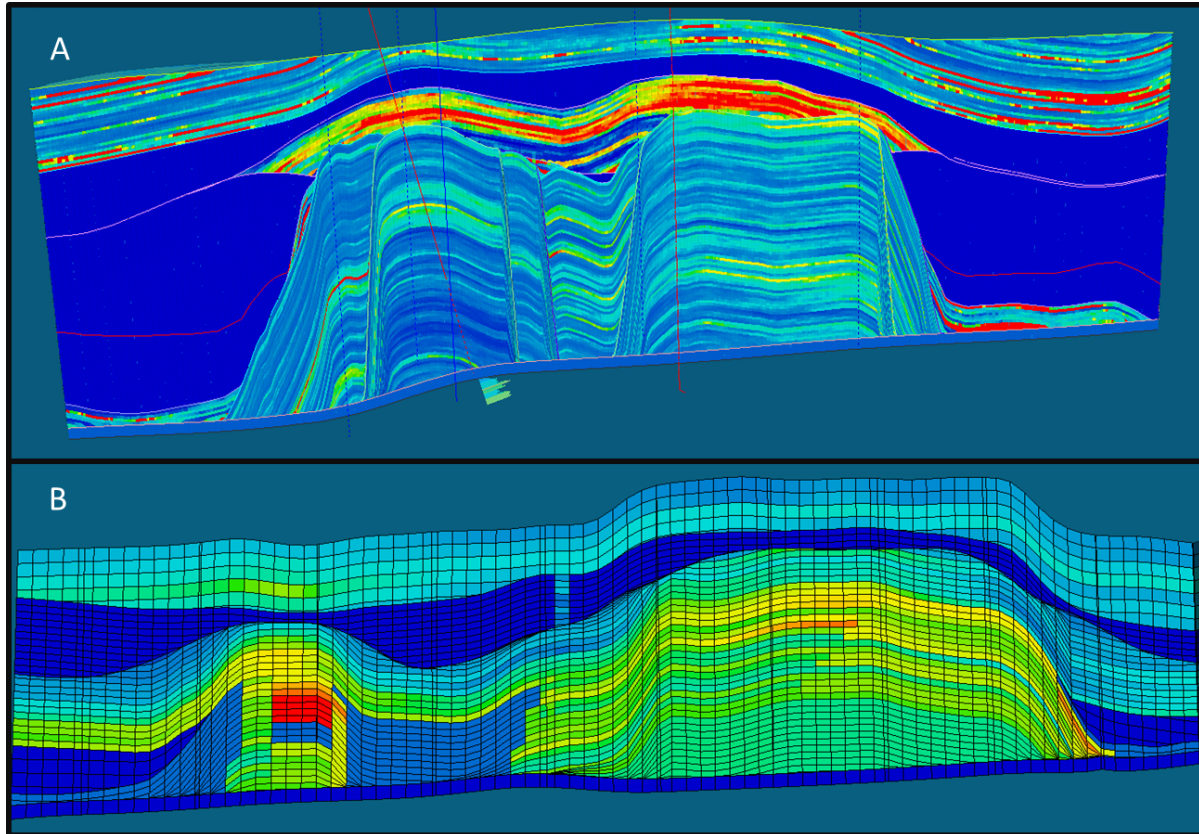


Figure 8. Example slice through a 3D SEM showing porosity distribution through Chester 16 (A) and Dover 33 (B)

Core Energy in collaboration with MRCSP has completed a significant amount of characterization and modeling on select reefs (Figure 9). To date, all 10 reefs have undergone basic geologic characterization to develop a 2D conceptual model of the reef. Five reefs have been developed into SEMs and taken into dynamic modeling. Even though the reefs have variable reservoir properties, there are predictable controls on reservoir performance such as amount of dolomitization, secondary porosity development, and salt plugging which can be identified through geologic characterization. For example, limestone reefs tend to have tighter porosity mid to lower reef with highest porosity and permeability in the upper reef and A1 Carbonate, as illustrated in Figure 8A with hotter colors for higher porosity. Dolomitized reefs tend to have more enhanced porosity throughout the reef due to secondary porosity development as illustrated in Figure 8B with hotter colors for higher porosity. The variability or heterogeneity in rock/facies type is related to a reef's location within the larger Michigan Basin geologic setting.

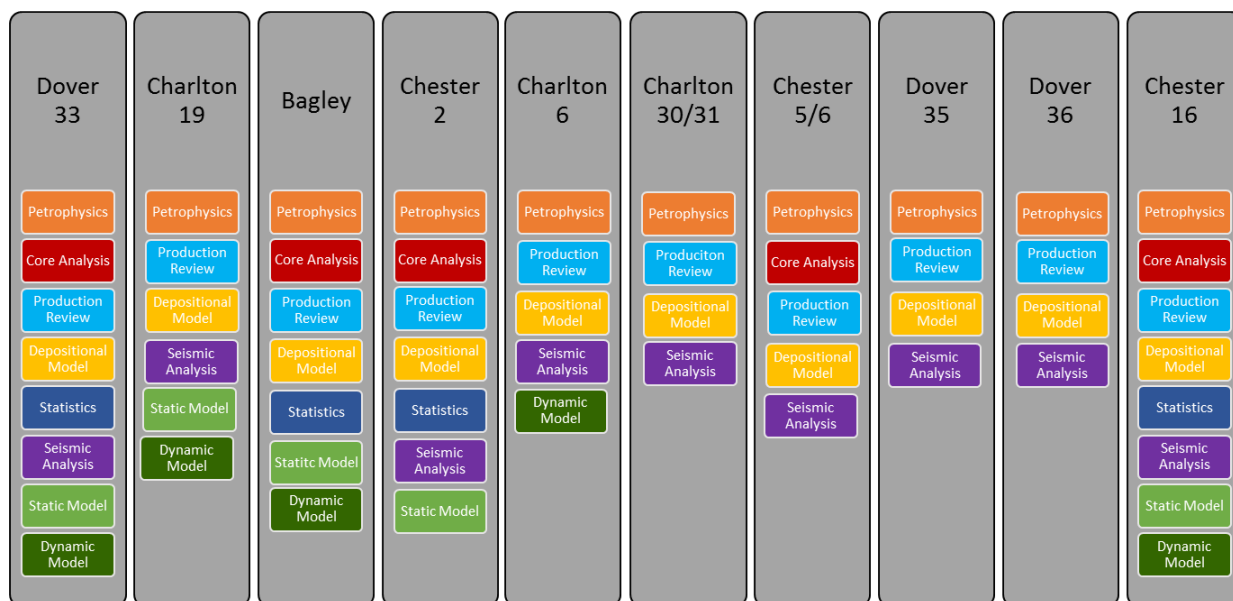


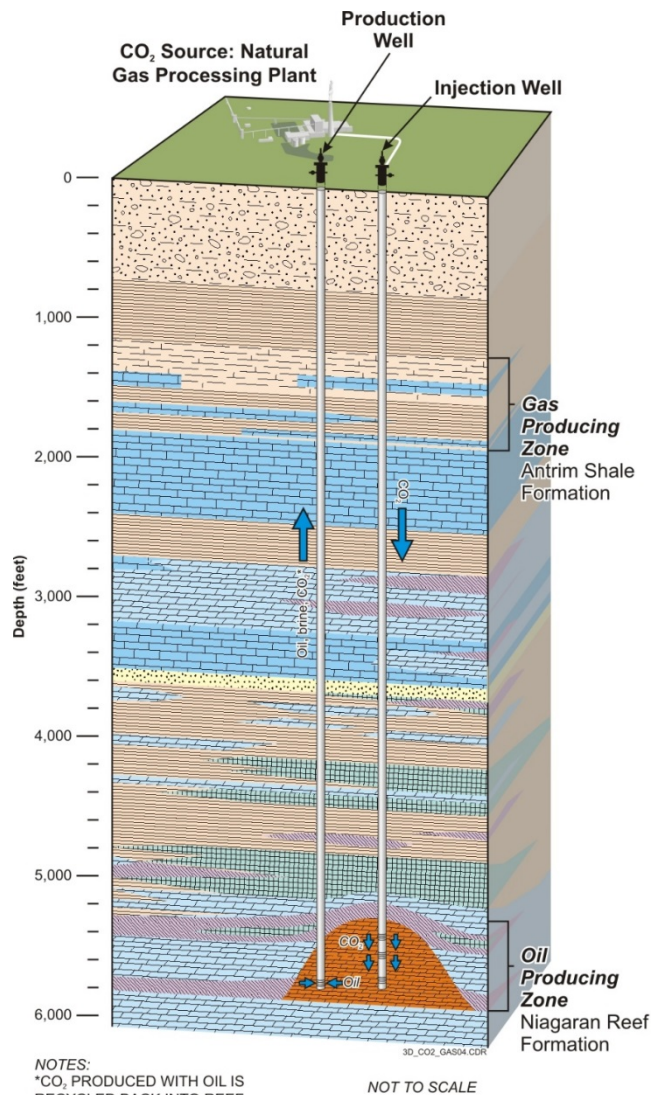
Figure 9: Analyses completed to date by reef.

## 2.2.2 Conceptual Understanding of CO<sub>2</sub> EOR in Reef Structures

The modeling and extensive history of oil and gas production in the NNPR have demonstrated the varying degree of compartmentalization of the reefs and the efficiency of the overlying evaporites and carbonates as seals. The reefs act as a closed reservoir system, which provides excellent conditions for CO<sub>2</sub>-EOR operations.

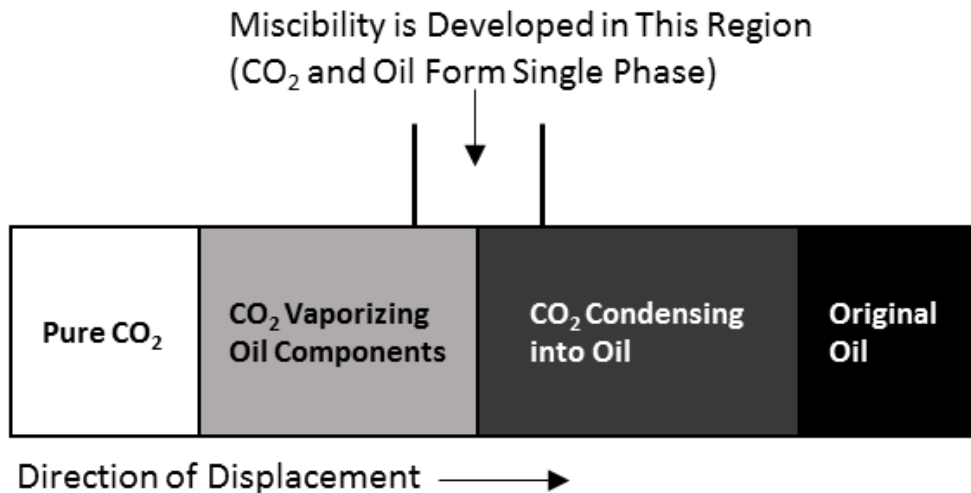
The discovery pressure in the oil-bearing NNPR reefs averages about 3,000 (psi). Primary production utilized this pressure to flow oil to the surface. Secondary production, using water flooding, was attempted but not widely used. Tertiary production, using CO<sub>2</sub> EOR, was initiated in the late 1990's and expanded by Core Energy as it started operations in 2003.

Core Energy typically initiates CO<sub>2</sub> EOR in reefs that have undergone primary and in some cases after secondary production. As CO<sub>2</sub> is injected into the reefs, it contacts the oil trapped in the pore space while it simultaneously increases the reservoir pressure. As contact and pressure increase, the CO<sub>2</sub> eventually becomes miscible with the oil which allows it to flow towards a designed production well. Figure 10 illustrates the CO<sub>2</sub> EOR process in a reef field for a CO<sub>2</sub> injection well and the associated production well. Note that the source of CO<sub>2</sub> is from the gas producing zone indicated at the top of the column.



NOTES:  
 \*CO<sub>2</sub> PRODUCED WITH OIL IS RECYCLED BACK INTO REEF.  
 ALL LOCATIONS ARE APPROXIMATE.  
 Figure 10: Simplified diagram illustrating CO<sub>2</sub>-EOR process in a reef.

Figure 11 shows a graphic representation of how CO<sub>2</sub> and oil become miscible. At either end of the image are pure CO<sub>2</sub> and original oil. As the two come into contact and pressure increases, CO<sub>2</sub> vaporizes oil and also condenses into it, forming a single-phase fluid mixture of CO<sub>2</sub> and oil. This mixture of CO<sub>2</sub> and oil, along with formation brine present in some cases, is then produced from the well.



From Zick, 1986

Figure 11: CO<sub>2</sub> Miscibility Diagram (SPE Monograph 22)

At the end of CO<sub>2</sub> EOR operations, when a project is no longer economically viable and in preparation for closure, Core Energy typically attempts to recover as much CO<sub>2</sub> as it can by producing fluids back through a CPF until such time the reservoir pressure has been reduced to a level whereby wells can no longer flow (approximately 500 psi or less). After the CO<sub>2</sub> recovery effort has been completed, the reservoir pressure has been depleted, and wells will no longer flow; it leaves the reef in a state whereby there is significant voided pore space.

The Core Energy facility has significant operational flexibility due to the modular nature of the reefs and the diversity of their development status. The Core Energy reefs are isolated from each other, and each goes through a phase development maturation process that ranges from new or “fill up”, to operational, onto depleted.

New reefs are in the fill up stage in which the initial volume of CO<sub>2</sub> is being injected to raise reservoir pressure above the minimum miscibility pressure (~1190 psi MMP) of CO<sub>2</sub> in oil. Above this MMP, the CO<sub>2</sub> and oil become a single phase fluid and begin to flow to producer wells depending on the pressure gradient between the injection well and the producer wells. After the reef has been pressurized above the MMP (the fill-up phase), these reefs transition into the operational phase, which can last for many years.

Once a reef is determined to be operational, pipelines will be extended from the producing wells to a central processing facility, if they are not already in place. Based on the oil type and the temperature of the reservoirs, Core Energy found that conducting miscible CO<sub>2</sub> flooding is optimized at roughly 1,300 PSI.

Core has also tested the capacity to increase pressure above the optimal range and finds that while it has the headroom (available pore space) and ability to increase pressure to well above 1,300 psi, it does not have equipment that could raise pressure to levels near or above the fracture pressure.

When the bulk of economically available oil has been produced via EOR, the reef is considered depleted or nearing depletion. In depleted reefs, the economic return on CO<sub>2</sub> EOR is not as high as in the operational reefs. However, these reefs still have some oil left in place and can also effectively act as short-term storage for CO<sub>2</sub> in the system. When CO<sub>2</sub> EOR operations in a reef end, Core Energy typically recovers as much CO<sub>2</sub> as it can by producing fluids back through a CPF until such a time as the reservoir pressure has been reduced to a level whereby the wells can no longer flow (approximately 500 psi). The amount of CO<sub>2</sub> which remains in the reef below this pressure cannot be recovered and is stored under current conditions.

This development cycle for each reef, combined with operating multiple reefs at once, provides Core Energy with unique operational flexibility. At any time, the number of reefs and the diversity of their status enables Core to accept as much CO<sub>2</sub> as it can capture and then use it over time. This is especially important due to the depleting nature of their anthropogenic source of CO<sub>2</sub> (i.e. gas processing plants servicing the Antrim Shale production).

**2.3 Operational History of the Core Energy Reefs**

The NNPRRT reefs, originally developed in the 1970-1980s, have undergone primary production and, in some cases, secondary recovery through water flood and other methods. Oil operations largely subsided in the early 1990s and then picked up sporadically towards the end of the decade. Core Energy entered the play in 2003, taking over two operating reefs and slowly expanding into eight additional reefs.

**2.3.1 Core Energy EOR Reef Complex Development**

Core Energy currently operates 10 active EOR reefs in Otsego County in northern Michigan. CO<sub>2</sub> EOR was initiated in each of these reefs at different times as indicated in Table 1. Figure 12 shows the location of each reef.

**Table 1: Active CO<sub>2</sub>-EOR reefs and date of initial flooding.**

Reef	Date CO <sub>2</sub> Flooding Initiated
Dover 33	1996
Dover 36	1997
Dover 35	2004
Charlton 30/31	2005
Charlton 6	2006
Chester 2	2009
Chester 5	2011
Charlton 19	2015
Bagley 11-14-23	2015
Chester 16	2017



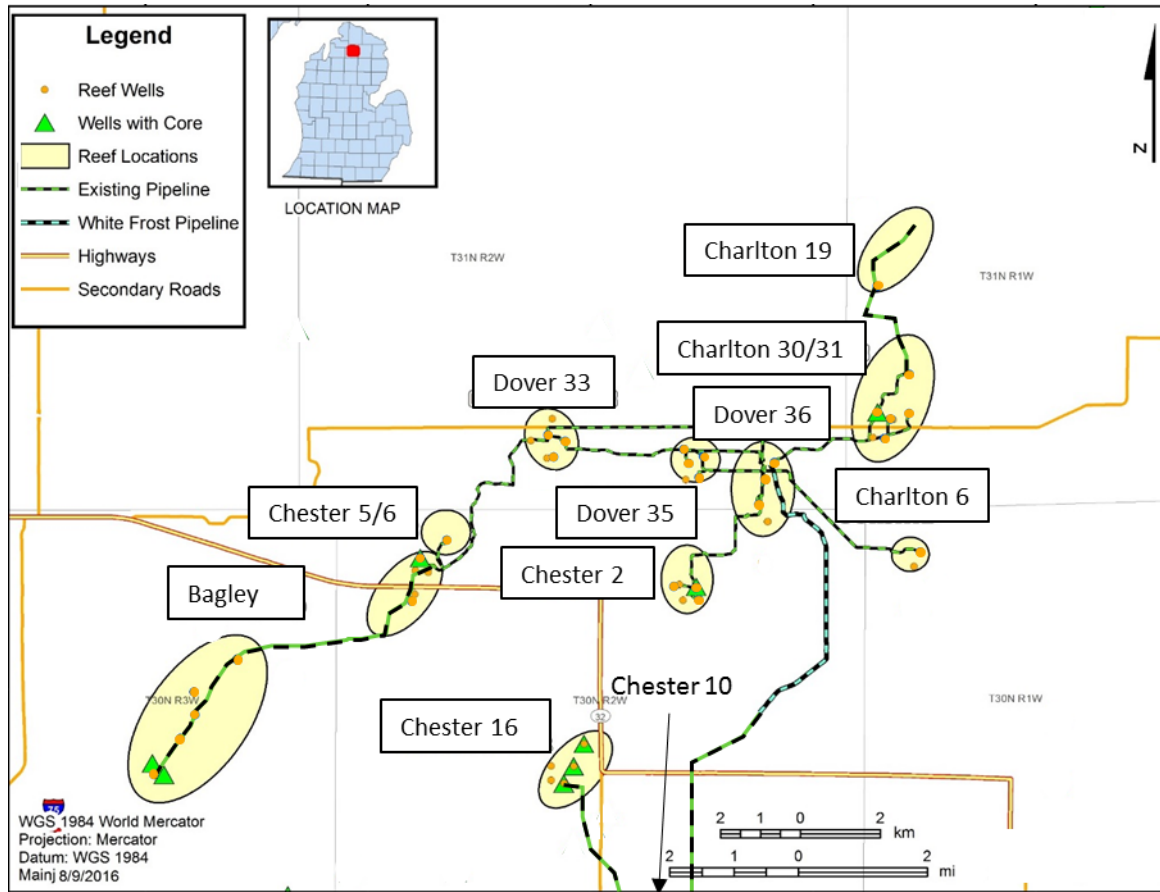


Figure 12: Location of active reefs operated by Core Energy.

### 2.3.2 CO<sub>2</sub> Production and Injection History

All of the active reefs have undergone primary production in the past. Core Energy maintains production records for all wells in the active reefs, including volumes of the following:

- oil produced,
- gas produced (commingled natural gas and CO<sub>2</sub>)
- water produced
- water injected (if applicable), and
- CO<sub>2</sub> injected.

Core Energy worked with Battelle to develop a baseline accounting as of December 31, 2017 of the CO<sub>2</sub> that has been injected since 1996. Since 1996, 2.11 million tonnes of CO<sub>2</sub> has been injected into the Core Energy reefs.

Core Energy is starting its mass balance accounting for CO<sub>2</sub> at zero. This means that the amount of CO<sub>2</sub> already in the system will ultimately be reflected in the mass balance calculation of the amount stored. Over time, the total amount stored will be roughly equal to the sum of CO<sub>2</sub>

from Chester 10 and the inventory of CO<sub>2</sub> produced through Dover 36 less any losses from equipment or subsurface leaks, which are expected to be minimal.

#### 2.4 Description of CORE Energy CO<sub>2</sub>-EOR and Ancillary Storage Project Facilities and the Injection Process

Core Energy operates an integrated facility that includes CO<sub>2</sub> capture, dedicated pipelines, injection and production wells, a central processing facility for fluids, and compressors. Figure 13 is a detailed flow chart with equipment names and meter numbers. The rest of this section will use Figure 13 to review the facilities and processes taking place at the Core Energy facility.

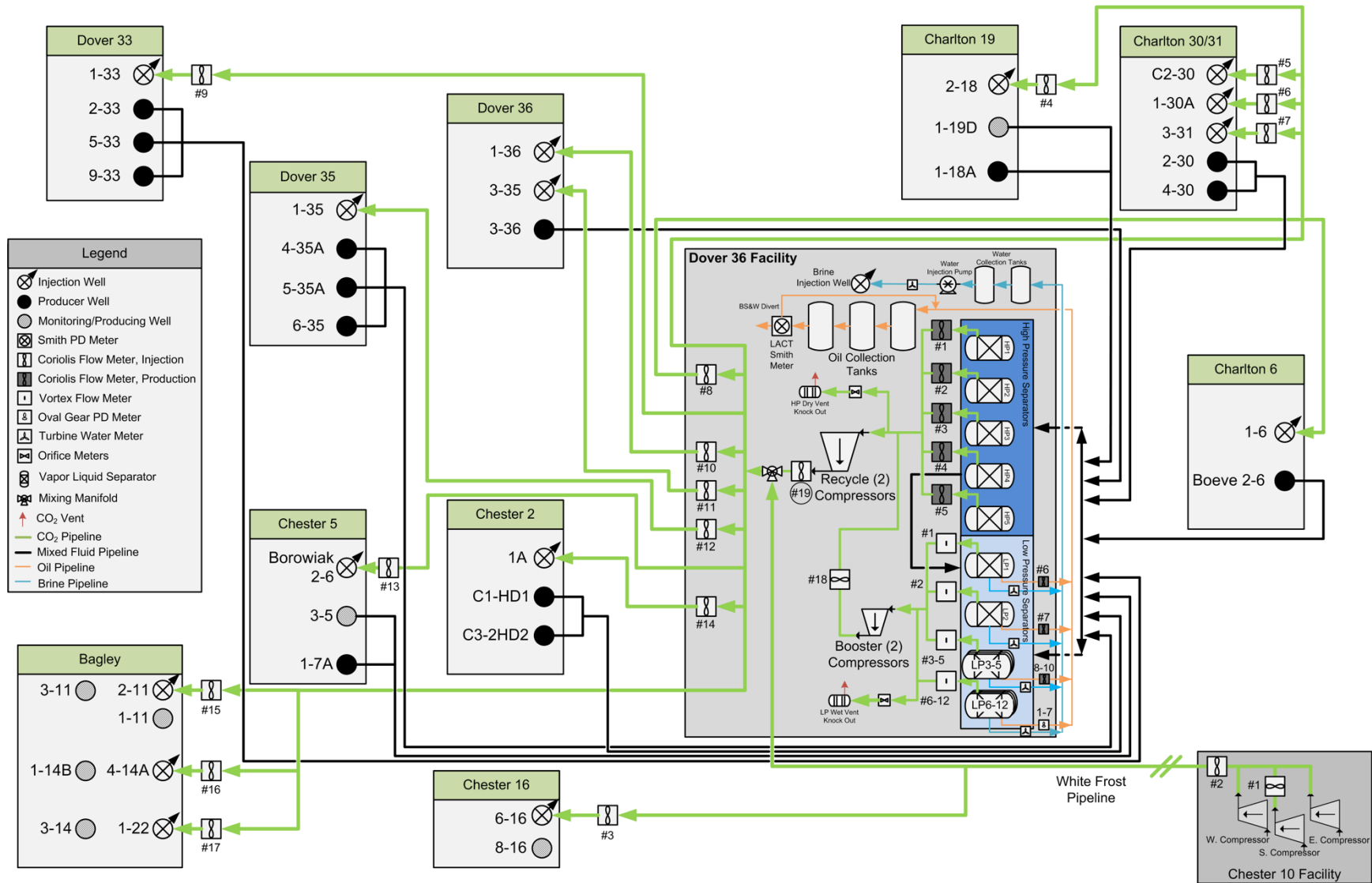


Figure 13 – Simplified Process Flow Diagram of Core Energy's EOR Facility



## 2.4.1 CO<sub>2</sub> Capture

Core Energy captures CO<sub>2</sub> at two locations:

- Chester 10 Facility (shown in bottom right corner of Figure 13): This facility captures CO<sub>2</sub> from a natural gas processing facility that treats gas produced from the Antrim Shale. Core Energy has the right to capture up to 100% of the CO<sub>2</sub> that would normally be vented from the natural gas plant. Core has made investments to expand capture operations over time and plans to make additional investments in the future. It currently captures between 300,000 to 350,000 tonnes of new CO<sub>2</sub> per year. Also, there is potential to capture an additional 100,000 tonnes per year, resulting in net potential 450,000 tonnes of new CO<sub>2</sub> per year. It is expected that the natural gas processing plant will continue operations for at least 10 to 20 years but continued operations depend on market conditions. Core currently has three compressor units at this facility, with the mass of all new CO<sub>2</sub> measured using Coriolis mass flow meter number 2 (Figure 13).
- Dover 36 Facility (large rectangular box in Figure 13): This facility is co-located along with the Dover 36 reef. This facility contains the main Recycle Compressor along with capture equipment which captures CO<sub>2</sub> from various high-pressure (HP) and low-pressure (LP) fluid separators that treat the fluids from the production wells. Core Energy currently captures ~300,000 tonnes of gas per year at the Dover 36 Facility. This gas consists of CO<sub>2</sub> (~95% by wt.) with small quantities of hydrocarbon gas which is recompressed and sent back to various EOR reefs. The mass of this gas is measured using Coriolis mass flow meter number 19.

## 2.4.2 CO<sub>2</sub> Distribution and Injection

Core Energy maintains about 80 miles of pipelines that are used to move CO<sub>2</sub>, produced fluids, and oil. A diagram of the pipeline network and locations of 10 EOR reefs is shown in Appendix II.

A portion of CO<sub>2</sub> from the Chester 10 Facility delivered via the White Frost Pipeline can be withdrawn directly for injection into Chester 16 reef (measured using Coriolis mass flow meter number 3); the remainder of the CO<sub>2</sub> from Chester 10 flows to the Dover 36 Facility, where it mixes with CO<sub>2</sub> from the Recycle Compressor at the Mixing Manifold. From the Mixing Manifold, Core can re-arrange various piping and valves to direct CO<sub>2</sub> to any one of the reefs.

Dedicated Coriolis mass flow meters are attached to each injection well at the EOR reefs. Some of the meters are located at the Dover 36 Facility while others are located directly at the wellhead. These meters are numbered 3 through 17 (Figure 13) for the 15 injection wells at 10 EOR reefs. It is important to note that Core can change the operational configuration of wells whereby an injector well may become a producer or monitoring well, or a producer well may be converted to an injector well. If in future, a producer well is reconfigured to be an injector well, Core will install a Coriolis or other suitable flow meter to measure the quantity of CO<sub>2</sub> being injected into that well and will indicate such changes in the annual reporting.

### 2.4.3 Produced Fluids Handling and Processing

Table A-1 in Appendix I lists the active wells, of which 20 are “producers”. These 20 wells are further indicated by status as a current producer (PR), a shut-in producer (SI-P) or an observation (OBS) well. Generally, at least one production well is located in each reef. For the new reefs, the production wells will be connected to pipelines for produced fluids once they start producing. For the other reefs, all produced fluids from the reefs flow directly to dedicated separators at central processing facilities.

Core Energy currently has a network of 5 HP separators and 12 LP separators at the Dover 36 Facility. Product streams from reefs that are producing oil under high pressure (> 340 psi) are first sent to an HP separator; product streams from reefs that are producing under low pressure (<340psi) are sent to one of the LP separators. The remaining liquid product stream (containing mostly oil and brine) from an HP separator is further sent to an LP separator for separation and stripping of any entrained gas. The produced gas that is separated in the HP separator is sent to the Recycle Compressor, while the gas separated from the LP separator is first sent to a Booster Compressor prior to being sent to the Recycle Compressor.

The produced gas which primarily consists of CO<sub>2</sub> (>95% by wt) is separated from the produced fluid and flows through a Coriolis mass flow meter at each of the HP separators before being sent to the Recycle Compressor (meters numbered 1 through 5). The bulk of the produced gas is captured in the HP separators (> 90% by wt). Meanwhile, the produced gas that is separated at the LP separator, flows through a Vortex type flow meter. The system of Coriolis mass flow meters (attached to the HP separators) and Vortex flow meters (attached to the LP separators) measures the mass of recycle gas produced from each operational reef. Additionally, one Coriolis mass flow meter (number 18) measures the mass of all recycle gas captured at the LP separators while another (number 19) measures the total quantity of produced gas that is produced by all operational EOR reefs.

Brine is separated by the LP separators. The collected brine is sent to a brine disposal well located onsite at the Dover 36 Facility.

Oil is gathered in collection tanks before flowing through a LACT meter for offsite sales. A small amount of CO<sub>2</sub> remains entrained in the oil after the CO<sub>2</sub> separation process, which bleeds off as the oil moves through the LP meters into a temporary storage/gathering tanks. Core hired an external engineering firm to conduct a survey in 2011 to determine the amount of CO<sub>2</sub> entrained in oil. This study indicates that the concentration of CO<sub>2</sub> entrained in oil is 0.7512% by weight. This translates into roughly 150 tons per year at current operations levels. Because the oil is blended in the gathering tank, Core Energy believes this factor applies uniformly to all oil.

While rare, operational outages periodically occur, which forces produced gas to be vented to the atmosphere. Core has orifice type flow meters installed at its Wet and Dry Vent locations to measure the mass of recycle gas that is vented. Looking back for the last 12 months (May 17 to April 18), a small volume of CO<sub>2</sub> was vented during eight (8) of those months (roughly 50 tons). The volume of CO<sub>2</sub> vented represents less 0.0174% of the produced volume.

#### 2.4.4 Data Collection

The system of flow metering at the Dover 36 Facility is centrally tied to a Core Energy HMI computer system. Coriolis mass flow meters that are located at the reef-site locations (at injection wellheads) typically have data-loggers which collect and store injection data. The HMI system records continuous production and injection data files on a per-minute basis for each day of operations. Operators typically record totalizer readings from injection and production parameters at 9 AM each day for the previous operational day. Additionally, there are daily site visits to the wellsites where operators record well data (e.g., tubing pressure, casing pressures, and wellhead temperatures). Together, these data streams provide accurate accounting of all CO<sub>2</sub> being acquired (from the Chester 10 Facility), injected into EOR reefs, and recycled at the Dover 36 Facility.

The method used when estimating the volume of CO<sub>2</sub> “lost” due to an interruption in data collection or mechanical failure of a meter (equipment) is to use the most recent daily volume of CO<sub>2</sub> associated with the meter and calculate the proportionate volume of “lost” CO<sub>2</sub> based on the number of hours involved in the data gap or until the meter was repaired. Core Energy has well and facility data in three forms: 1) Paper copies (scanned to server), 2) Keyed in data from paper copies into database, and 3) Automated capture of limited set of data that was recently instrumented (Fall of 2016).

Subsequent sections of this Plan, Section 5.5 and Section 6, provide a more detailed explanation for how this data and other means will be used as baseline data for comparison to detect possible surface leakage.

#### 2.4.5 Existing Wells

Core Energy operates 16 injection wells (1 of which is a shut-in injector) and 20 production/observation wells. These wells are listed in Appendix I.

Well status is discussed in Section 4.1.

Wells are configured as each EOR project is developed (see Table 1). Mechanical integrity for injection wells is monitored through daily readings of casing pressure, quarterly fill-up tests and mandatory mechanical integrity tests (MIT) every five years. All injection wells utilize a corrosion inhibited packer fluid in the annular space between the tubing string and casing, above the required isolation packer. Corrosion coupons are placed at various nodes in the system as a way to monitor metal loss.

Maps showing the locations of the wells in each reef are provided in Figure 12. In general, the basic open-hole geophysical logs (e.g. gamma ray, density, resistivity, neutron porosity, photoelectric) are available for most of the wells in the active reefs. A sonic log is available for approximately half of the wells. Cement-bond logs are sparingly available.

## 2.5 Core Energy Procedures for CO<sub>2</sub>- EOR Facility Modification

Core Energy plans to continue routine business operations, which may include securing additional CO<sub>2</sub>; modifying, adding, or closing wells; adding or closing reefs, and adding new facility equipment and pipelines. These modifications represent a continuation of the basic integrated current configuration and MRV approach and not a material change that triggers a revised plan (see 40CFR Part 98.448(d)). Therefore, Core Energy intends to indicate such changes in the annual monitoring report rather than submitting new MRV plans. The monitoring report would demonstrate how the change is a continuation of the existing EOR Facility and would also include any new site characterization, risk assessment, monitoring, and mass balance information as is already included for the existing EOR Facility. The existing provisions for the MRV would continue to apply. Each of these potential changes is discussed in more detail below.

### 2.5.1 New Sources of CO<sub>2</sub>

Core Energy is considering the addition of new equipment to capture additional CO<sub>2</sub> from the adjacent natural gas processing plant through its Chester 10 Compression Facility. It is also exploring the potential to obtain additional CO<sub>2</sub> through nearby sources that are in development.

In the event new sources of CO<sub>2</sub> are added, the amount of CO<sub>2</sub> would be measured using flow meters and added to the reported amount of CO<sub>2</sub> received onsite as indicated in Section 7. Injected CO<sub>2</sub> from these sources would be measured using flow meters and added to the reported amount of CO<sub>2</sub> injected as indicated in Section 7.

### 2.5.2 Adding New Wells

In order to add any new injection wells, Core Energy would have to work with the US EPA (or if Michigan gains primacy for Class II, MDEQ/OGMD) to obtain the permits and from MDEQ/OGMD to obtain permits for any new production wells. Such wells would be sited, completed, and operated in the same manner as the existing wells, under the oversight of the US EPA and/or MDEQ. The existing modeling and learned transferable principles would be combined with reef characteristics to determine location and operational plans for such wells. Well numbers and information would be included in the annual statement.

### 2.5.3 Abandoning Existing Wells

Core Energy follows the UIC Class II requirements and/or the MDEQ/OGMD requirements for closing wells. Any wells closed within a reporting year would be noted in the annual statement.

### 2.5.4 Changing the status of Existing Wells

Core Energy may change the status of an existing well from producer to injector or vice versa. In such situations, Core Energy will work with US-EPA and/or MDEQ/OGMD to obtain the necessary permits and will indicate the status change in the annual statement.

### 2.5.5 Acquiring New Reefs

Core Energy is looking to expand into new reefs based on their potential development value, which is a reflection of past operational history and current ownership structures as well as other factors. Based on the modeling and history of reef development in the area, Core Energy does not anticipate that past operations will preclude any reef from being selected as an expansion candidate. As part of the permitting process, Core Energy will conduct a site characterization, determine the boundaries of the reef, and assess the Area of Review (AoR) of at least ¼ mile around the reef to determine if there are any old wellbores that need to be remediated or closed and whether there are any other impediments to the successful implementation of CO<sub>2</sub> EOR on that reef. All potential new reefs are located in the MMA as indicated in Section 3.2 and would be moved into the AMA as indicated in Section 3.1 if they are developed by Core Energy.

### 2.5.6 Abandoning Existing Reefs

Core Energy will follow the requirements for closing wells and will follow any contractual or permit requirements for abandoning a reef. Core Energy will prepare a closure report for any abandoned reefs that assesses the amount of CO<sub>2</sub> that will be incidentally stored in that reef after closure and serving as the foundation for removing that reef and the related CO<sub>2</sub> from the active MRV reporting program.

### 2.5.7 Adding New Facility Equipment

Core Energy may add new equipment that could have an impact on the mass balance. This might include additional compressors, processing equipment, and/or other equipment. These changes would be noted in the annual statement and CO<sub>2</sub> losses from this equipment would be calculated as in Section 7 and the results included in the mass balance.

### 2.5.8 Acquiring New Pipeline Routes

Core Energy may build additional pipelines to connect new wells to the Core Energy Facility or to connect fill up reefs to production facilities. These changes would be noted in the annual statement and CO<sub>2</sub> losses from this pipeline would be calculated as in Section 7 and the results included in the mass balance.

## 3. Delineation of the Monitoring Area

### 3.1 Active Monitoring Area

Due to the highly compartmentalized nature of the Niagaran reefs, the Active Monitoring Area (AMA) is defined by the boundary of the Unit Area of each individual reef/field as established in the Order by the Supervisor of Wells for the MDEQ authorizing each EOR project. The following factors are considered in defining the boundaries:

- CO<sub>2</sub> injected into a reef remains contained in the reef because of the efficient seals along the edges and overlying the reef

- The edge of the reef is typically defined using 3D seismic data. Where 3D seismic data is not available, reef edges are approximated using all wells surrounding and penetrating a reef, along with analog reef geometry.
- Stored CO<sub>2</sub> will remain within a reef and will not migrate over geologic time, as is demonstrated by the long history of oil and gas production occurring within a reef. Just as the oil and/or gas were trapped in and contained by the reef, the same would be true for the CO<sub>2</sub>.
- Free-phase CO<sub>2</sub> is contained within the reefs and will remain there after injection ceases and wells are shut-in or closed
- MDEQ rules state that an operator must demonstrate that the reservoir is wholly contained in the Unit Area before an EOR project is authorized.

### 3.2 Maximum Monitoring Area

The maximum monitoring area (MMA) for the MRV Plan, based on the anticipated future of expansion to conduct CO<sub>2</sub> EOR operations in reefs within the NNPRT, extends geologically along the northern edge of the Michigan Basin. The NNPRT extends as a band of reefs from Lake Huron (Presque Isle County) to Lake Michigan (Manistee County), of which there are prospective CO<sub>2</sub> EOR reefs in every labeled county shown in Figure 14. In accordance with § 98.448-449, the actual MMA will extend for ½ mile beyond the reefs. The red dashed line in Figure 14 encompasses the half mile buffer to the north and south of the reefs in the MMA.

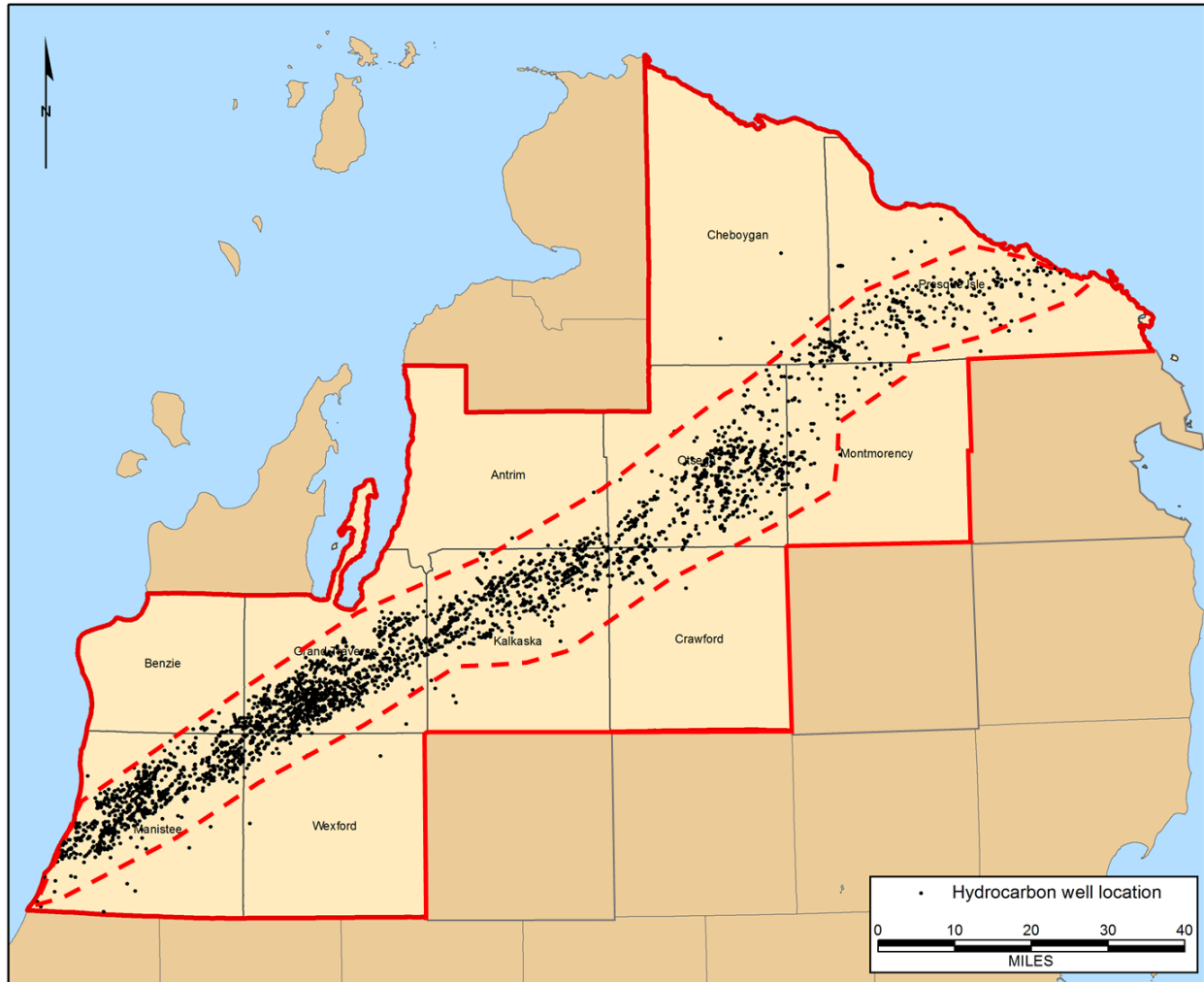


Figure 14 Areal Extent of Maximum Monitoring Area includes the hydrocarbon bearing pinnacle reefs in the NNPRT

The reefs that are currently undergoing CO<sub>2</sub> EOR in Otsego County and all of the reefs in the NNPRT that would be suitable CO<sub>2</sub> EOR targets in the future are found at the same place within Michigan's geological stratigraphic column. The reefs are always contained below the B-Salt and A2-Carbonate and above the White Niagaran (see Figure 15).



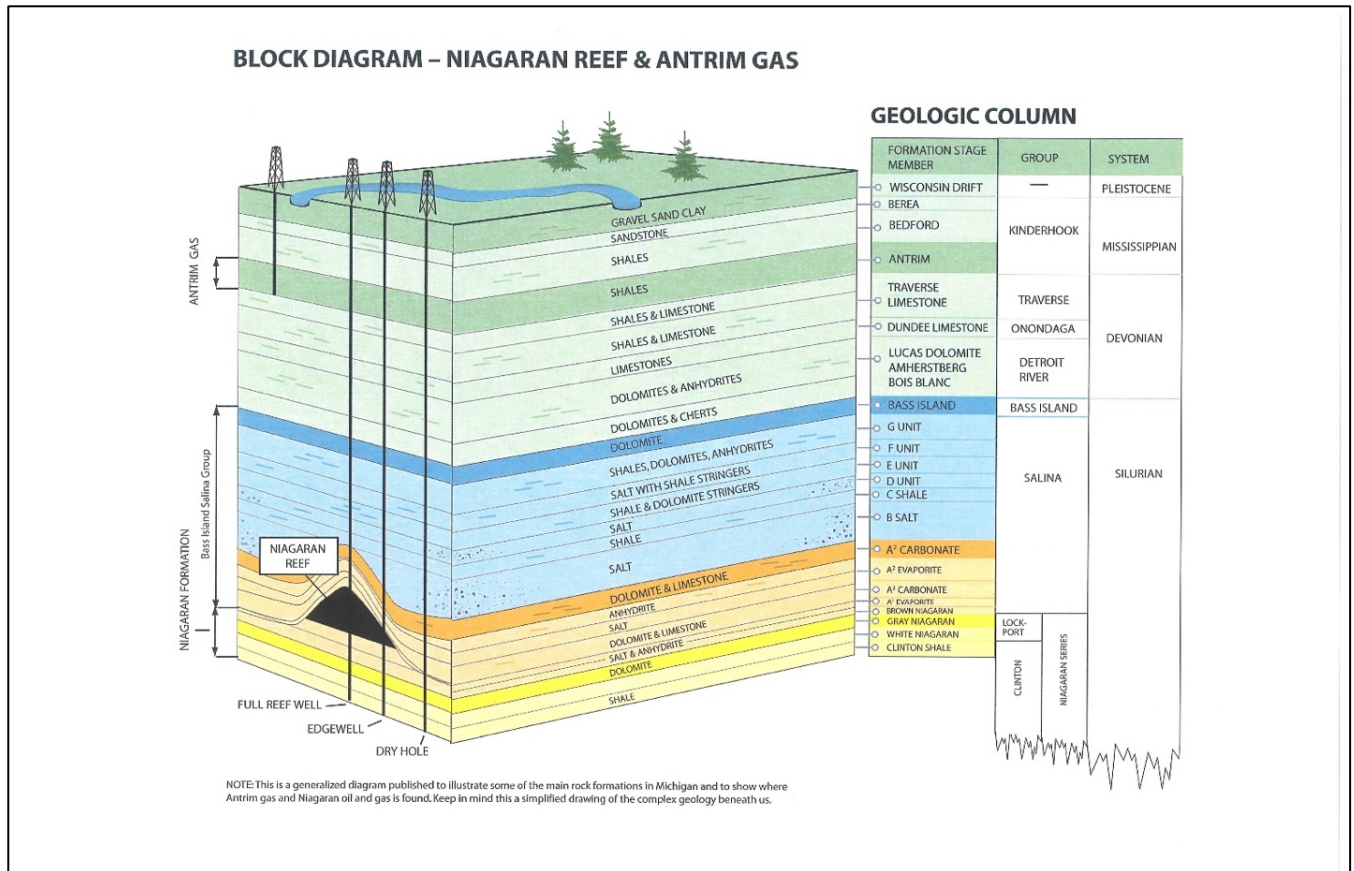


Figure 15 Michigan Stratigraphic Column

The potential risk of leakage is consistent from reef-to-reef in the MMA for several reasons. The hydrocarbon bearing reefs that Core Energy will develop are always found in the same geologic setting within the Michigan Basin. They are isolated, self-contained reservoirs, and the risk associated with leakage pathways are the same from reef-to-reef. Further, any reef added to Core Energy’s EOR operations would first be screened for suitability for EOR operations and would then have to undergo the Michigan unitization process by MDEQ. New wells or well changes would go through the state (MDEQ) and federal (US EPA) permitting requirements.

### 3.3 Monitoring Timeframes

Core Energy’s primary purpose for injecting CO<sub>2</sub> is to produce oil that would otherwise remain trapped in the reservoir and not, as in UIC Class VI, “specifically for the purpose of geologic storage.”<sup>1</sup> During a Specified Period, Core Energy will have a subsidiary purpose of establishing the long-term containment of a measurable quantity of CO<sub>2</sub> in the reefs that it operates. The Specified Period will be shorter than the period of production from the Core Energy facility. At the conclusion of the Specified Period, Core Energy will submit a request for discontinuation of reporting. This request will be submitted when Core Energy can provide a demonstration that current monitoring and model(s) show that the cumulative mass of CO<sub>2</sub> reported as sequestered during the Specified Period is not expected to migrate in the future in a manner likely to result in

<sup>1</sup> EPA UIC Class VI rule, EPA 75 FR 77291, December 10, 2010, section 146.81(b).



surface leakage. It is expected that it will be possible to make this demonstration within three years after injection for the Specified Period ceases. The demonstration will rely on three principles: 1) the amount of CO<sub>2</sub> stored in properly abandoned reefs will be considered unlikely to migrate to the surface, 2) the continued process of fluid management during the years of CO<sub>2</sub> EOR operation after the Specified Period will contain injected fluids in the reefs, and 3) that the cumulative mass reported as sequestered during the Specified Period is a fraction of the theoretical storage capacity of the reefs in the field. See 40 C.F.R. § 98.441(b)(2)(ii).

#### 4. Evaluation of Leakage Pathways

Knowledge gained through the long history of oil and gas production in the Niagaran reefs coupled with the regional geological characterization conducted by Battelle for the [MRCSP](#) were used to identify and assess potential pathways for leakage of CO<sub>2</sub> to the surface. The following potential pathways are reviewed:

- Existing wellbores
- Faults and fractures
- Natural and induced seismic activity
- Lateral migration outside of a reef
- Diffuse leakage through the seal
- Pipeline/surface equipment

##### 4.1 Existing Wellbores

Wellbores that penetrate the reef constitute the most likely pathway for leakage, however this risk is assessed as very small because of the well construction specifications implemented by Core Energy. Wells are constructed with four strings of casing (i.e. conductor, surface, intermediate and total depth string), three of which are cemented in place; the surface casing is cemented all the way to the surface. Additionally, all wells have tubing strings run to near the permitted injection zones. Injection wells require a packer attached to the tubing string, located no more than 100 feet (30 m) above the permitted injection zone and mechanical integrity on injection wells must be established and maintained. Core Energy adheres to all regulatory requirements of the state and federal agencies charged with oversight as they relate to well drilling, completion and operation as means to maintain mechanical integrity and prevent wellbore leakage. Though previously drilled wells and plugged/abandoned wells may be thought to have a higher risk for leakage pathways than newly drilled wells, all wells within a defined AoR for a project are evaluated. All wells in northern Michigan have been ranked based on age, status, and depth (penetrating seal). It was concluded that wells which penetrated the seals were ranked with high integrity because they were more recent and adhered to regulatory requirements. Figure 16 shows all the well rankings in Otsego County (green is high integrity) and the number of wells which penetrate each reef.

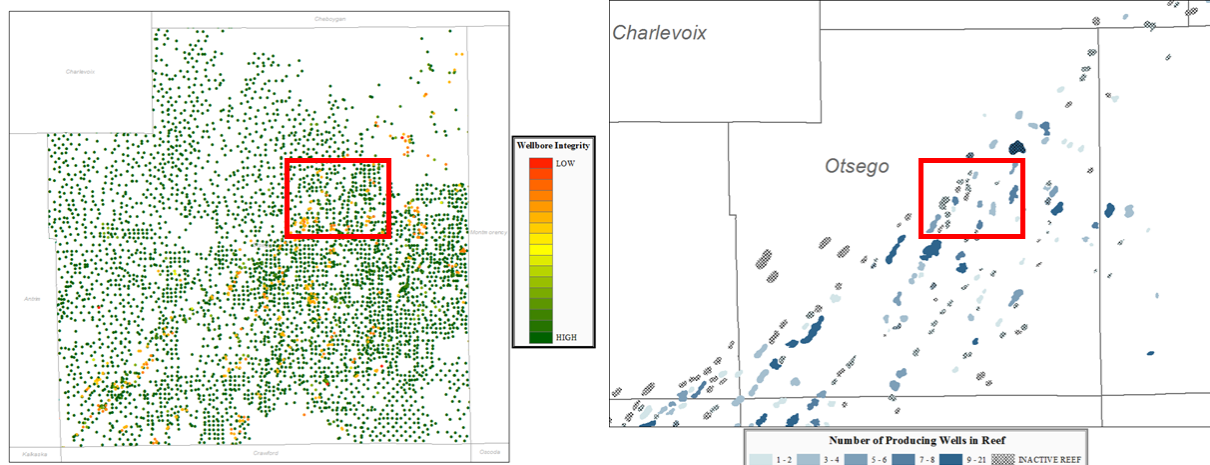


Figure 16: Wellbore integrity ranking (left) of all wells in Otsego County showing dominantly high integrity and the number of wells which penetrate each reef (blue) showing few seal penetrations within the Core Energy reef area (red)

MRCSP's systematic wellbore integrity evaluation in seven fields in the Michigan Basin which were actively being used for CO<sub>2</sub> EOR also included an assessment of cement plugs. In this study, cement plugs were analyzed and ranked based on depth, the number of plugs, thickness, and age. It was concluded that plugged wells which penetrated the reefs and nearby off reef locations had sufficient plug placement and thickness to prevent leakage.<sup>2</sup>

Leakage through wellbore cement was also researched in the NNPRT by analyzing several cement bond logs in the region. Cement was categorized based on the bond index. Cement with 80 to 100% bond was considered sufficient, 60 to 80% was intermediate, and less than 60% was not ideal. Wells which penetrated the reef were shown to have at least 50 feet of sufficient cement bond within the seal, which by industry standards is sufficient (Figure 17). Several wells were also tested for sustained casing pressure after being exposed to CO<sub>2</sub> and did not demonstrate any sustained casing pressure which would be caused by leakage through a cement annulus.

<sup>2</sup> Haagsma, A. , Weber, S. , Moody, M. , Sminchak, J. , Gerst, J. and Gupta, N. (2017), Comparative wellbore integrity evaluation across a complex of oil and gas fields within the Michigan Basin and implications for CO<sub>2</sub> storage. Greenhouse Gas Sci Technol, 7: 828-842. doi:[10.1002/ghg.1620](https://doi.org/10.1002/ghg.1620)

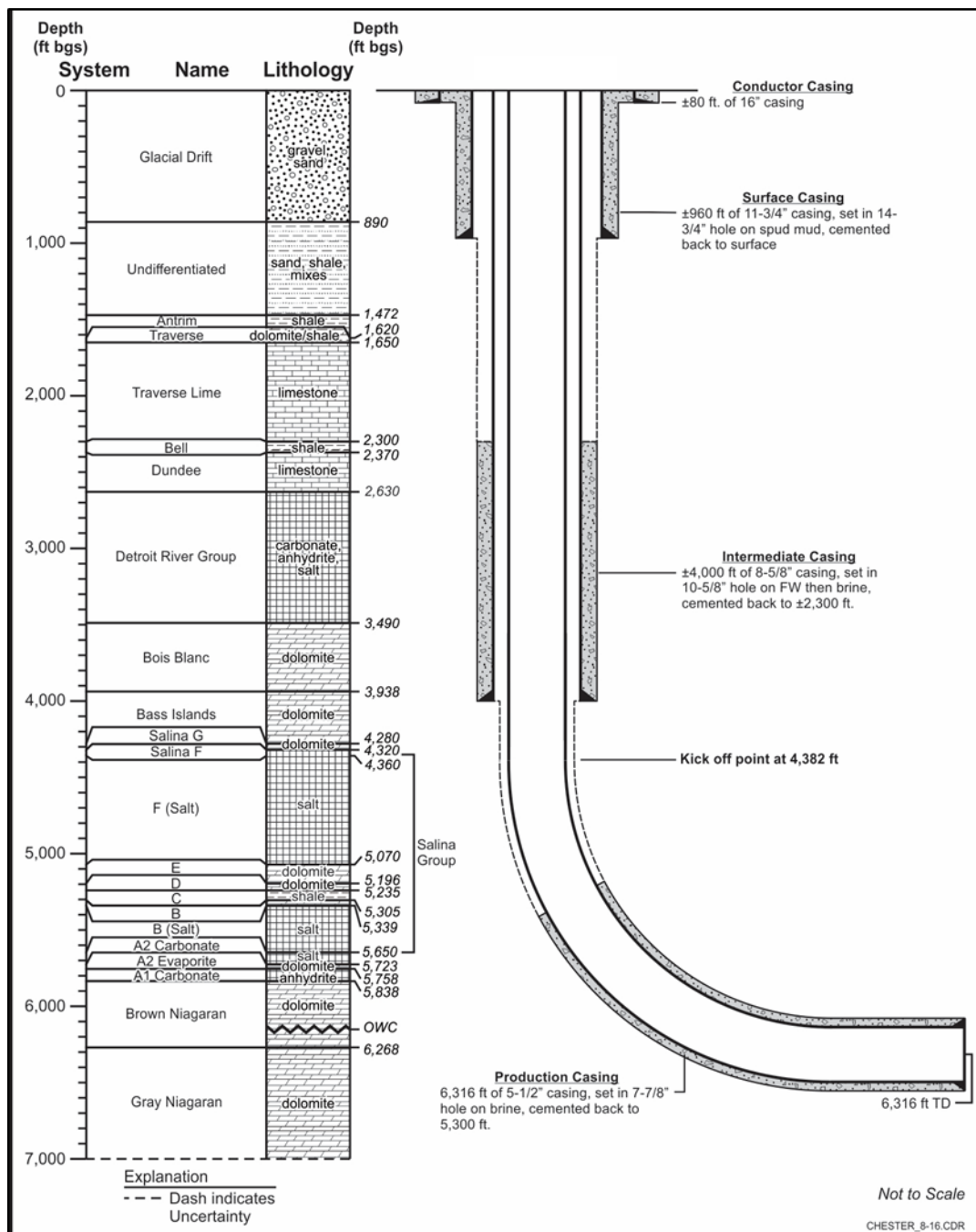


Figure 17: Example of well construction for a Core Energy well showing intervals of cement over crucial formations.

Overall, wellbore integrity studies and the oil and gas history demonstrate that while leakage through a wellbore is possible, the wells have been constructed ideally to prevent such leakage. Core Energy also conducts routine monitoring of active wellbores by performing bottom hole pressure measurements and wellhead inspections.

### 4.1.1 Future Wells

The highly-compartmentalized nature of the NNPRT reefs and the state requirements for drilling wells in active and new reefs will prevent new wells from posing a threat of leakage. As discussed in section 2.1, the structure of each reef ensures that they are separated from each other and that there is no fluid communication. This means that any well drilled in the MMA that does not intersect or pass through a reef, even if drilled to a depth deeper than that of the NNPRT reefs, is not a potential leakage pathway. Additionally, because reefs undergoing CO<sub>2</sub> EOR have to be unitized prior to commencing EOR operations, Core Energy controls all the pertinent rights that would preclude (or allow) for a well to be drilled within its unit, thus, no well could be drilled within the unit boundary of an active EOR project.

### 4.2 Faults and Fractures

Basement crustal features such as the Mid-Michigan Rift/geophysical anomaly and the Grenville Front (Figure 18) may affect formation thickness and the tectonic movement of Paleozoic structures in the sedimentary rock section. Many ancient faults and folds in the Paleozoic section are parallel or perpendicular to the basement features. There are fewer identified faults in the northern most counties of Michigan than there are in southern Michigan, making the NNPRT an ideal location for CO<sub>2</sub>-EOR. The faults in northern Michigan are deeper features and do not influence the integrity of the caprocks for the reefs.

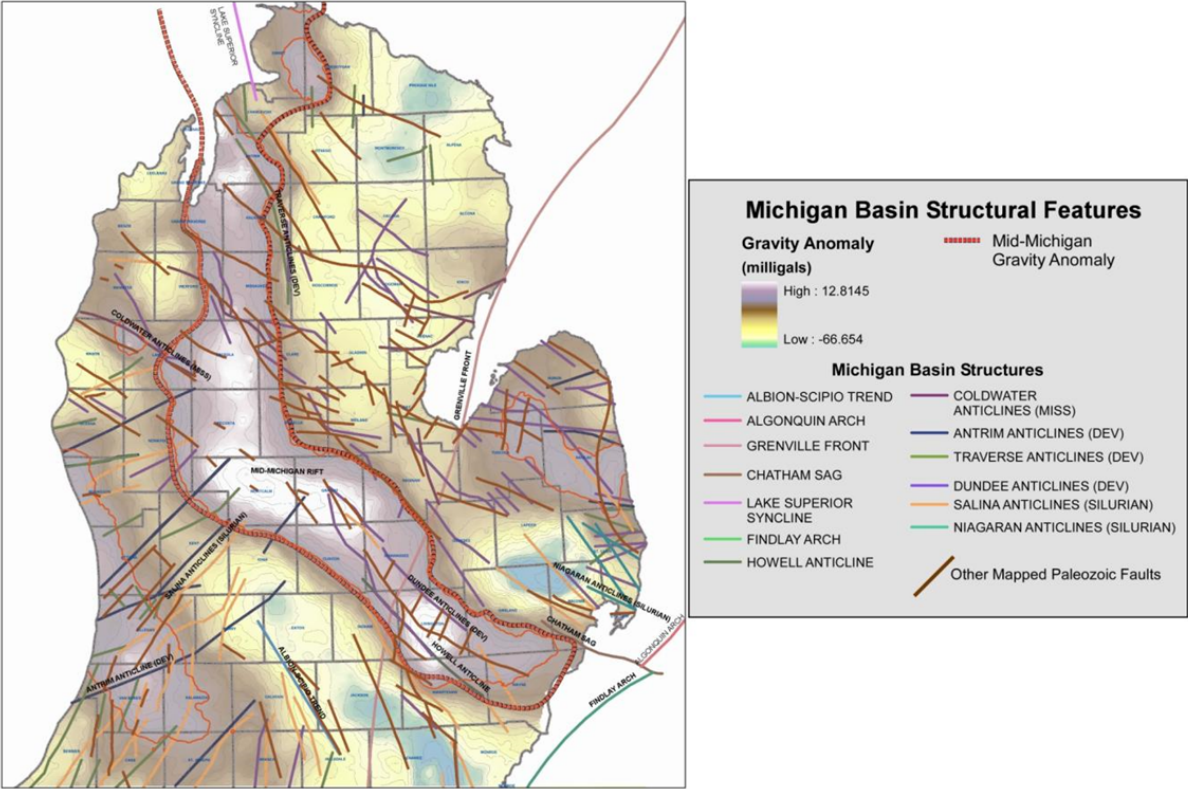


Figure 18: Michigan Basin structural feature



### 4.3 Natural and Induced Seismic Activity

Michigan Basin is structurally stable with few known faults. There are no recorded seismic events in northern Michigan and risk of seismic activity is low with a 0 to 4% chance of a seismic event in northern Michigan and no recorded seismic events (Figure 19A). Nearby 2D and 3D seismic data confirm there are no major structural features around the sites of interest (Figure 19B).

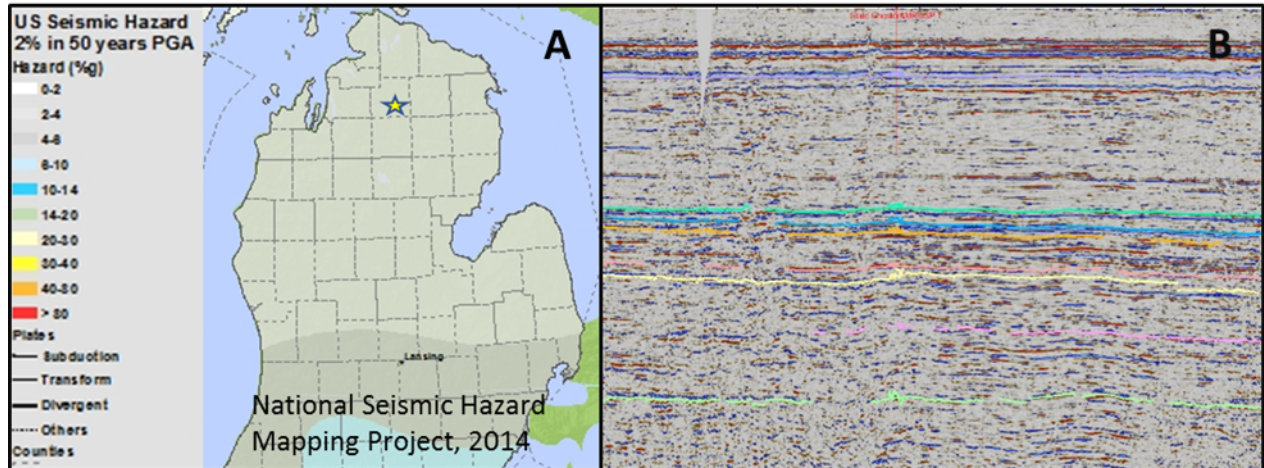


Figure 19: US seismic hazard map (A) with example 2D seismic line (B) showing low risk for seismic activity and no major structural features.

### 4.4 Lateral Migration Outside of a Reef

It is highly unlikely that injected CO<sub>2</sub> will migrate outside of the boundaries of a reef due to the following factors:

- 1) The containment provided by the inherent reef geology consisting of non-porous salts and evaporites along the flanks and overlying the reef structure. This containment is believed to effectively isolate the individual reefs resulting in closed reservoir dynamics observed over the course of MRCSP CO<sub>2</sub> injection (see section 2.1)
- 2) Operational procedures at Core Energy, which monitor injection and production volumes from well-managed wells.
- 3) Periodic material balance associated with the measured reservoir fluid amounts, which has helped correlate and reconfirm that no CO<sub>2</sub> has been lost to the surroundings from the reef thus far.

Containment is also validated by the numerical modeling exercises (both analytical and dynamic numerical models) undertaken for each of the reefs of interest aimed at investigating reef response and CO<sub>2</sub> migration over time.

#### 4.5 Diffuse Leakage through the Seal

Diffuse leakage through the seal, overlying Salina group, is highly unlikely. The seal is composed of several hundred feet of salt, shale, and tight carbonate. Oil and gas production also confirms the successful trapping of fluids in the reefs over geologic time. Additional pressure monitoring and geomechanical modeling of the seals in several reefs confirmed the efficiency and integrity of the confining system.

The fracture gradient is 0.8 psi/ft which is approximately 4130 psi at a depth of 5162 ft (shallowest perforation in Core Energy reefs). The coordinating wellhead (surface) pressure equates to 1761 psi. The maximum pressure tubing can experience is 1400 psi, based on the pressure that can be delivered from the injection compressors. Thus, the fracture pressure is higher than can physically be realized within the well and there is no risk of fracturing the seals. Further, each CO<sub>2</sub> injection well is assigned a maximum surface injection pressure as a part of the US EPA permitting process, whose purpose is to ensure that the reservoir fracture pressure is not exceeded.

Additionally, geomechanical analyses were conducted using wireline logs and core tests for select reefs. Analytical techniques were used to estimate changes in minimum horizontal stress,  $\sigma_h$ , caused by changes in pressure and temperature during CO<sub>2</sub> injection and to determine whether the stress state compromises the ability of reservoirs for safe and effective CO<sub>2</sub> storage. It was found that fracturing of the reservoir or caprock is not likely as long as the injection pressure is maintained below the UIC permit pressure limit.

#### 4.6 Pipeline/surface equipment

Leakage through pipelines and surface equipment is a potential risk. Core Energy uses its routine maintenance and daily inspection procedures to minimize this risk. Further, it will deploy three approaches to calculate the amounts of CO<sub>2</sub> lost through pipelines and surface equipment: 1) following GHGRR Subpart W methods for estimating fugitive and vented emissions, 2) using direct metering to measure specific venting events as discussed in Section 2.4.3, and 3) in the event an extreme event were to occur, using engineering best practices to estimate a loss.

### 5. Monitoring

This section describes the general approach to monitoring at the Core Energy facility and indicates how data will be collected for this MRV plan.

#### 5.1 General Monitoring Procedures

As part of its ongoing operations, Core Energy monitors and collects flow, pressure, and gas composition data from each reef in the central HMI computer system.

As indicated in Figure 13 Core Energy uses Coriolis mass flow meters for all measurements included in the mass balance (Section 7) and also uses Vortex flow meters for some operational monitoring. Fluid composition will be determined, at a minimum, quarterly, consistent with EPA

GHGRP's Subpart RR, section 98.447(a). All meter and composition data are documented, and records will be retained for the Specified Period. Quarterly composition analysis will be done at meter #2 at Chester 10 Facility for pure CO<sub>2</sub> gas and at meter #19 at Dover 36 Facility for combined recycle gas. If any other combined recycle gas processing facilities are added, as indicated in Section 2.5, similar Coriolis mass flow meters will be installed and quarterly composition analyses will be conducted. Such new meters would be included in the monitoring report and Section 7 calculations. If not done on a routine basis, Core will use initial baseline data or last available quarter composition analysis as continuation of reporting quarter, with justification as to why analysis was not done/deemed necessary. All composition analysis will be on % wt. basis of CO<sub>2</sub> in gas stream.

Core Energy has invested in Micro Motion Coriolis Mass Flow Meters throughout its operations. These meters are designed to retain calibration. The meters have no moving parts and a non-intrusive measuring sensor. As a result, there are no probes or detectors that come into direct contact with process fluids. The benefit of this design is that there are no bearings or rotors to wear, turbines to be deformed, electrodes to coat, or degradation of orifices to be concerned about. The manufacturer reports that "It has been our experience, and that of our customers, that Coriolis meters do not shift or lose their calibration during the life of the meter.

When calibration issues arise, the focus of the problem is normally traceable to the flowmeter installation or a characteristic of the process that was not previously taken into consideration." As a result, there are no prevailing industry standard(s) for meter calibration for these meters.

Core Energy observes trend data from the meters and has on occasion sent meters back to the company for recalibration but this does not occur routinely. This type of meter would have to be severely abused (serious mechanical damage, overheating beyond metal plasticity limits) to change calibration. These types of abuses do not happen during normal operations. Therefore, Core Energy considers this approach to be consistent with EPA GHGRP's Subpart RR, section 98.444(e)(3). These meters will be maintained, operated continually, and will feed data directly to the central HMI computer system. The meters meet the industry standard for meter accuracy and calibration frequency. The level of precision and accuracy for these meters currently satisfies the requirements for reporting in existing UIC permits.

Core Energy contracts with a third party firm that specializes in GHG Reporting Rule compliance to determine Core Energy's emissions using the Subpart W methodology. This results in an annual Subpart W report for Core Energy. Based on the results of this report to date, Core Energy does not meet the threshold for reporting its emissions to EPA through the EGRT system. Core Energy tracks its Subpart W emissions internally and will use these calculations, as specified the Subpart RR, for determining the mass of CO<sub>2</sub> stored.

## 5.2 CO<sub>2</sub> Received

Core Energy measures the volume of received CO<sub>2</sub> using Coriolis mass flow meters at the Chester 10 Facility and, as indicated in section 2.4.1, the Dover 36 Facility. As indicated in Section 2.5, any new recycle gas processing would be measured using Coriolis mass flow meters. No CO<sub>2</sub> is received in containers.

### 5.3 CO<sub>2</sub> Injected into the Subsurface

Injected CO<sub>2</sub> will be metered using the Coriolis mass flow meters dedicated to each injection well at a reef.

### 5.4 CO<sub>2</sub> Produced, Entrained in Products, and Recycled

For purposes of reporting under Subpart RR, Core energy will measure the mass of CO<sub>2</sub> produced through separators using Coriolis mass flow meters #19.

For any new production facilities added, as indicated in Section 2.5, the mass of CO<sub>2</sub> produced would similarly be measured using Coriolis mass flow meters.

CO<sub>2</sub> is produced as entrained or dissolved CO<sub>2</sub> in produced oil. As the oil passes through low-pressure separation to a gathering tank, a small amount of CO<sub>2</sub> is released. Core Energy has determined the concentration of CO<sub>2</sub> entrained in oil to be 0.7512% by weight (see Section 2.4.3).

### 5.5 CO<sub>2</sub> Emitted by Surface Leakage

Core Energy uses an event-driven process to assess, address, track, and if applicable quantify potential CO<sub>2</sub> leakage to the surface. Core Energy will reconcile the internal Subpart W report and results from any event-driven quantification to assure that surface leaks are not double counted.

The monitoring program for event-driven incidents has been designed to meet two objectives, in accordance with the leakage risk assessment in Section 4: 1) to detect problems before CO<sub>2</sub> leaks to the surface; and 2) to detect and quantify any leaks that do occur. This section discusses how this monitoring will be conducted and used to quantify the volumes of CO<sub>2</sub> leaked to the surface.

#### 5.5.1 Monitoring for potential Leakage from the Injection/Production Zone:

Core Energy routinely tracks and reports on a daily basis, the following surface data for all wells: Injection Rate (MCF), Production Rates (BO, BW, MCF), Tubing Pressure (psig), Casing Pressure (psig), Wellhead Temperatures (°F) and Runtime (Hours). Where there is instrumentation, data are collected more frequently but in the oilfield it is normal and customary for data to be reduced to daily volumes and/or averages. Core utilizes this data primarily for operational oversight and monitoring of EOR projects, but also intends to use this data to determine when further investigation of potential CO<sub>2</sub> leakage is warranted.

Core utilizes modeling, analog performance, operational practice, and historical project performance; bounded by permit conditions that take into account reservoir characteristics (e.g. injection pressure, injectant density, fracture gradient) to develop targeted daily/monthly injection rates, pressures and volumes. If injection rate or pressure significantly deviate from that which is targeted, it generates a flag and alerts operational personnel to investigate and resolve the matter. Operational and engineering personnel will collectively work to resolve these flagged events. Data flags and operational investigations do not mean that leakage of CO<sub>2</sub> has occurred, rather they are an indication that the injection rate and pressure are not conforming to the targeted values. In



most cases, the flagged events result in an easy fix (e.g. pressure gauge failure and subsequent replacement) and pose no threat of CO<sub>2</sub> leakage. However, in those rare cases whereby flagged events cannot be easily resolved, a more thorough and detailed investigation would be initiated, garnering wider Company or industry support as needed. Whenever any investigation identifies that CO<sub>2</sub> leakage has occurred, the volume of CO<sub>2</sub> that has escaped from the closed system will be quantified using operational and engineering judgement and included in the annual RR reporting.

Similarly, Core uses the collected data along with modeling, analogs and project performance to forecast produced volumes (i.e. oil, water, CO<sub>2</sub>) and composition. If producing wells do not have individual separation vessels and meters, they are individually well tested at least quarterly (more frequently if overall project production or individual well pressure data warrant it). The production data is reviewed at least monthly and if there is a significant deviation from past performance or forecast, operational and engineering personnel investigate further. If the cause of the deviation cannot be understood and resolved quickly, a more thorough and detailed investigation would be initiated, garnering wider Company or industry support as needed. Whenever any investigation identifies that CO<sub>2</sub> leakage has occurred, the volume of CO<sub>2</sub> that has escaped from the closed system will be quantified using operational and engineering judgement and included in the annual RR reporting.

Again, because of the unique geology of the NNPRT, to date, there has never been a case whereby leakage was suspected to have occurred in the EOR flood zone. In the very rare event that CO<sub>2</sub> leakage may be suspected in the EOR flood zone, Core would deploy methods to quantify the volume of CO<sub>2</sub> involved. With respect to tracking reservoir pressure, episodic surveys are conducted, on a field-by-field or well-by-well basis to gather information about reservoir pressure and other parameters (e.g. kh, skin). Because of the heterogeneity of these carbonate pinnacle reefs, it is not feasible to let injection wells fall-off or producing wells build-up for periods long enough to reach static conditions, thus, the bottom hole pressure measured in an injection well can be very significantly higher than that measured in a producing well over the typical survey duration (e.g. 3 to 7 days). Therefore, over time, well pressure survey histories are developed for both injection and production wells, that yield general performance behavior and characteristics for each well (field). Then, if a survey is run and its results diverge from this survey history in a statistically significant way, it triggers a deeper evaluation to discern what may be taking place and causing the anomaly. For example if injection wells in a field, over time, yield similar pressure survey results and then suddenly a survey yields an anomalous and lower result, then further evaluation is done to discern what may be causing the change (e.g. net CO<sub>2</sub> in reservoir declined considerably since last survey and/or an injection well was shut-in or its injection rate reduced, then the measured pressure would be expected to be lower than previous surveys).

If leakage in the flood zone were detected, Core Energy would use an appropriate method to quantify the involved volume of CO<sub>2</sub>. This might include use of material balance equations based on known injected quantities and monitored pressures in the injection zone to estimate the volume of CO<sub>2</sub> involved.

A subsurface leak might not lead to a surface leak. In the event of a subsurface leak, Core Energy would determine the appropriate approach for tracking subsurface leakage to determine and quantify leakage to the surface. To quantify leakage to the surface, Core Energy would estimate the relevant parameters (e.g., the rate, concentration, and duration of leakage) to quantify the leak volume. Depending on specific circumstances, these determinations may rely on engineering estimates.

#### 5.5.2 Monitoring of Wellbores:

Core Energy monitors wells through continual pressure monitoring in the injection zone (as described in Section 5.1), monitoring of the annular pressure in wellheads, and routine maintenance and inspection. At any time, in the case of an injection well, where there is a loss of MIT, the well must be and is shut-in until such time the wellbore is repaired. Upon completion of the workover, a new MIT is performed under the oversight of the EPA. The results of the MIT along with workover information are supplied to the EPA and if all is in order, they issue a letter authorizing injection to be resumed. Under no circumstances is injection commenced until such time the letter is in hand.

Leaks from wellbores would be detected through the follow-up investigation of pressure anomalies and visual inspection.

Anomalies in injection zone pressure may not indicate a leak, as discussed above. However, if an investigation leads to a work order, field personnel would inspect the equipment in question and determine the nature of the problem. If it is a simple matter, the repair would be made and the volume of leaked CO<sub>2</sub> would be included in the internal Subpart W report for the Core Energy Facility. If more extensive repair were needed, Core Energy would determine the appropriate approach for quantifying leaked CO<sub>2</sub> using the relevant parameters (e.g., the rate, concentration, and duration of leakage).

Anomalies in annular pressure or other issues detected during routine maintenance inspections would be treated in the same way. Field personnel would inspect the equipment in question and determine the nature of the problem. For simple matters the repair would be made at the time of inspection and the volume of leaked CO<sub>2</sub> would be included in the internal Subpart W report for the Core Energy Facility. If more extensive repairs were needed, the well would be shut in until repairs could be completed and Core Energy would determine the appropriate approach for quantifying leaked CO<sub>2</sub> using the relevant parameters (e.g., the rate, concentration, and duration of leakage).

In the event CO<sub>2</sub> is lost during a repair, the most recent daily volume of CO<sub>2</sub> would be prorated against the number of hours that the failure caused CO<sub>2</sub> to leak from the system. It should be noted that when doing workovers, the wells are always “killed” by using appropriate density fluid and the wells are “dead” (no CO<sub>2</sub> flow), thus, leakage has not occurred during workovers to wells to date. In the rare and unlikely event surface leakage does occur during a workover, an estimate of the volume would be made using engineering and operational judgements.

## 5.6 Mass of CO<sub>2</sub> Emissions from Equipment Leaks and Vented Emissions of CO<sub>2</sub> from Surface Equipment Located Between the Injection Flow Meter and the Injection Wellhead

Core Energy evaluates and estimates leaks from equipment, the CO<sub>2</sub> content of produced oil, and vented CO<sub>2</sub>, using the procedures in 40 CFR Part 98 Subpart W. Core Energy will use this method for reporting under Subpart RR.

## 5.7 Mass of CO<sub>2</sub> Emissions from Equipment Leaks and Vented Emissions of CO<sub>2</sub> from Surface Equipment Located Between the Production Flow Meter and the Production Wellhead

Core Energy evaluates and estimates leaks from equipment, the CO<sub>2</sub> content of produced oil, and vented CO<sub>2</sub>, using the procedures in 40 CFR Part 98 Subpart W. It also measures CO<sub>2</sub> emissions from dry and wet vents attached to the separators. Both of these measurements will be included under Subpart RR.

## 5.8 Demonstration that Injected CO<sub>2</sub> is not expected to Migrate to the Surface

At the end of the Specified Period, Core Energy intends to cease injecting CO<sub>2</sub> for the ancillary purpose of establishing the long-term storage of CO<sub>2</sub> in the Core Energy Facility. After the end of the Specified Period, Core Energy anticipates that it will submit a request to discontinue monitoring and reporting. The request will demonstrate that the amount of CO<sub>2</sub> reported as stored “is not expected to migrate in the future in a manner likely to result in surface leakage” ( §98.441).

At that time, Core Energy will be able to support its request with years of data collected during the Specified Period as well as two to three (or more, if needed) years of data collected after the end of the Specified Period. This demonstration will provide the information necessary for the EPA Administrator to approve the request to discontinue monitoring and reporting including:

- i. An assessment of injection data for each reef indicating the total volume of injected and stored CO<sub>2</sub> as well as the actual surface injection pressures;
- ii. An assessment of the CO<sub>2</sub> leakage detected, if any, including discussion of the estimated amount of CO<sub>2</sub> leaked and the distribution of emissions by leakage pathway; and
- iii. An assessment of reservoir pressure that demonstrates the reservoir pressure in a reef is either too low to enable flow to the surface (i.e., reef has been blown down) or that the reservoir pressure is stable enough to demonstrate that the CO<sub>2</sub> is contained within the reef and not expected to migrate in a manner to create a potential leakage pathway.

## 6. Determination of Baselines for Monitoring CO<sub>2</sub> Surface Leakage

Core Energy will use the results from daily monitoring of field conditions and operational data, as well as routine testing and maintenance information to monitor for surface leakage.

As indicated in sections 2.4.4. and 5, Core Energy uses onsite management and an automatic data system to conduct its EOR operations. Core Energy will use data from these efforts to identify and investigate variances from expected performance that could indicate CO<sub>2</sub> leakage. Below is a description of how this data will be used to determine when further investigation of potential CO<sub>2</sub> leakage is warranted.

- **Visual Inspections:** Operations personnel make daily rounds of the facilities and wells, providing a visual inspection of equipment used in the operations (e.g. vessels, piping, valves, wellheads). Making these rounds provide opportunity to identify issues early and address them proactively, which may preclude leaks from happening and/or minimize any CO<sub>2</sub> leakage. If an identified issue cannot be resolved by the person who first observes it, a work order will be generated to resolve the matter. Each event will be documented, include an estimate of the amount of CO<sub>2</sub> leaked and included in the annual RR reporting. Records for such events will be kept on file for a minimum of three years.
- **Injection Well Surveillance:** Core establishes target rates and pressures for all injection wells based on various parameters (e.g. CO<sub>2</sub> availability, field performance, delivery agreements, permit conditions). When a statistically significant deviation occurs that is outside of the established over or under range of the targeted values, it triggers further investigation to determine if the variance poses a leak threat. If investigation of an event identifies that a leak has occurred, those events will be documented, include an estimate of the amount of CO<sub>2</sub> leaked and included in the annual RR reporting. Records for such events will be kept on file for a minimum of three years.
- **Production Well Surveillance:** Core establishes a forecast for producing wells and projects, estimating the volumes of fluids (e.g. oil, CO<sub>2</sub>, water) that are likely to be produced over a period of time. Evaluation of the produced volumes along with other data (e.g. pressure, composition) informs operational decisions for how to manage a project and aid in identifying possible issues that may involve CO<sub>2</sub> leakage. These evaluations can direct engineering and/or operational personnel to investigate matters further, which can lead to work orders being issued to work on wells and/or surface equipment involved in a CO<sub>2</sub> EOR project. If investigation of an event identifies that a leak has occurred, those events will be documented, include an estimate of the amount of CO<sub>2</sub> leaked and included in the annual RR reporting. Records for such events will be kept on file for a minimum of three years.
- **Mechanical Integrity Testing (MIT):** Each CO<sub>2</sub> injection well has a permit condition whereby mechanical integrity has to be established and maintained. This involves the regular monitoring of the tubing-casing annular pressure and conducting annular fill-up tests. Core operational personnel monitor the pressure and conduct the tests in accordance with the permit conditions. In the event a loss of mechanical integrity occurs, the injection well is immediately shut-in and an investigation is initiated to determine what caused the loss of mechanical integrity. If investigation of an event identifies that a leak has occurred, those events will be documented, include an estimate of the amount of CO<sub>2</sub> leaked and included in the annual RR reporting. Records for such events will be kept on file for a minimum of three years.

## 7. Site Specific Considerations for the Mass Balance Equation

The Core Energy facility is small relative to many other EOR operations. It operates a current total of 15 injection, 14 production, and 7 monitoring/production wells located in 10 reefs. Core Energy also has 2.11 million metric tonnes of CO<sub>2</sub> inventory that will be reflected, over time, in the mass balance equation. Core Energy considers the following site specific conditions for using the equations in Subpart RR §98.443.

### 7.1. Mass of CO<sub>2</sub> Received

Core Energy will use equation RR-1 as indicated in Subpart RR §98.443 to calculate the mass of CO<sub>2</sub> received from the Chester 10 Facility and all recycle gas (currently from Dover 36 Facility but to include other new recycling facilities as indicated in Section 2.5.). In the annual monitoring report, Core Energy will track the current and cumulative volume of Dover 36 Facility CO<sub>2</sub> and indicate when it has reached 2,110,000 metric tonnes of working inventory; at that time, it will stop reporting the amount from Dover 36 under RR-1 / RR-3. In the future, any additional new sources of CO<sub>2</sub> will be added in the same manner.

$$CO_{2T,r} = \sum_{p=1}^4 (Q_{r,p} - S_{r,p}) * C_{CO_2,p,r} \quad \text{Equation RR-1}$$

where:

CO<sub>2T,r</sub> = Net annual mass of CO<sub>2</sub> received through flow meter r (metric tons).

Q<sub>r,p</sub> = Quarterly mass flow through a receiving flow meter r in quarter p at standard conditions (metric tons).

S<sub>r,p</sub> = Quarterly mass flow (metric tons) through a receiving flow meter r that is redelivered to another facility without being injected into a site well in quarter p

C<sub>CO<sub>2</sub>,p,r</sub> = Quarterly CO<sub>2</sub> concentration measurement in flow for flow meter r in quarter p (wt. percent CO<sub>2</sub>, expressed as a decimal fraction).

p = Quarter of the year.

r = Receiving flow meters.

Core Energy will sum to total Mass of CO<sub>2</sub> Received using equation RR-3 in §98.443

$$CO_2 = \sum_{r=1}^R CO_{2T,r} \quad \text{Equation RR-3}$$

where:

CO<sub>2</sub> = Total net annual mass of CO<sub>2</sub> received (metric tons).

CO<sub>2T,r</sub> = Net annual mass of CO<sub>2</sub> received (metric tons) as calculated in Equation RR-1 for flow meter r.

r = Receiving flow meter.

## 7.2 Mass of CO<sub>2</sub> Injected into the Subsurface

Core Energy will use equation RR-4 as indicated in Subpart RR §98.443 to calculate the mass of CO<sub>2</sub> injected into the subsurface at each of the ten reefs. Core proposes to use a method to calculate “C<sub>CO<sub>2</sub>,p,u</sub>” that uses a weighted average concentration that reflects the different CO<sub>2</sub> concentrations in the different sources of CO<sub>2</sub> as explained below.

$$CO_{2,u} = \sum_{p=1}^4 Q_{p,u} * C_{CO_2,p,u}$$

Equation RR-4

where:

CO<sub>2,u</sub> = Annual CO<sub>2</sub> mass injected (metric tons) as measured by flow meter u.

Q<sub>p,u</sub> = Quarterly mass flow rate measurement for flow meter u in quarter p (metric tons per quarter).

C<sub>CO<sub>2</sub>,p,u</sub> = Quarterly CO<sub>2</sub> concentration average measurement in flow for all injection flow meters (wt. percent CO<sub>2</sub>, expressed as a decimal fraction) as determined from Equation A below.

p = Quarter of the year.

u = Injection Flow meter.

For the weighted average concentration, C<sub>CO<sub>2</sub></sub>, Equation A indicates the current calculation using CO<sub>2</sub> from Chester 10 Facility and Dover 36 Facility. If new facilities are added, the weighted concentration average would be modified to include them in the same manner.

Equation A

$$Concentration\ Average = \frac{Q_{p,CH10} * C_{CO_2,p,CH10} + Q_{p,D36} * C_{CO_2,p,D36}}{Q_{p,CH10} + Q_{p,D36}}$$

Where:

Q<sub>p,CH10</sub> = Quarterly mass flow rate measurement of pure CO<sub>2</sub> (from Chester 10 Facility at flow meter #2) in quarter p (metric tons per quarter).

Q<sub>p,D36</sub> = Quarterly mass flow rate measurement of recycle gas (from Dover 36 Facility at flow meter #19) in quarter p (metric tons per quarter).

C<sub>CO<sub>2</sub>,p,CH10</sub> = Quarterly CO<sub>2</sub> concentration of pure CO<sub>2</sub> (from Chester 10 Facility at flow meter #2) in quarter p (wt. percent CO<sub>2</sub>, expressed as a decimal fraction).

C<sub>CO<sub>2</sub>,p,D36</sub> = Quarterly CO<sub>2</sub> concentration of recycle gas (from Dover 36 Facility at flow meter #19) in quarter p (wt. percent CO<sub>2</sub>, expressed as a decimal fraction).

Core Energy will aggregate injection data using equation RR-6:

$$CO_{2i} = \sum_{u=1}^U CO_{2,u} \quad \text{Equation RR-6}$$

where:

$CO_{2i}$  = Total annual  $CO_2$  mass injected (metric tons) through all injection wells.

$CO_{2,u}$  = Annual  $CO_2$  mass injected (metric tons) as measured by flow meter u.

### 7.3 Mass of $CO_2$ Produced

Core Energy uses Coriolis mass flow meters to measure  $CO_2$  in produced fluids as follows. If new production facilities are added, as indicated in Section 2.5, the same approach will be applied.

$$CO_{2,w} = \sum_{p=1}^4 Q_{p,w} * C_{CO_2,p,w} \quad \text{Equation RR-7}$$

Where:

$CO_{2,w}$  = Annual  $CO_2$  mass produced (metric tons) through separator w.

$Q_{p,w}$  = Quarterly gas mass flow rate measurement for separator w in quarter p (metric tons).

$C_{CO_2,p,w}$  = Quarterly  $CO_2$  concentration of recycle gas (currently at Dover 36 Facility flow meter #19) for separator w in quarter p (wt. percent  $CO_2$ , expressed as a decimal fraction).

p = Quarter of the year.

w = Separator.

Core will aggregate production data using equation RR-9 net of the mass of  $CO_2$  entrained in oil as follows:

$$CO_{2P} = \sum_{w=1}^W CO_{2,w} + X \quad \text{Equation RR-9}$$

Where:

$CO_{2P}$  = Total annual  $CO_2$  mass produced (metric tons) through all separators in the reporting year.

$CO_{2,w}$  = Annual  $CO_2$  mass produced (metric tons) through separator w in the reporting year.

w = Separator flow meter.

X= Mass of entrained  $CO_2$  in oil in the reporting year measured utilizing commercial meters and electronic flow-measurement devices at each point of custody transfer. The mass of  $CO_2$  will be calculated by multiplying the total volumetric rate by the  $CO_2$  concentration.



## 7.4 Mass of CO<sub>2</sub> emitted by Surface Leakage

Core Energy will calculate and report the total annual Mass of CO<sub>2</sub> emitted by Surface Leakage using an approach that is tailored to specific leakage events. As described in Sections 4 and 5.1.5-5.1.7, Core Energy is prepared to address the potential for leakage in a variety of settings. Estimates of the amount of CO<sub>2</sub> leaked to the surface will likely depend on a number of site-specific factors including measurements, engineering estimates, and emission factors, depending on the source and nature of the leakage.

Core Energy's process for quantifying leakage will entail using best engineering principles or emission factors. While it is not possible to predict in advance the types of leaks that will occur, Core Energy describes some approaches for quantification in Section 5.1.5-5.1.7. In the event leakage to the surface occurs, Core Energy would quantify and report leakage amounts, and retain records that describe the methods used to estimate or measure the volume leaked as reported in the Annual Subpart RR Report. Further, Core Energy will reconcile the internal Subpart W report and results from any event-driven quantification to assure that surface leaks are not double counted.

Equation RR-10 in 48.433 will be used to calculate and report the Mass of CO<sub>2</sub> emitted by Surface Leakage:

$$CO_{2E} = \sum_{x=1}^X CO_{2,x} \quad \text{Equation RR-10}$$

where:

CO<sub>2E</sub> = Total annual CO<sub>2</sub> mass emitted by surface leakage (metric tons) in the reporting year.

CO<sub>2,x</sub> = Annual CO<sub>2</sub> mass emitted (metric tons) at leakage pathway x in the reporting year.

x = Leakage pathway.

## 7.5 Mass of CO<sub>2</sub> sequestered in subsurface geologic formations.

Core Energy will use equation RR-11 to determine the mass of CO<sub>2</sub> that is incidentally stored each year.

$$CO_2 = CO_{2I} - CO_{2P} - CO_{2E} - CO_{2FI} - CO_{2FP} \quad \text{Equation RR-11}$$

where:

CO<sub>2</sub> = Total annual CO<sub>2</sub> mass sequestered in subsurface geologic formations (metric tons) at the facility in the reporting year.

CO<sub>2I</sub> = Total annual CO<sub>2</sub> mass injected (metric tons) in the well or group of wells covered by this source category in the reporting year.

CO<sub>2P</sub> = Total annual CO<sub>2</sub> mass produced (metric tons) net of CO<sub>2</sub> entrained in oil in the reporting year.

CO<sub>2E</sub> = Total annual CO<sub>2</sub> mass emitted (metric tons) by surface leakage in the reporting year.

CO<sub>2FI</sub> = Total annual CO<sub>2</sub> mass emitted (metric tons) from equipment leaks and vented emissions of CO<sub>2</sub> from equipment located on the surface, between the flow meter



used to measure injection quantity and the injection wellhead in the reporting year, calculated as provided in subpart W.

$CO_{2FP}$  = Total annual CO<sub>2</sub> mass emitted (metric tons) from equipment leaks and vented emissions of CO<sub>2</sub> from equipment located on the surface between the production wellhead and the flow meter used to measure production quantity in the reporting year, calculated as in Subpart W and including the metered CO<sub>2</sub> measurements at the wet and dry vents attached to the separators.

## 7.6 Cumulative mass of CO<sub>2</sub> reported as sequestered in subsurface geologic formations

Core Energy will sum up the total annual volumes obtained using equation RR-11 in 98.443 to calculate the Cumulative Mass of CO<sub>2</sub> Sequestered in Subsurface Geologic Formations.

## 8. Estimated Schedule for Implementation of MRV Plan

This plan will be effective as of January 1, 2018.

## 9. Quality Assurance Program

### 9.1 Monitoring

Core Energy will follow the requirements in 40 CFR part 98.444 as indicated in Sections 2, 5 and 7. As indicated in Section 5.1, Core Energy has invested in Micro Motion Coriolis Mass Flow Meters throughout its operations. These meters are designed to retain calibration. The meters have no moving parts and a non-intrusive measuring sensor. As a result, there are no probes or detectors that come into direct contact with process fluids. The benefit of this design is that there are no bearings or rotors to wear, turbines to be deformed, electrodes to coat, or degradation of orifices to be concerned about. The manufacturer reports that “It has been our experience, and that of our customers, that Coriolis meters do not shift or lose their calibration during the life of the meter. When calibration issues arise, the focus of the problem is normally traceable to the flow meter installation or a characteristic of the process that was not previously taken into consideration.” As a result, there are no prevailing industry standard(s) for meter calibration for these meters. Core Energy observes trend data from the meters and has on occasion sent meters back to the company for recalibration but this does not occur routinely. Core Energy considers this approach to be consistent with EPA GHGRP’s Subpart RR, section 98.444(e)(3). These meters will be maintained, operated continually, and will feed data directly to the central HMI computer system. The meters meet the industry standard for meter accuracy and calibration frequency. The level of precision and accuracy for these meters currently satisfies the requirements for reporting in existing UIC permits.

### 9.2 Procedures for estimating missing data.

In the event Core Energy is not able to collect data for the mass balance equations, it will follow the requirements in 40 CFR part 98.445 to provide missing data.

When estimating the volume of missing CO<sub>2</sub> data due to an interruption in data collection or mechanical failure of a meter (equipment) is to use the most recent daily volume of CO<sub>2</sub>

associated with the meter and calculate the proportionate volume of “lost” CO<sub>2</sub> based on the number of hours involved in the data gap or until meter repaired.

### 9.3 MRV Plan Revisions

In the event there is a material change to the monitoring and/or operational parameters of the Core Energy CO<sub>2</sub> EOR operations that is not anticipated in this MRV plan, the MRV plan will be revised and submitted to the EPA Administrator within 180 days as required in §98.448(d).

## 10. Records Retention

Core Energy will maintain and submit records required under 40 CFR Part 98.3(g) and 40 CFR Part 98.447. Records will be maintained by Core Energy in electronic format at the Core Energy headquarters. In addition, Core Energy has well and facility data in three forms; A.) Paper copies (scanned to server), B.) Keyed in data from paper copies into database, and C.) Automated capture of limited set of data that was recently instrumented (Fall of 2016).

## 11. References

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# Appendix

## Appendix I: List of Wells

Table A-1. Core Energy Wells used for Monitoring and Accounting

Unit	Facility	API Permit	DEQ Permit	Well Name	Well Type	Well Status
<b>Dover 33 EOR Unit</b>	Dover 36 CPF	21-137-29565-00-00	29565	Lawnichak & Myszkiec 1-33	Injection	INJ
<b>Dover 33 EOR Unit</b>	Dover 36 CPF	21-137-00652-00-00	61209	Lawnichak 9-33	Oil	PR
<b>Dover 33 EOR Unit</b>	Dover 36 CPF	21-137-51603-00-00	51603	Lawnichak & Myszkiec 5-33 HD1	Oil	PR
<b>Dover 33 EOR Unit</b>	Dover 36 CPF	21-137-50985-04-00	55942	Lawnichak & Myszkiec 2-33 HD4	Oil	PR
<b>Bagley 11-14-23 EOR</b>	Dover 36 CPF	21-137-39758-01-00	39866	Wrubel 4-14A	Injection	INJ
<b>Bagley 11-14-23 EOR</b>	Dover 36 CPF	21-137-30536-00-00	30536	MBM 1-22	Injection	INJ
<b>Bagley 11-14-23 EOR</b>	Dover 36 CPF	21-137-38240-00-00	38240	Daughters of Friel 2-11	Injection	INJ
<b>Bagley 11-14-23 EOR</b>	Dover 36 CPF	21-137-37794-00-00	37794	Janik Mackowiac 1-11	Oil	OBS
<b>Bagley 11-14-23 EOR</b>	Dover 36 CPF	21-137-38286-00-00	38286	Janik Stevens 3-11	Oil	OBS
<b>Bagley 11-14-23 EOR</b>	Dover 36 CPF	21-137-39748-00-00	39748	Janik Strappazon 3-14	Oil	OBS
<b>Bagley 11-14-23 EOR</b>	Dover 36 CPF	21-137-38859-02-00	39897	Glasser 1-14B	Oil	OBS
<b>Charlton 19 Unit (EOR)</b>	Dover 36 CPF	21-137-42766-00-00	42766	El Mac Hills 2-18	Injection	INJ
<b>Charlton 19 Unit (EOR)</b>	Dover 36 CPF	21-137-40911-04-00	57261	El Mac Hills 1-19D	Oil	SI-P
<b>Charlton 19 Unit (EOR)</b>	Dover 36 CPF	21-137-41801-01-00	61197	El Mac Hills 1-18A	Oil	PR
<b>Charlton 30/31 EOR Unit</b>	Dover 36 CPF	21-137-30203-00-00	30203	State Charlton C2-30	Injection	INJ
<b>Charlton 30/31 EOR Unit</b>	Dover 36 CPF	21-137-59048-00-00	59048	State Charlton & Larsen 3-31	Injection	INJ
<b>Charlton 30/31 EOR Unit</b>	Dover 36 CPF	21-137-29989-00-00	29989	State Charlton 1-30A	Injection	INJ
<b>Charlton 30/31 EOR Unit</b>	Dover 36 CPF	21-137-57916-00-00	57916	State Charlton 4-30	Oil	PR
<b>Charlton 30/31 EOR Unit</b>	Dover 36 CPF	21-137-31287-00-00	31287	State Charlton 2-30	Oil	PR
<b>Charlton 6 EOR Unit</b>	Dover 36 CPF	21-137-35209-00-00	35209	Zeimet-Higgins & St Charlton 1-6	Injection	INJ
<b>Charlton 6 EOR Unit</b>	Dover 36 CPF	21-137-59086-00-00	59086	State Charlton & Boeve 2-6	Oil	PR
<b>Chester 2 EOR Unit</b>	Dover 36 CPF	21-137-29430-00-00	29430	Wolf, Carl 1A	Injection	INJ
<b>Chester 2 EOR Unit</b>	Dover 36 CPF	21-137-29958-01-00	29958	Wolf, Carl et al C1-HD1	Oil	PR

<b>Chester 2 EOR Unit</b>	Dover 36 CPF	21-137- 60596-01-00	60596	Cargas 3-2 HD2	Oil	PR
<b>Chester 5 EOR Unit</b>	Dover 36 CPF	21-137- 59237-00-00	59237	Borowiak 2-6	Injection	INJ
<b>Chester 5 EOR Unit</b>	Dover 36 CPF	21-137- 58926-00-00	58926	Butler 3-5	Injection	SI-I
<b>Chester 5 EOR Unit</b>	Dover 36 CPF	21-137- 29265-01-00	60833	Piasecki 1-7A	Oil	PR
<b>Dover 35 EOR Unit</b>	Dover 36 CPF	21-137- 29236-00-00	29236	Salling Hanson Trust 1-35	Injection	INJ
<b>Dover 35 EOR Unit</b>	Dover 36 CPF	21-137- 37324-01-00	59238	Pomarzynski et al 5-35A	Oil	SI-P
<b>Dover 35 EOR Unit</b>	Dover 36 CPF	21-137- 29947-01-00	29995	Salling Hanson Trust 4-35A	Oil	PR
<b>Dover 35 EOR Unit</b>	Dover 36 CPF	21-137- 57787-00-00	57787	Pomarzynski et al 6-35	Oil	PR
<b>Dover 36 EOR Unit</b>	Dover 36 CPF	21-137- 29348-00-00	29348	Kubacki State 3-35	Injection	INJ
<b>Dover 36 EOR Unit</b>	Dover 36 CPF	21-137- 29235-00-00	29235	Kubacki State 1-36	Injection	INJ
<b>Dover 36 EOR Unit</b>	Dover 36 CPF	21-137- 52719-00-00	52719	Dover State 36 Unit 3-36	Oil	PR
<b>Chester 16 EOR Unit</b>	Dover 36 CPF	21-137- 61189-00-00	61189	Chester 16 Unit 6-16 Pilot	Injection	INJ
<b>Chester 16 EOR Unit</b>	Dover 36 CPF	21-137- 61186-00-00	61186	Chester 16 Unit 8-16	Oil	OBS

Table A-2. Summary of Niagaran Wells by Reef With Listing of Depth, Completion Date, and Wireline Log Inventory used for Geologic Characterization

Source: [Michigan DEQ Oil and Gas Well Database](#)

Note: CAL=CALIPER; GR=GAMMA RAY; NPFI=NEUTRON POROSITY; RHOB=DENSITY; PE=PHOTOELECTRIC; SON=SONIC; RES=RESISTIVITY; CBL=CEMENT BOND LOG; CBIL= circumferential borehole image log (acoustic image log); NEUTRON= neutron log reported in neutron units; PNC=Pulsed Neutron Capture log.

(a) Indicates currently active (not plugged/abandoned) producing well.

(b) Indicates currently active (not plugged/abandoned) injection well.

(c) Deviated well; total depth amsl will be determined after acquiring deviation survey.

Reef	Well Permit No.	Well Name	Well No.	Total Depth, ft		Date Completed	Wireline Logs
				bgs	amsl		
Bagley	29074	Yule King Tree	1-15	6135	- 4815	1/14/1973	CAL,GR,NPFI,RHOB,RES
	29085	Alan Gornick	1-23	6177	- 4867	1/18/1973	CAL,GR,NPFI,RHOB
	29249	Alan Gornick	1-14	6165	- 4869	11/23/1973	CAL,GR,NPFI,RHOB
	30536 <sup>(a)</sup>	MBM	1-22	6013	- 4689	10/24/1975	CAL,GR,NPFI,RHOB,RES
	37794 <sup>(a)</sup>	Janik & Mackowiac	1-11	6326	- 5021	9/11/1984	CAL,GR,NPFI,RHOB,RES,PNC
	38240 <sup>(b)</sup>	Daughters of Friel	2-11	6250	- 4739	10/30/1984	CAL,GR,NPFI,RHOB,RES
	38286 <sup>(a)</sup>	Janik & Stevens	3-11	6045	- 4676	11/2/1984	CAL,GR,NPFI,RHOB,RES
	38859	Glasser	1-14A	6115	- 4811	3/2/1986	CAL,GR,NPFI,RES
	38923	Yule King Tree	1-14	6024	- 4725	10/17/1985	CAL,GR,NPFI,RES,PNC

Reef	Well Permit No.	Well Name	Well No.	Total Depth, ft		Date Completed	Wireline Logs
				bgs	amsl		
	39554	Stevens and State Bagley	1-22	6295	- 4975	1/13/1986	CAL,GR,NPHI,RHOB,RES
	39748 <sup>(a)</sup>	Janik & Strappazon	3-14	6000	- 4706	2/24/1986	CAL,GR,NPHI,RHOB,RES
	39758	Wrubel	4-14	6140	(c)	3/9/1986	CAL,GR,NPHI,RHOB,RES
	39850	Glasser	1-14A	6367	- 4839	3/12/1986	CAL,GR,NPHI,RHOB,RES
	39866 <sup>(a)</sup>	Wrubel	4-14A	6191	- 4822	4/21/1986	CAL,GR,NPHI,RHOB,RES
	39897 <sup>(a)</sup>	Glasser	1-14B	6130	- 4752	5/7/1986	CAL,GR,NPHI,RES,PNC
	55307	Stevens and State Bagley	1-22A	6270	- 4910	1/9/2003	CAL,GR,NPHI,RHOB,RES
Charlton 6	28895	Zeimet & Higgins	1-6	6008	- 4724	6/21/1972	CAL,GR,NPHI,RHOB,RES
	35209 <sup>(b)</sup>	Zeimet, Higgins & State Charlton	1-6	5975	- 4745	12/10/1981	CAL,GR,NPHI,RHOB,PE,RES
	59086 <sup>(a)</sup>	State Charlton & Boeve	2-6	6202	- 4796	6/19/2008	CAL,GR,NPHI,RHOB,RES,PE
Charlton 19	40911	El Mac Hills	1-19	5675	- 4552	3/9/1988	CAL,GR,NPHI,RHOB,RES,SON
	41801	El Mac Hills	1-18A	5466	- 4341	2/24/1989	CAL,GR,NPHI,RHOB,RES,PNC
	42766 <sup>(b)</sup>	El Mac Hills	2-18	5555	(c)	2/5/1990	CAL,GR,NPHI,RHOB,RES,PNC
	54416	El Mac Hills	1-19A	5433	- 4297	6/22/2001	Not Logged
	54582	El Mac Hills	1-19B	5421	(c)	6/27/2001	Not Logged
	54583	El Mac Hills	1-19C	5321	- 4246	7/1/2001	Not Logged
	57261 <sup>(a)</sup>	El Mac Hills	1-19D	5495	- 4335	12/21/2005	CAL,GR,NPHI,RHOB,RES,SON,PNC
Charlton 30-31	29073	Salling Hanson et al	1-31	5770	- 4645	1/9/1973	CAL,GR,NPHI,RHOB,SON,RES
	30195	State Charlton "C"	1-30	5679	- 4497	3/21/1975	CAL,GR,NPHI,RHOB,RES

Reef	Well Permit No.	Well Name	Well No.	Total Depth, ft		Date Completed	Wireline Logs
				bgs	amsl		
	32605	State Charlton "C"	3-30	5746	- 4563	12/16/1978	CAL,GR,NPHI,RHOB,RES
	29989 <sup>(b)</sup>	State Charlton	1-30A	5650	- 4582	12/24/1974	CAL,GR,NPHI,SON,RES
	30203 <sup>(b)</sup>	State Charlton "C"	2-30	6255	- 4588	4/22/1975	CAL,GR,NPHI,RHOB,RES
	31287 <sup>(a)</sup>	State Charlton	2-30	5660	- 4517	12/7/1976	CAL,GR,NPHI,SON,RES
	57916 <sup>(a)</sup>	State Charlton	4-30	5800	- 4599	11/30/2006	CAL,GR,NPHI,RHOB,PE,RES
	59048 <sup>(b)</sup>	State Charlton & Larsen	3-31	5800	- 4689	7/7/2008	CAL,GR,NPHI,RHOB,PE,RES
Chester 2	28459	Cargas, Perry J	1	6005	- 4762	10/4/1971	CAL,GR,NPHI,RHOB,SON,RES
	28706	Finnegan, Bernard et al	1	6051	- 4818	1/6/1972	CAL,GR,NPHI,RES
	29677	Wolf, Carl	1-B	5847	- 4568	6/27/1974	CAL,GR,NPHI,RHOB,RES
	31646	Cargas, Perry J	1-2A	5990	- 4745	9/9/1977	CAL,GR,NPHI,RHOB,RES
	29430 <sup>(b)</sup>	Wolf, Carl	1-A	5973	- 4710	12/2/1973	CAL,GR,NPHI,RHOB,RES
	29958 <sup>(a)</sup>	Wolf, Carl et al "C"	1	5806	- 4536	12/9/1974	CAL,GR,NPHI,RHOB,RES
	29958-01 <sup>(a)</sup>	Wolf, Carl et al "C"	1 HD1	6570	- 4509	10/9/2001	CAL,GR,CBL
	60596 <sup>(a)</sup>	Cargas, Perry J	3-2 HD-1	6962	- 4556	10/9/2012	CAL,GR,NPHI,RHOB,RES,SON,PNC
Chester 5-6	29067	Borowiak	1-6	6022	- 4673	1/11/1973	CAL,GR,NPHI,SON,RES
	29234	Borowiak	1-5	5725	- 4409	4/13/1973	CAL,GR,NPHI,SON,RES
	29254	Kosiara	2-7	5750	- 4398	5/24/1973	CAL,GR,SON,RES
	29265	Piasecki	1-7	5770	- 4416	5/4/1973	CAL,GR,NPHI,SON,RES,PNC



Reef	Well Permit No.	Well Name	Well No.	Total Depth, ft		Date Completed	Wireline Logs
				bgs	amsl		
	31515	Piasecki, John State Chester	1-7	5800	- 4462	6/1/1977	CAL,GR,NPHI,RHOB,RES
	32207	Kosiara, Josephine	2-7A	5881	(c)	3/20/1978	CAL,GR,NPHI,RHOB,RES
	38424	Gottloeb	1-8	6080	(c)	11/21/1984	CAL,GR,NPHI,RHOB,PE,RES
	40169	Nienaber	2-5	5985	- 4633	12/16/1986	CAL,GR,NPHI,RHOB,PE,RES
	58926 <sup>(b)</sup>	Butler	3-5	5897	- 4585	5/1/2008	CAL,GR,NPHI,RHOB,RES,CBIL,CRA
	59237 <sup>(b)</sup>	Borowiak	2-6	6100	- 4751	7/25/2008	CAL,GR,NPHI,RHOB,PE,RES,CBIL,CBL
Chester 16	28159	Gaylord Mortgage	1-16	6210	- 4873	1/4/1971	CAL,GR,NPHI,RHOB,RES,SNP
	28433	Veraghen, Martin G	4-21	6303	- 4972	8/13/1971	CAL,GR,NPHI,RHOB,RES,SNP,SON
	28511	Gaylord Mortgage	2-16	6250	- 4907	9/4/1971	CAL,GR,NPHI,RES,SNP,SON
	28743	Veraghen & Rypkowski	5-21	6350	- 5037	3/29/1972	CAL,GR,NPHI,RES,SNP,SON
	28796	Gaylord Mortgage	3-16	6222	- 4896	8/22/1972	CAL,GR,NPHI,RES,SNP
	28798	Dreffi	4-16	6265	- 4913	3/13/1972	RES,SNP, SON
	28918	Veraghen & Dreffi	6-21	6318	- 4995	7/20/1972	CAL,GR,RES,SNP,SON
	61186	Chester	8-16	6455	- 5020	2/26/2017	CAL,GR,NPHI,RES,RHOB,SON
	61189***	Chester	6-16	6697	- 5061	12/23/2016	CAL,GR,NPHI,RES,RHOB,SON,PNC
Dover 33	29565 <sup>(b)</sup>	Lawnichak & Myszkier	1-33	5675	- 4528	5/20/1974	CAL,GR,NPHI,RES,RHOB,SON,PNC
	29781	Lawnichak & Myszkier	3-33	5625	- 4404	8/16/1974	CAL,GR,NPHI,RES
	29809	Koblinski & Fisher	1-28	5514	- 4397	8/22/1974	CAL,GR,NPHI,RES,SNP

Reef	Well Permit No.	Well Name	Well No.	Total Depth, ft		Date Completed	Wireline Logs
				bgs	amsl		
	29840	Kirt House	2-28	5475	- 4290	8/7/1974	CAL,GR,NPHI,RES,SON
	30392	Winter	2-33	5840	- 4560	8/9/1975	CAL,GR,NPHI,RES,SON
	31108	Amejka	2-34	5886	- 4657	9/5/1976	CAL,GR,NPHI,SON
	31228	Boughner State Dover	3-28	5520	- 4401	7/23/1977	CAL,GR,NPHI,SON
	31303	Thompson	1-33	5690	- 4540	11/22/1976	CAL,GR,NPHI,RES,RHOB
	32298	Boughner State Dover	4-28	5505	(c)	7/7/1978	CAL,GR,NPHI
	33830	Lawnichak & Myszkier	5-33	5775	- 4565	7/28/1980	CAL,GR,NPHI,RES,SON
	33937	Lawnichak & Myszkier	5-33A	5746	- 4536	8/4/1980	CAL,GR,NPHI,RES,SON
	35195	Winter	1-33	5740	- 4457	12/31/1982	CAL,GR,NPHI,RES,RHOB
	35584	Lawnichak & Morey	1-33	5703	- 4539	8/24/1982	CAL,GR,NPHI,RHOB
	50985	Lawnichak & Myszkier	2-33	5763	- 4597	11/22/1996	CAL,GR,NPHI,RHOB,PNC
	51601	Lawnichak & Myszkier	2-33 HD1	6990	- 4315	12/30/1996	CAL,GR,TDT
	51603	Lawnichak & Myszkier	5-33 HD1	6456	- 4354	2/2/1997	CAL,GR,PNC
	55479	Lawnichak & Myszkier	2-33 HD2	6138	(c)	8/21/2003	Not Logged
	55845	Lawnichak & Myszkier	2-33 HD3	7335	- 4368	9/23/2003	Not Logged
	55942	Lawnichak & Myszkier	2-33 HD4	7134	- 4348	12/29/2003	Not Logged
	61209	Lawnichak	9-33	6085	- 4677	12/3/2016	CAL,GR,NPHI,RES,RHOB,SON
□ ○ ☹	29374	Pomerzynski	2-35	5760	- 4619	9/27/1973	CAL,GR,NPHI,SON,RES

Reef	Well Permit No.	Well Name	Well No.	Total Depth, ft		Date Completed	Wireline Logs
				bgs	amsl		
	29947	Salling Hanson Trust	4-35	5564	- 4450	10/18/1974	CAL,GR,SON
	35941	Tinsey	1-35	5792	(c)	8/23/1982	CAL,GR,NPHI,RHOB,PE,RES
	37324	Pomerzynski et al	5-35	5715	- 4575	12/22/1983	CAL,GR,NPHI,RHOB,PE,RES
	37381	Taskey & Saddler Estate	1-35	5768	- 4615	2/14/1984	CAL,GR,NPHI,RHOB,RES
	29236 <sup>(b)</sup>	Salling & Hanson	1-35	5780	- 4656	5/25/1973	CAL,GR,NPHI,SON,RES
	29995 <sup>(b)</sup>	Salling Hanson Trust	4-35A	5715	- 4504	11/4/1974	CAL,GR,NPHI,SON,RES
	57787 <sup>(a)</sup>	"Pomarzynski"	6-35	5950	- 4688	11/30/2006	CAL,GR,NPHI,RHOB,PE,RES
	(59238) <sup>(a)</sup>	"Pomarzynski"	5-35A	5864	- 4437	8/24/2008	CAL,GR,NPHI
Dover 36	29303	Kubacki Cole	2-36	5765	- 4592	6/14/1973	CAL,GR,NPHI,SON,RES
	29664	Freese, Charles E III et al	1-2	5830	- 4614	4/8/1974	CAL,GR,NPHI,SON,RES
	29235 <sup>(b)</sup>	Kubacki & State Dover	1-36	5835	- 4683	4/29/1973	CAL,GR,NPHI,SON,RES
	29348 <sup>(b)</sup>	Kubacki State	3-35	6431	(c)	7/6/1973	CAL,GR,NPHI,SON,RES
	52719 <sup>(a)</sup>	Dover 36 Unit	3-36	5700	- 4533	7/31/1998	CAL,GR,NPHI,RHOB,PE,RES

Source: [Michigan DEQ Oil and Gas Well Database](#)

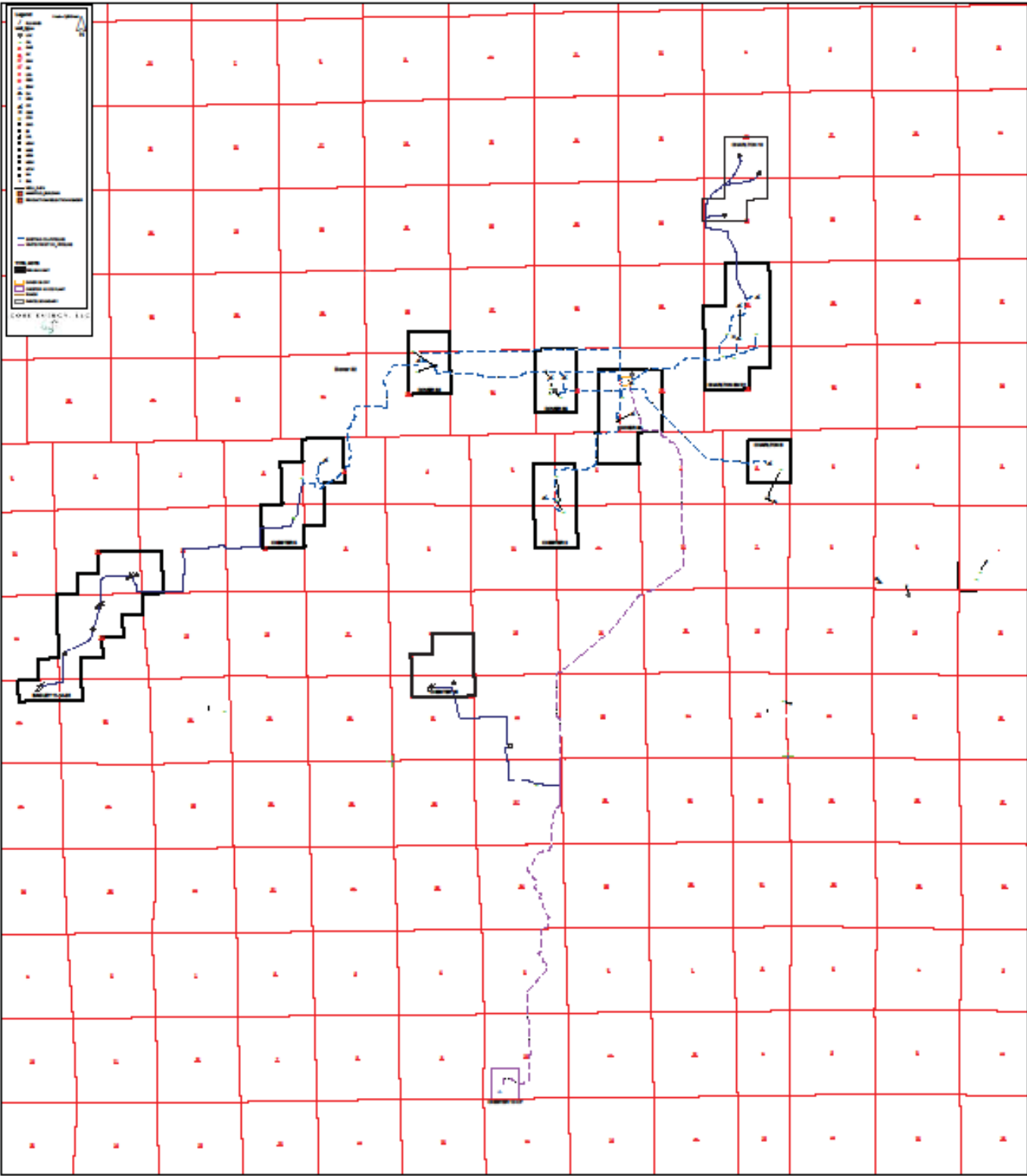
Note: CAL=CALIPER; GR=GAMMA RAY; NPHI=NEUTRON POROSITY; RHOB=DENSITY; PE=PHOTOELECTRIC; SON=SONIC; RES=RESISTIVITY; CBL=CEMENT BOND LOG; CBIL= circumferential borehole image log (acoustic image log); NEUTRON= neutron log reported in neutron units; PNC=Pulsed Neutron Capture log.

(a) Indicates currently active (not plugged/abandoned) producing well.

(b) Indicates currently active (not plugged/abandoned) injection well.

(c) Deviated well; total depth amsl will be determined after acquiring deviation survey.

Appendix II: Map of Core Energy pipelines



**Request for Additional Information: Core Energy Subpart RR MRV Plan  
September 25, 2018**

Instructions: Please enter responses into this table. Any long responses, references, or supplemental information may be attached to the end of the table as an appendix. Supplemental information may also be provided in a resubmitted MRV plan.

No.	MRV Plan		EPA Questions	Responses
	Section	Page		
1.	2.2	17, 19	<p>MRV plan: [pg 17] Core Energy typically initiates CO<sub>2</sub> EOR in reefs that have undergone primary and often secondary production and then “blown down” in preparation for closure. The typical average reservoir pressure is well below 500 psi in these reefs after blow down and there is significant voided pore space.</p> <p>[pg 19] When <u>EOR CO<sub>2</sub></u> operations in a reef end, Core Energy typically recovers as much CO<sub>2</sub> as it can by producing fluids back through a CPF until such a time as the reservoir pressure has been reduced to a level whereby the wells can no longer flow (approximately 500 psi).</p> <ul style="list-style-type: none"> <li>• The language on page 17 referring to “blow down” perhaps should reflect the corrected language on page 19 so that it is consistent and not confused with venting natural gas or CO<sub>2</sub> to the atmosphere.</li> <li>• For the text that is underlined, it should perhaps read “CO<sub>2</sub> EOR” for consistency with the rest of the document.</li> </ul>	The text has been amended for consistency in both places.
2.	4.1	33	<p>MRV plan: <u>MRCSP’s a systematic wellbore integrity evaluation in seven fields in the Michigan Basin which were actively being used for CO<sub>2</sub> EOR also included cement plugs.</u></p> <p>The first part of this sentence is incomplete.</p>	The typo has been corrected so that complete sentence is now included.

No.	MRV Plan		EPA Questions	Responses
	Section	Page		
3.	7.0	44	<p>MRV plan: To account for the site conditions and complexity Core Energy proposes the following modifications for using the equations in Subpart RR §98.443.</p> <p>This text may be left over from an older MRV Plan version.</p>	In the final plan, Core Energy did not modify the formulas and removed this reference.
4.	7.3	44	Does the facility have an estimate for the amount of entrained CO <sub>2</sub> in produced oil as a decimal fraction?	The decimal fraction has been included in the site description and will be used in the mass balance equations as required in 40 CFR part 98.
5.	7.5	47-48	<p>MRV plan: CO<sub>2</sub>I = Total annual CO<sub>2</sub> mass injected (metric tons) in the well or group of wells covered by this source category in the reporting year. CO<sub>2</sub>P = Total annual CO<sub>2</sub> mass produced (metric tons) net <u>of</u> CO<sub>2</sub> entrained in oil in the reporting year.</p> <p>CO<sub>2</sub>E = Total annual CO<sub>2</sub> mass emitted (metric tons) by surface leakage in the reporting year. CO<sub>2</sub>FI = Total annual CO<sub>2</sub> mass emitted (metric tons) from equipment leaks and vented emissions of CO<sub>2</sub> from equipment located on the surface, between the Equation RR-10 Equation RR-11 flow meter used to measure injection quantity and the injection wellhead in the reporting year, calculated as provided in subpart W.</p> <ol style="list-style-type: none"> <li>Can the CO<sub>2</sub>P and CO<sub>2</sub>FI definitions be listed separately for clarity? As is, they are lumped with other definitions. It appears that a hard return was deleted or lost in the conversion to the pdf.</li> <li>A small typo is underlined.</li> </ol>	The line spacing was a typo that has been corrected and the small typo has been corrected.

**Core Energy**

**Northern Niagaran Pinnacle Reef Trend (NNPRT)  
CO<sub>2</sub> Monitoring, Reporting, and Verification (MRV) Plan**

September, 2018



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## Introduction

Core Energy LLC (Core Energy) operates an integrated carbon dioxide (CO<sub>2</sub>) capture and enhanced oil recovery (EOR) facility in the Northern Niagaran Pinnacle Reef Trend (NNPRT) in Michigan. The Core Energy facility includes equipment to capture CO<sub>2</sub> from various sources, dedicated pipelines, a set of subsurface geologic reef formations, and equipment to process oil.

Core Energy joined the Midwest Regional Carbon Sequestration Partnership (MRCSP) in 2005 and has worked closely with the research team to advance the technical understanding of the reefs and the regional geology in the context of ongoing EOR operations. This research demonstrates that CO<sub>2</sub>-EOR results in incidental CO<sub>2</sub> storage in the reefs at the end of the CO<sub>2</sub>-EOR life cycle. Core Energy intends to inject CO<sub>2</sub> with a secondary purpose of establishing long-term containment of a measurable quantity of CO<sub>2</sub> in subsurface geological formations in the NNPRT for a term referred to as the "Specified Period."

The MRCSP regional geologic characterization indicates that there is potential capacity for hundreds of millions tonnes of CO<sub>2</sub> through ancillary CO<sub>2</sub> EOR storage in the NNPRT. This potential far exceeds the amount of CO<sub>2</sub> available for EOR and, ultimately, ancillary storage capacity. This means that Core Energy anticipates being limited by the amount of available CO<sub>2</sub> in the future rather than by the amount of economically viable CO<sub>2</sub> EOR opportunity. In addition, the nature of the reef geology, as described in Section 2, provides operational flexibility that is much like buffer storage capacity. As a result, Core Energy anticipates continuing its business practice of capturing as much CO<sub>2</sub> as it can while the Antrim Shale play is still active and storing it within the reef system to support its EOR operations. Since it began operations, Core Energy has developed an inventory of anthropogenic CO<sub>2</sub> that is in circulation within the existing reef structures. Calculation of this inventory of working CO<sub>2</sub> is discussed further in Section 2.

During the Specified Period, Core Energy will utilize the working inventory of CO<sub>2</sub> through capture at the Dover 36 Facility and combine it with new CO<sub>2</sub> captured through the Chester 10 Facility. Over time, the mass balance calculation of stored CO<sub>2</sub> will reflect the existing inventory of CO<sub>2</sub> plus the new CO<sub>2</sub>, as discussed in Sections 2, 5, and 7. Core Energy plans to further expand the amount of CO<sub>2</sub> introduced to the field if new sources become available. This additional amount would also be reflected in the mass balance calculation of stored CO<sub>2</sub>.

Core Energy developed this monitoring, reporting, and verification (MRV) plan in accordance with 40 CFR §98.440-449 (Subpart RR) to provide for the monitoring, reporting and verification of the quantity of CO<sub>2</sub> sequestered at the Core Energy facility during the Specified Period. This plan describes how CO<sub>2</sub> EOR and ancillary storage take place in the reefs and how Core Energy will apply the requirements in 40 CFR §98.440-449 (Subpart RR) to calculate the annual amount of CO<sub>2</sub> stored throughout the entire Core Energy CO<sub>2</sub> EOR facility

In accordance with Subpart RR, flow meters are used to quantify the mass of CO<sub>2</sub> received, injected, produced, contained in products, and lost through venting or leakage. If leakage is detected, the mass of leaked CO<sub>2</sub> will be quantified using three approaches. First, Core Energy follows the procedures in 40 CFR §98.230-238 (Subpart W) to quantify fugitive emissions, planned and unplanned releases of CO<sub>2</sub>, and other surface releases from equipment. Second,

Core uses orifice type flow meters installed at its Wet and Dry Vent locations to measure the mass of recycle gas that is vented. And finally, Core Energy's risk-based monitoring program uses surveillance techniques in the subsurface and above ground to detect CO<sub>2</sub> leaks from potential subsurface leakage pathways. The CO<sub>2</sub> mass data, including CO<sub>2</sub> mass at different points in the injection and production process, equipment leaks, and surface leaks, will be used in the mass balance equations included in 40 CFR §98.440-449 (Subpart RR) to calculate the mass of CO<sub>2</sub> stored on an annual and cumulative basis.

**This MRV plan contains 12 sections:**

- Section 1 contains general facility information.
- Section 2 presents the project description. This section describes the geologic setting, reservoir modeling of the reefs, the operational history in the area, and the Core Energy facility operations.
- Section 3 describes the monitoring area for the Core Energy facility.
- Section 4 presents the evaluation of potential pathways for CO<sub>2</sub> leakage to the surface and demonstrates that the potential for leakage through pathways other than the man-made well bores and surface equipment is minimal.
- Section 5 describes Core Energy's risk-based monitoring process.
- Section 6 describes the baselines against which monitoring results will be compared to assess whether changes indicate potential leaks.
- Section 7 describes Core Energy's approach to determining the mass of CO<sub>2</sub> stored using the mass balance equations in 40 CFR §98.440-449, Subpart RR of the Environmental Protection Agency's (EPA) Greenhouse Gas Reporting Program (GHGRP).
- Section 8 presents the schedule for implementing the MRV plan.
- Section 9 describes the quality assurance program to ensure data integrity.
- Section 10 describes Core Energy's record retention program.
- Section 11 contains References.
- Section 12 contains Appendices.

**Technical Notes:**

1. Unless otherwise stated, this document uses the term "tonnes" to indicate metric tons (MT).

2. All calculations and reporting will be done on a metric ton basis (1000 kgs to 1 MT). Anytime CO<sub>2</sub> numbers are reported on a volume basis, Core Energy will utilize a conversion factor of 0.019 million cubic feet (MMCF), or 19,000 cubic feet, of CO<sub>2</sub> per metric ton of CO<sub>2</sub>. This translates to approximate conversion between weight basis to volume basis of CO<sub>2</sub> at 60° F, 1 atm (~1.87 kg/m<sup>3</sup> density).

**1. Facility Information**

- i) Reporter number – 545462
- ii) US Environmental Protection Agency (USEPA) (Region V) administers the Underground Injection Control (UIC) program for all classes of injection wells in Michigan. The Michigan Department of Environmental Quality (MDEQ) Oil, Gas and Minerals Division (OGMD) administers the statutes and rules subject to Part 615, Supervisor of Wells, of the Natural Resources and Environmental Protection Act, 1994, PA 451, as amended (NREPA). The injection wells operated by Core Energy are permitted as UIC Class II wells by US EPA and all wells (including production, injection and monitoring wells) are regulated by OGMD.
- iii) As of April 2018, there are 36 active wells penetrating the Niagaran reefs operated by Core Energy and there are additional wells that have been plugged and abandoned. A summary of these wells is included in Appendix I. Table A-1 indicates the active wells and includes the unit (reef), processing facility, API and MDEQ permit numbers, well name, depth and status. Table A-2 lists all wells that penetrate the reefs and includes reef, permit number, well name, well number, completion depth and date, type, and a wireline log inventory. Changes to the well inventory will be included in annual reporting.

**2. Project Description**

Core Energy operates in the upper north portion of Michigan in what is known as the NNPRT. (Figure 1).

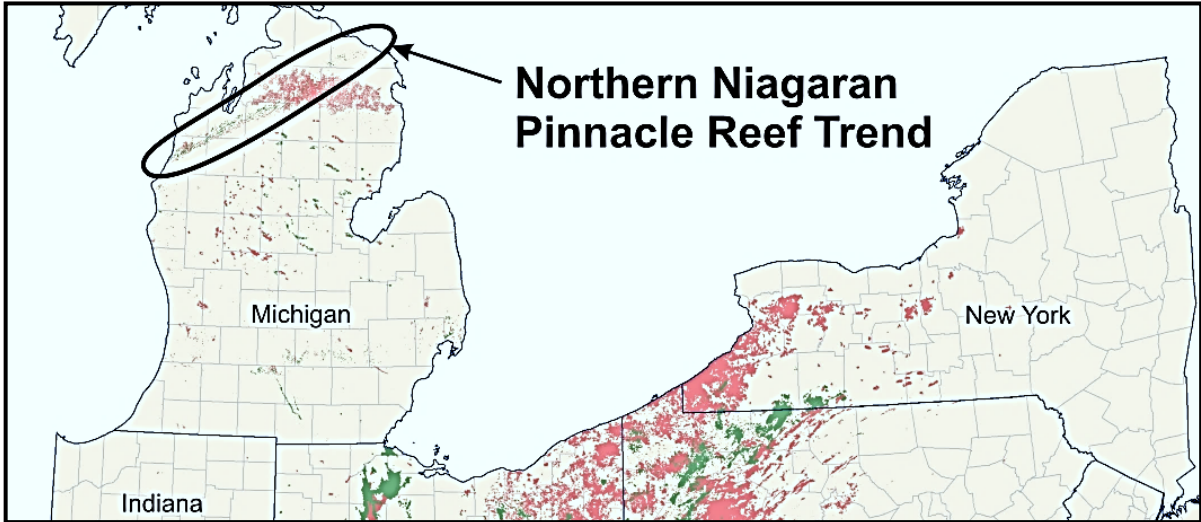


Figure 1 - General location of Core Energy operations

The NNPRT consists of closely spaced but highly-compartmentalized pinnacle reefs located, on average, about 6,000 feet below the ground surface (bgs) but can range from 3,000 to 8,000 feet (Most of the oil- and gas-producing reefs along the NNPRT are at depths of approximately 3500 to 5500 feet). This formation began as a series of coral reefs that formed millions of years ago in a setting similar to what we now observe in the Bahamas or Great Barrier Reef.

Since the reefs formed, sediments and other debris were deposited in layers around and above the reefs, forming hard structures that are excellent for containing the oil and gas that collected in them when the ocean receded and the corals died. It is estimated that in northern Michigan alone, such reefs could sequester several hundred million tonnes of CO<sub>2</sub>.

Data was compiled for all reefs including data from ten cores and covering five Core Energy reefs: Bagley, Chester 16, Dover 33, Chester 2 and Chester 5. Core analyses included descriptions, photographs, porosity and permeability measurements, and advanced analyses in select cores. More than 40 additional Niagaran cores were collected in Otsego County with data available at the Michigan Geologic Repository for Research and Education (MGRRE).

Core Energy also collected 3D seismic data for nine reefs: Chester 16, Dover 33, Dover 35, Dover 36, Chester 2, Chester 5, Charlton 19, Charlton 30/31, and Charlton 6 (Figure 2). The data was used to identify the boundary of the reef edges and verify that there are no structural concerns in the area. Where 3D seismic data is not available, formation tops, thicknesses, and production are used along with nearby reefs to define the boundaries.

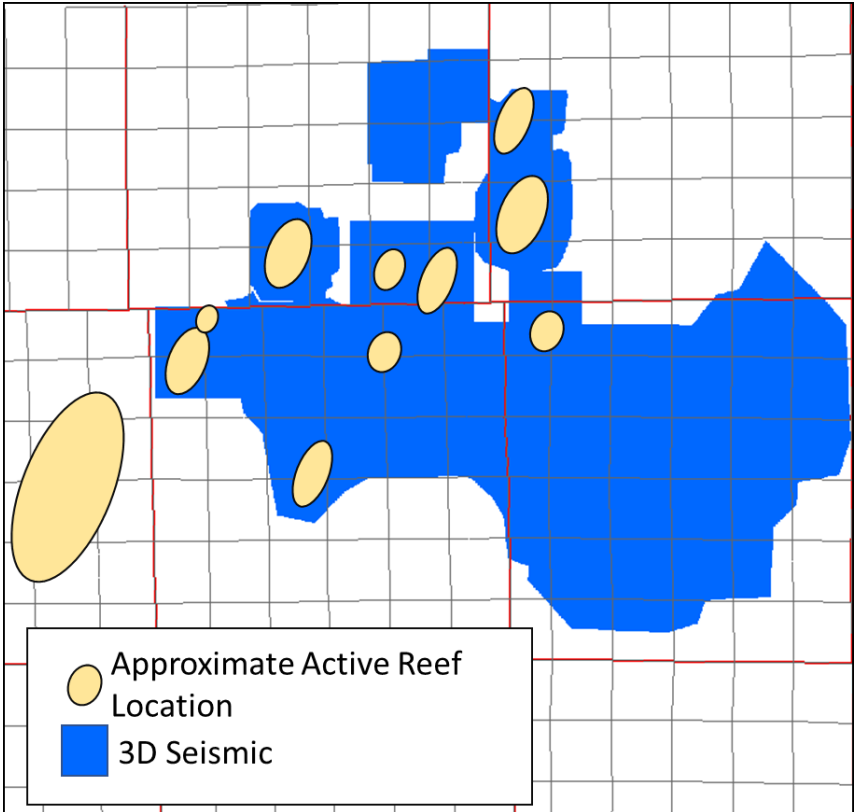
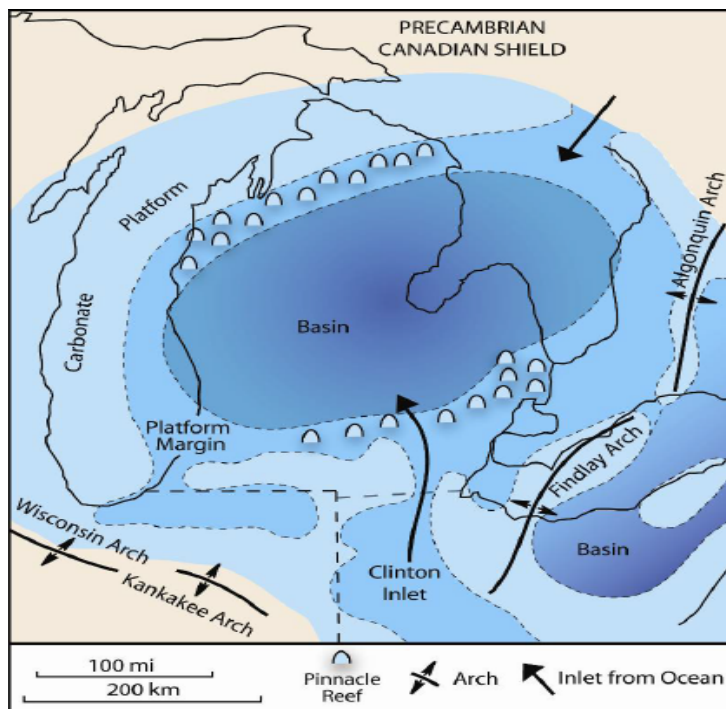


Figure 2: Map of approximate active reef locations (yellow) and 3D seismic (blue).

## 2.1 Geologic Setting

The NNPRT is part of an extensive paleo shallow shelf carbonate depositional system. The trend of pinnacle reefs forms a circular belt along the platform margin that rings the Michigan Basin (Figure 3). Most of the oil- and gas-producing reefs along the NNPRT are at depths of approximately 3500 to 5500 feet. While individual reef complexes are localized (averaging 50 to 400 acres in area), they may be up to 2000 acres in areal extent and 150 to 700 feet in vertical relief with the steeply dipping flanks. Reef height, pay thickness, burial depth, and reservoir pressure increase towards the basin center (Gill 1979). Currently, there are approximately 800 fields in the NNPRT and approximately 400 in the Southern Niagaran Pinnacle Reef Trend (SNPRT) of the Michigan Basin.

The NNPRT is generally divided in an updip direction into gas, oil, and water-saturated zones (Gill 1979). The reservoir facies primarily consist of porous and permeable dolomite and limestone. Some reefs are completely dolomitized, while others are essentially all limestone. Dolomitization of reefs increases as the reefs become shallower, and salt and anhydrite plugging of porosity occurs in the deeper reefs (Gill 1979). Effective porosity intervals for the reservoir range from only a few feet to several hundred feet from reef to reef. Porosity values extend to 35%, but typically average 3-12%; the best porosity and permeability are associated with dolomitized reef core and flank facies. The best reservoir rocks are characterized by well-developed inter-crystalline and vuggy porosity with average permeability values of 3 to 10 millidarcies. Secondary porosity can significantly enhance permeability within the reservoir.

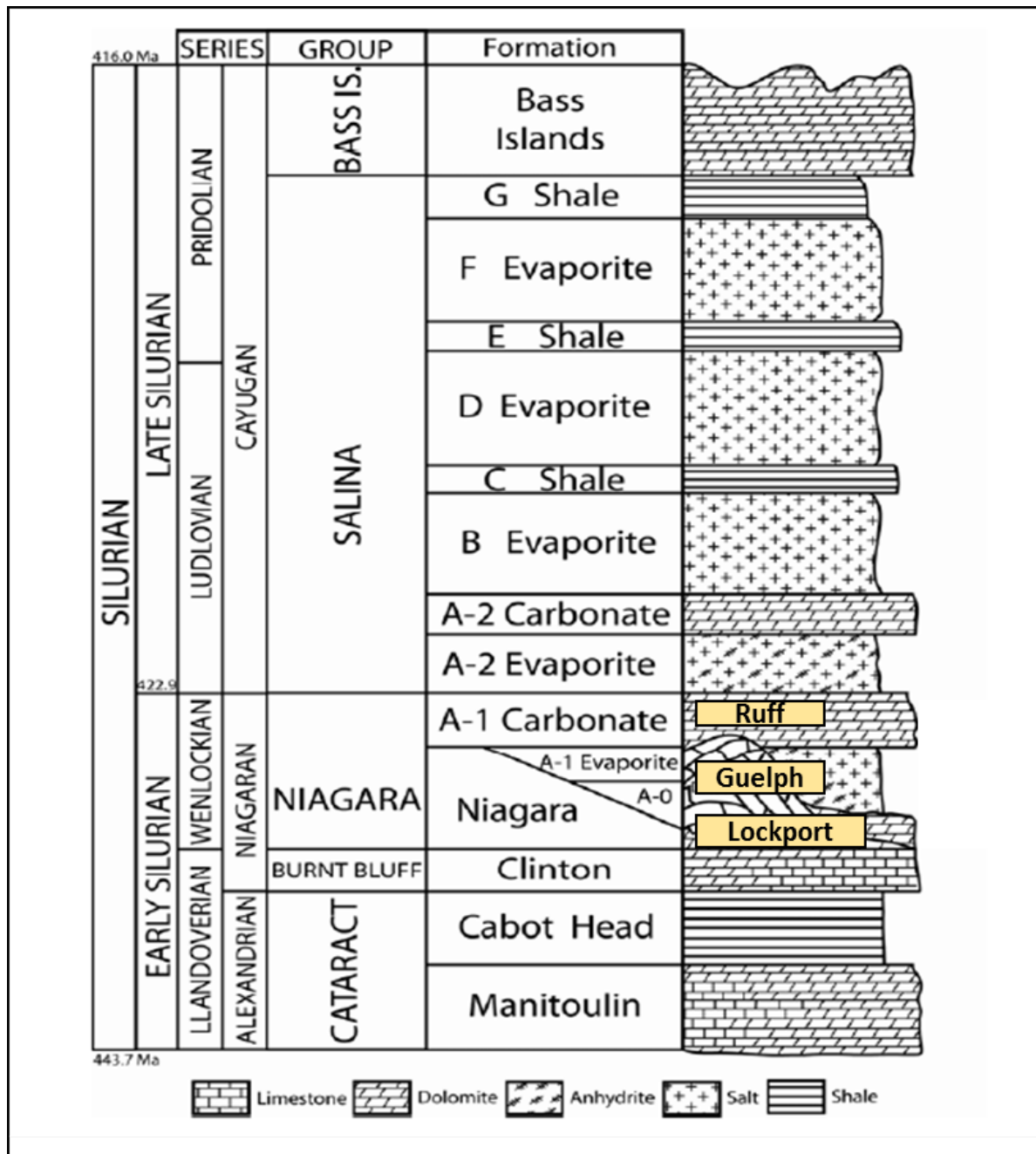


Ritter (2008), modified from Briggs and Briggs (1974)

Figure 3: Carbonate platform and Basin setting during NNPRT development in Michigan.



The reef facies developed within the Niagara Group and includes the Lockport and Guelph lithostratigraphic formations (Figure 4). The Lockport Formation is characterized by two types of crinoidal wackestones: dolomitized and low-porosity, undolomitized (Charbonneau 1990). The Lockport reaches a thickness of approximately 500 feet near the basin margins, but thins and has a more reddish color toward the center of the Basin (Huh 1973; Huh et al. 1977; Charbonneau 1990). The Lockport is frequently referred to as the “White Niagaran” but grades upward into a gray argillaceous, nodular crinoidal wackestone. The Guelph Formation contains the informal “Gray Niagaran” and the “Brown Niagaran”. The Guelph “Brown Niagaran” consists of skeletal wackestones, packstones, grainstones, and boundstones/bindstones associated with the carbonate pinnacle reef buildups. It includes thin off-reef carbonate detrital/conglomerate lithofacies below the A-0 carbonate (Huh 1973). The Guelph Formation forms the core of the reservoir rocks associated with producing reefs.



Ritter (2008), modified from Cercone (1984).

Figure 4. Generalized Stratigraphic Column for the Silurian Section noting Niagaran reefs.

The seals for the Niagaran reefs consist of a series of evaporites and salt-plugged carbonates that encase the flanks of the reefs and form regional seals over the entire reef complex (see Figure 4). The A-1 and A-2 evaporites regionally transition from salt off the reefs to anhydrites over the tops of the reef. The A-1 evaporite generally thins or is not present over the tops of the reef but forms restricted seals along the flanks of the reefs. MRCSP studied five representative reefs in detail: Chester 16, Dover 33, Charlton 19, Bagley 11-14-23, and Chester 2. This study included acquiring a full suite of density and acoustic logs in order to characterize the rapid changes in the composition of the evaporites surrounding the reef flanks. These data enabled

the MRCSP to understand and map reservoir porosity, seal integrity, and seismic response and are discussed below.

The A-1 carbonate belongs to the Ruff Formation and overlies the A-1 evaporite. It is a light-brown to tan, fine to medium crystalline, laminated, dolomitic mudstone and stromatolitic or microbial laminated boundstones, which may show truncation surfaces and rip-up clasts (Huh 1973; Gill 1973; Ritter 2008). Laminated, dolomitic mudstones occur in inter-reef deposits and on the reef; dolomitic microbial boundstone facies unconformably overlie the Brown Niagaran skeletal deposits (Gill 1973). The A-1 carbonate generally seals the flanks of the reefs, but some reservoir zones within the carbonate can be developed on the crests of the reefs.

Figure 5 illustrates the internal structure and geometry of reefs as well as their development cycle. This knowledge is important for predicting areas of best reservoir within the reef. The building of a Niagaran reef was initiated by carbonate mud-rich bioherm accumulation in warm, calm, shallow waters. The bioherm grew as sea level rose, following the prime conditions where biohermal organisms thrive (Stage 1). As sea level continued to rise, the reef core developed, dominated by corals and stromatoporoids. The wind direction during time of reef building was important because it created asymmetry within the reef (Rine 2015). The windward direction developed reef rubble where pieces of the reef core broke off and reduced in size by wave water impact. The leeward side developed a muddy detrital grain apron as fine-grained material sloughed off the reef. (Stage 2). When relative sea level stabilized, stromatolitic algal caps formed over top of the reef and created an intertidal, depositional environment. Next, as sea level fell within the Michigan Basin, the reef complex was exposed (Stage 3), and the living reef was killed. Evaporites such as salt and anhydrites were deposited along the flanks of the reefs and diagenesis occurred within the reef core. As post-Niagaran sea level rose and fell, layers of carbonates and evaporites were deposited over the reef complex (Stage 4).

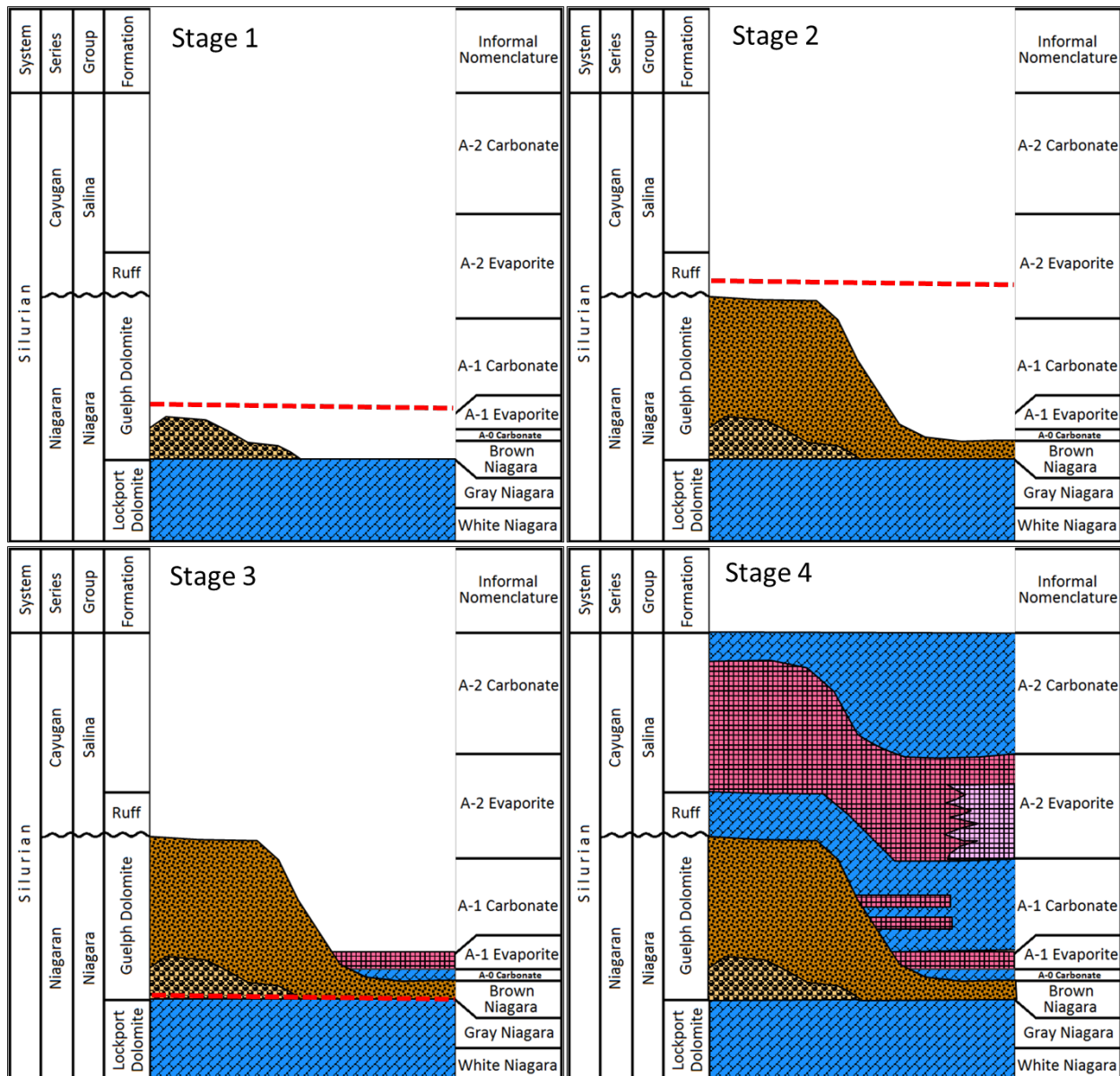


Figure 5: Simplified diagrams of the stages of Niagaran reef development. Red dashed line denotes approximate sea level relative to reef growth.

## 2.2 Reef Reservoir Characterization and Modeling

This subsection of the MRV plan describes the modeling that was developed to characterize the NNPRT reefs operated by Core Energy, Core Energy's understanding of the behavior of EOR operations in the reefs as indicated by the models, and the procedures going forward to use and or expand the modeling to determine which new reefs to include in operations as well as the operations plans for those reefs.

Core Energy worked with MRCSP to model six representative reef reservoirs. The key objectives of this modeling were to develop a detailed understanding of each modeled reef as well as the predictability of internal reef architecture. The modeling was successful in achieving both aims. Going forward, Core Energy does not plan to develop detailed models for each new

reef but will draw on a set of transferable principles from existing modeling that can be applied in operations and improving CO<sub>2</sub> flood performance.

2.2.1 Model Development

MRCSP used Static Earth Models (SEMs) to integrate all available geologic and geophysical information into a single framework used to conceptualize CO<sub>2</sub> migration and retention in the subsurface (Figure 6). The SEMs also provide the basis for incorporating geologic information into dynamic models for the reservoirs. The building of SEMs was an iterative process with multiple stages of quality checks to develop an SEM most representative of geology and reservoir properties. To build SEMS and dynamic models, the following information was integrated by geologists and engineers:

- Reef geometry (seismic and/or production), well locations and construction, formation depth and thickness, and delineation of lithofacies
- Rock properties including porosity, permeability, and fluid saturations from core and wireline log data
- Fluid flow such as density and viscosity of fluids, relative permeability, capillary pressure, and fluid phase

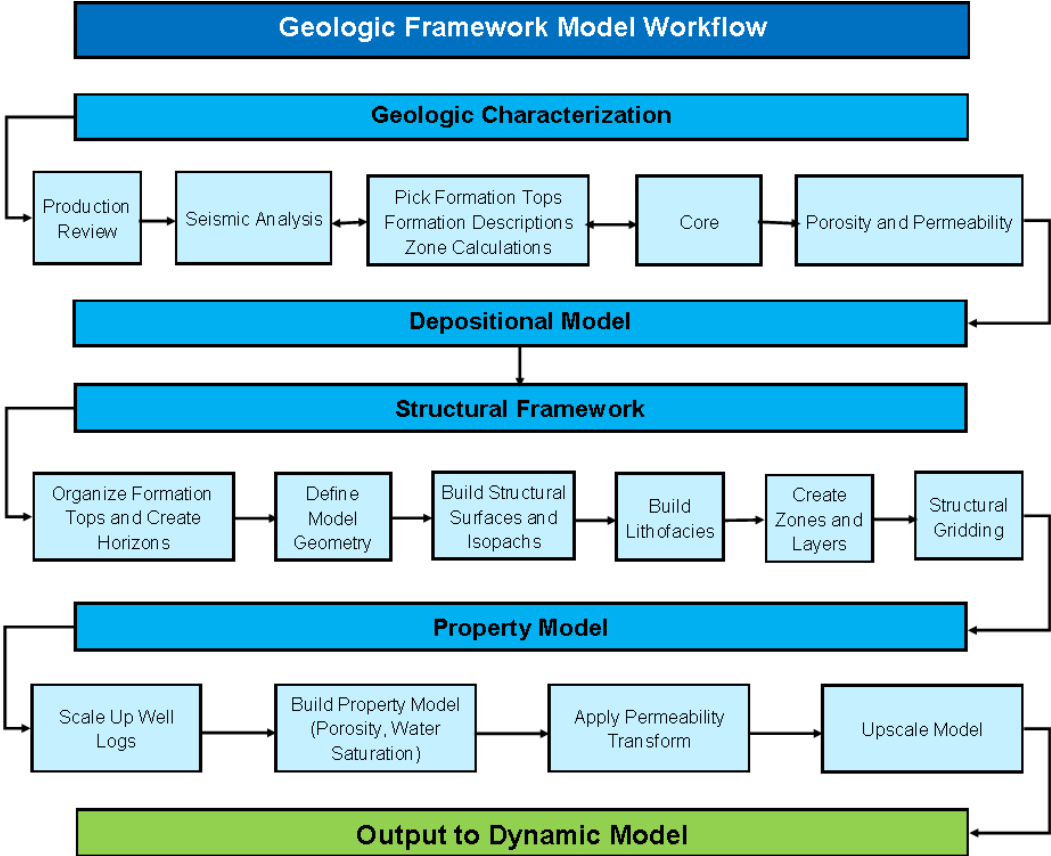


Figure 6: Typical geologic characterization and modeling workflow for reefs.



The modeling workflow began with geologic characterization of a reef which incorporated and integrated all information and data to develop a conceptual/depositional model. Figure 7 illustrates a 2D cross section through one such reef (Chester 16) with formations and reservoir flags. SEMs were then constructed using a conceptual geologic model, which allows for predictability of both vertical and horizontal lithofacies distributions by use of whole core and wireline log data. Figure 8 is an example 2D slice through a 3D SEM of Chester 16 (A) and Dover 33 (B) showing porosity distributions. Once SEMs were complete, they were outputted for dynamic modeling.

Dynamic modeling was used to history match with production records, simulate fluid flow and pressure changes, and assist with well design and CO<sub>2</sub>-EOR flood configuration design.

Basic geologic characterization is used to define the reef, describe formations, and identify reservoir and caprocks. Advanced geologic characterization and modeling are typically used to aid in planning or when a reef does not perform as expected. While Core Energy does not do the same level of characterization and modeling for each reef, lessons learned from advanced modeling show the predictability of internal reef architecture. Core Energy combines the knowledge gained from modeling regarding CO<sub>2</sub> flows within reef architecture along with the feedback from material balance and pressure monitoring and response to develop operational plans for CO<sub>2</sub> EOR.

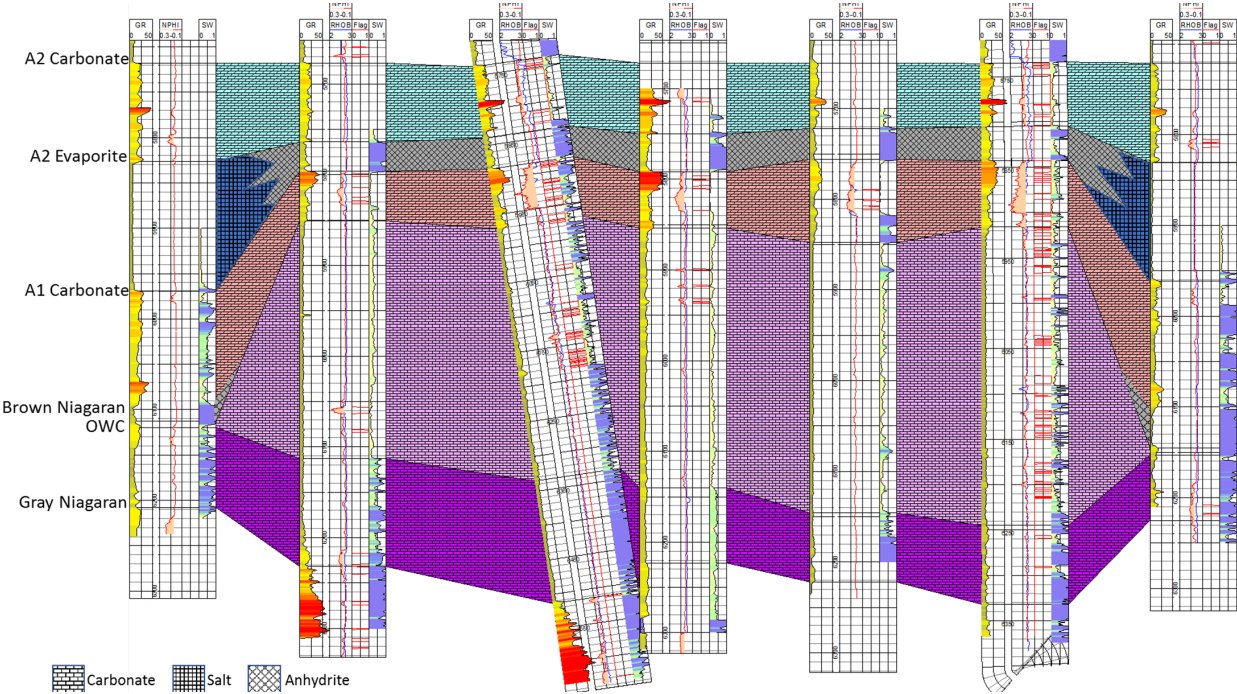


Figure 7: Example 2D conceptual model and geologic characterization of a reef.

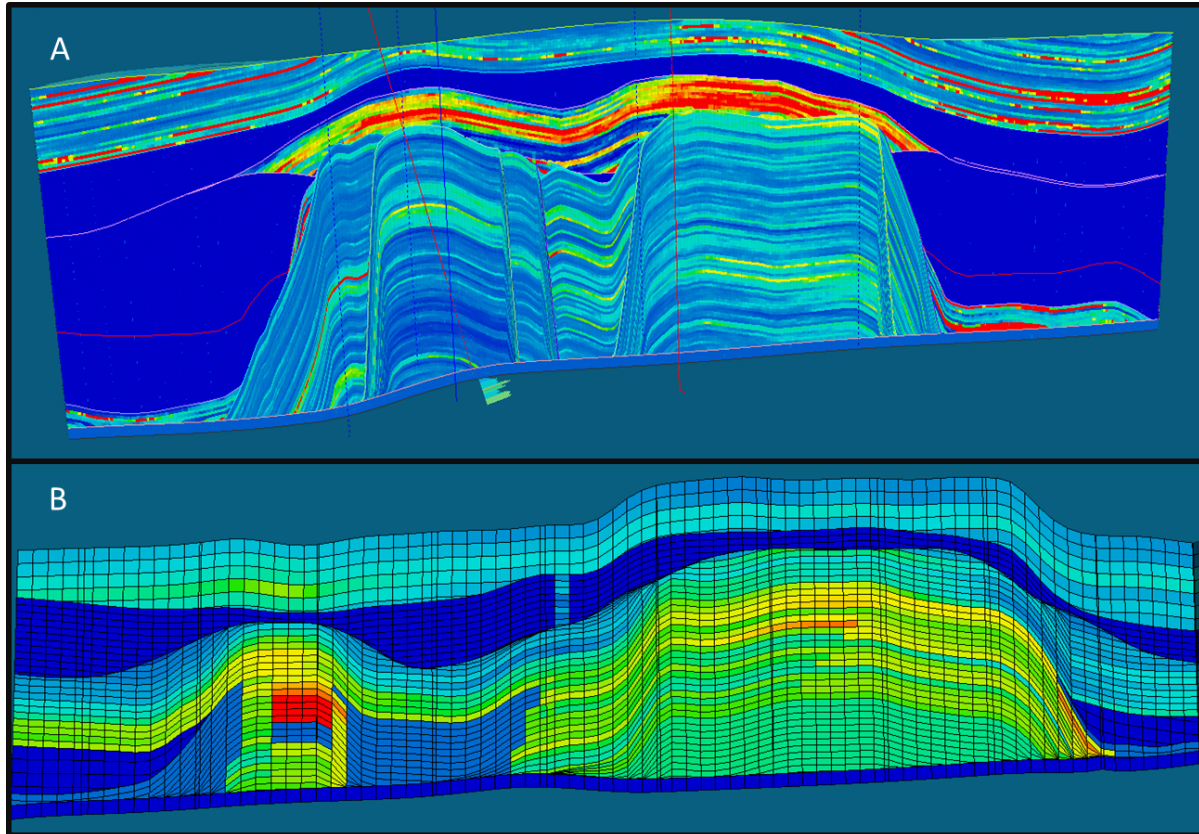


Figure 8. Example slice through a 3D SEM showing porosity distribution through Chester 16 (A) and Dover 33 (B)

Core Energy in collaboration with MRCSP has completed a significant amount of characterization and modeling on select reefs (Figure 9). To date, all 10 reefs have undergone basic geologic characterization to develop a 2D conceptual model of the reef. Five reefs have been developed into SEMs and taken into dynamic modeling. Even though the reefs have variable reservoir properties, there are predictable controls on reservoir performance such as amount of dolomitization, secondary porosity development, and salt plugging which can be identified through geologic characterization. For example, limestone reefs tend to have tighter porosity mid to lower reef with highest porosity and permeability in the upper reef and A1 Carbonate, as illustrated in Figure 8A with hotter colors for higher porosity. Dolomitized reefs tend to have more enhanced porosity throughout the reef due to secondary porosity development as illustrated in Figure 8B with hotter colors for higher porosity. The variability or heterogeneity in rock/facies type is related to a reef's location within the larger Michigan Basin geologic setting.

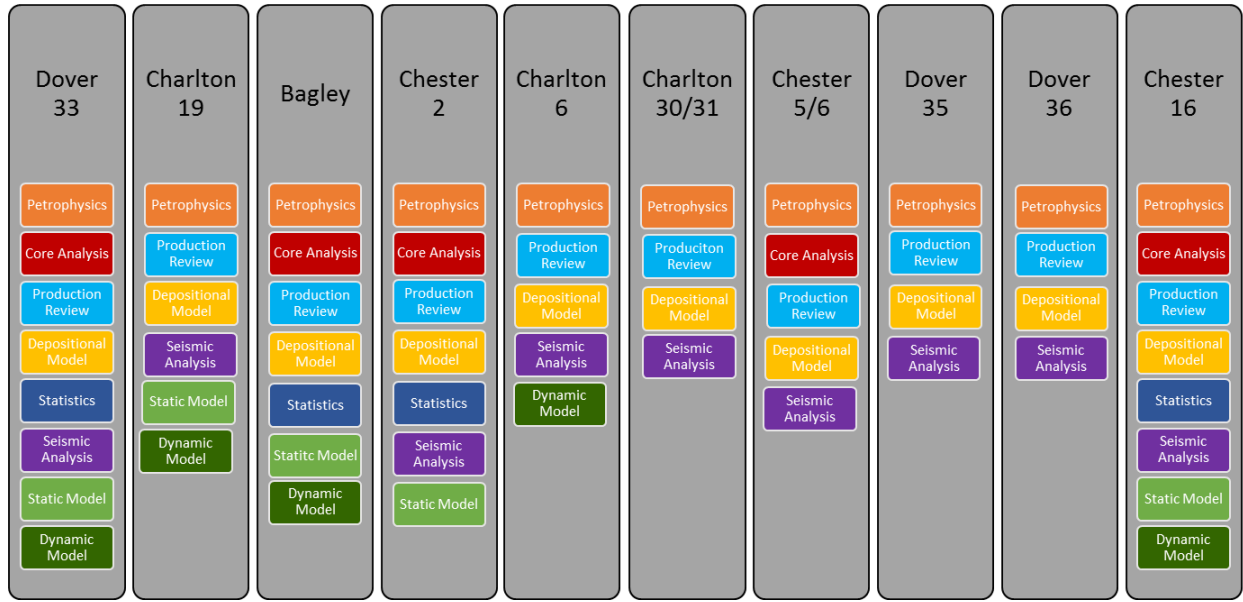


Figure 9: Analyses completed to date by reef.

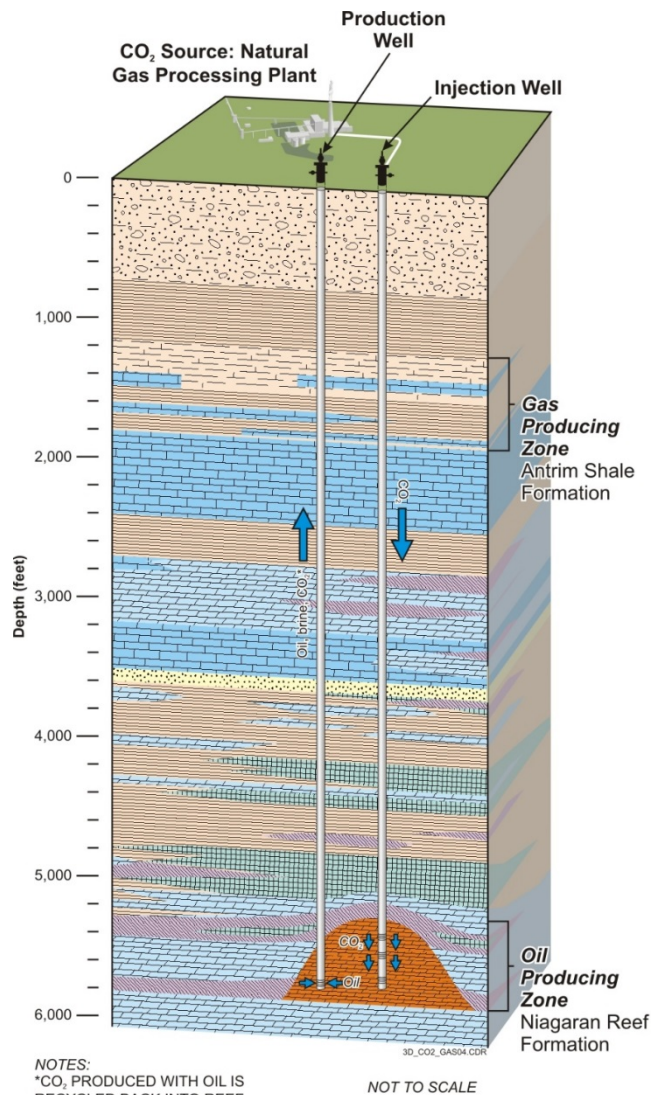
## 2.2.2 Conceptual Understanding of CO<sub>2</sub> EOR in Reef Structures

The modeling and extensive history of oil and gas production in the NNPR have demonstrated the varying degree of compartmentalization of the reefs and the efficiency of the overlying evaporites and carbonates as seals. The reefs act as a closed reservoir system, which provides excellent conditions for CO<sub>2</sub>-EOR operations.

The discovery pressure in the oil-bearing NNPR reefs averages about 3,000 (psi). Primary production utilized this pressure to flow oil to the surface. Secondary production, using water flooding, was attempted but not widely used. Tertiary production, using CO<sub>2</sub> EOR, was initiated in the late 1990's and expanded by Core Energy as it started operations in 2003.

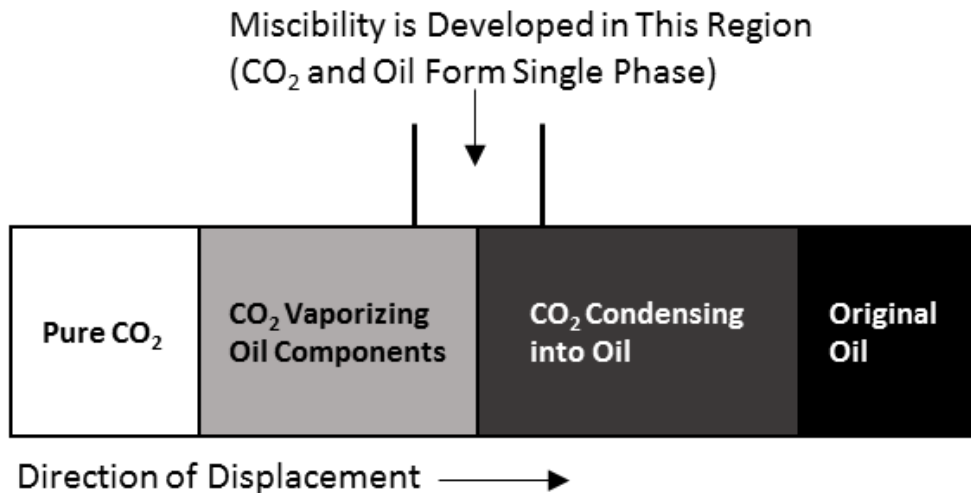
Core Energy typically initiates CO<sub>2</sub> EOR in reefs that have undergone primary and often secondary production and then "blown down" in preparation for closure. The typical average reservoir pressure is well below 500 psi in these reefs after blow down and there is significant voided pore space. As CO<sub>2</sub> is injected into the reefs, it contacts the oil trapped in the pore space while it simultaneously increases the reservoir pressure. As contact and pressure increase, the CO<sub>2</sub> eventually becomes miscible with the oil which allows it to flow towards a designed production well. Figure 10 illustrates the CO<sub>2</sub> - EOR process in a reef field for a CO<sub>2</sub> injection well and the associated production well. Note that the source of CO<sub>2</sub> is from the gas producing zone indicated at the top of the column.





NOTES:  
 \*CO<sub>2</sub> PRODUCED WITH OIL IS RECYCLED BACK INTO REEF.  
 ALL LOCATIONS ARE APPROXIMATE.  
 Figure 10: Simplified diagram illustrating CO<sub>2</sub>-EOR process in a reef.

Figure 11 shows a graphic representation of how CO<sub>2</sub> and oil become miscible. At either end of the image are pure CO<sub>2</sub> and original oil. As the two come into contact and pressure increases, CO<sub>2</sub> vaporizes oil and also condenses into it, forming a single-phase fluid mixture of CO<sub>2</sub> and oil. This mixture of CO<sub>2</sub> and oil, along with formation brine present in some cases, is then produced from the well.



From Zick, 1986

Figure 11: CO<sub>2</sub> Miscibility Diagram (SPE Monograph 22)

The Core Energy facility has significant operational flexibility due to the modular nature of the reefs and the diversity of their development status. The Core Energy reefs are isolated from each other, and each goes through a phase development maturation process that ranges from new or “fill up”, to operational, onto depleted.

New reefs are in the fill up stage in which the initial volume of CO<sub>2</sub> is being injected to raise reservoir pressure above the minimum miscibility pressure (~1190 psi MMP) of CO<sub>2</sub> in oil. Above this MMP, the CO<sub>2</sub> and oil become a single phase fluid and begin to flow to producer wells depending on the pressure gradient between the injection well and the producer wells. After the reef has been pressurized above the MMP (the fill-up phase), these reefs transition into the operational phase, which can last for many years.

Once a reef is determined to be operational, pipelines will be extended from the producing wells to a central processing facility, if they are not already in place. Based on the oil type and the temperature of the reservoirs, Core Energy found that conducting miscible CO<sub>2</sub> flooding is optimized at roughly 1,300 PSI.

Core has also tested the capacity to increase pressure above the optimal range and finds that while it has the headroom (available pore space) and ability to increase pressure to well above 1,300 psi, it does not have equipment that could raise pressure to levels near or above the fracture pressure.

When the bulk of economically available oil has been produced via EOR, the reef is considered depleted or nearing depletion. In depleted reefs, the economic return on CO<sub>2</sub> EOR is not as high as in the operational reefs. However, these reefs still have some oil left in place and can also effectively act as short-term storage for CO<sub>2</sub> in the system. When EOR CO<sub>2</sub> operations in a reef end, Core Energy typically recovers as much CO<sub>2</sub> as it can by producing fluids back through a CPF until such a time as the reservoir pressure has been reduced to a level whereby the wells can no longer flow (approximately 500 psi). The amount of CO<sub>2</sub> which remains in the reef below this pressure cannot be recovered and is stored under current conditions.

This development cycle for each reef, combined with operating multiple reefs at once, provides Core Energy with unique operational flexibility. At any time, the number of reefs and the diversity of their status enables Core to accept as much CO<sub>2</sub> as it can capture and then use it over time. This is especially important due to the depleting nature of their anthropogenic source of CO<sub>2</sub> (i.e. gas processing plants servicing the Antrim Shale production).

**2.3 Operational History of the Core Energy Reefs**

The NNPRRT reefs, originally developed in the 1970-1980s, have undergone primary production and, in some cases, secondary recovery through water flood and other methods. Oil operations largely subsided in the early 1990s and then picked up sporadically towards the end of the decade. Core Energy entered the play in 2003, taking over two operating reefs and slowly expanding into eight additional reefs.

**2.3.1 Core Energy EOR Reef Complex Development**

Core Energy currently operates 10 active EOR reefs in Otsego County in northern Michigan. CO<sub>2</sub> EOR was initiated in each of these reefs at different times as indicated in Table 1. Figure 12 shows the location of each reef.

**Table 1: Active CO<sub>2</sub>-EOR reefs and date of initial flooding.**

Reef	Date CO <sub>2</sub> Flooding Initiated
Dover 33	1996
Dover 36	1997
Dover 35	2004
Charlton 30/31	2005
Charlton 6	2006
Chester 2	2009
Chester 5	2011
Charlton 19	2015
Bagley 11-14-23	2015
Chester 16	2017

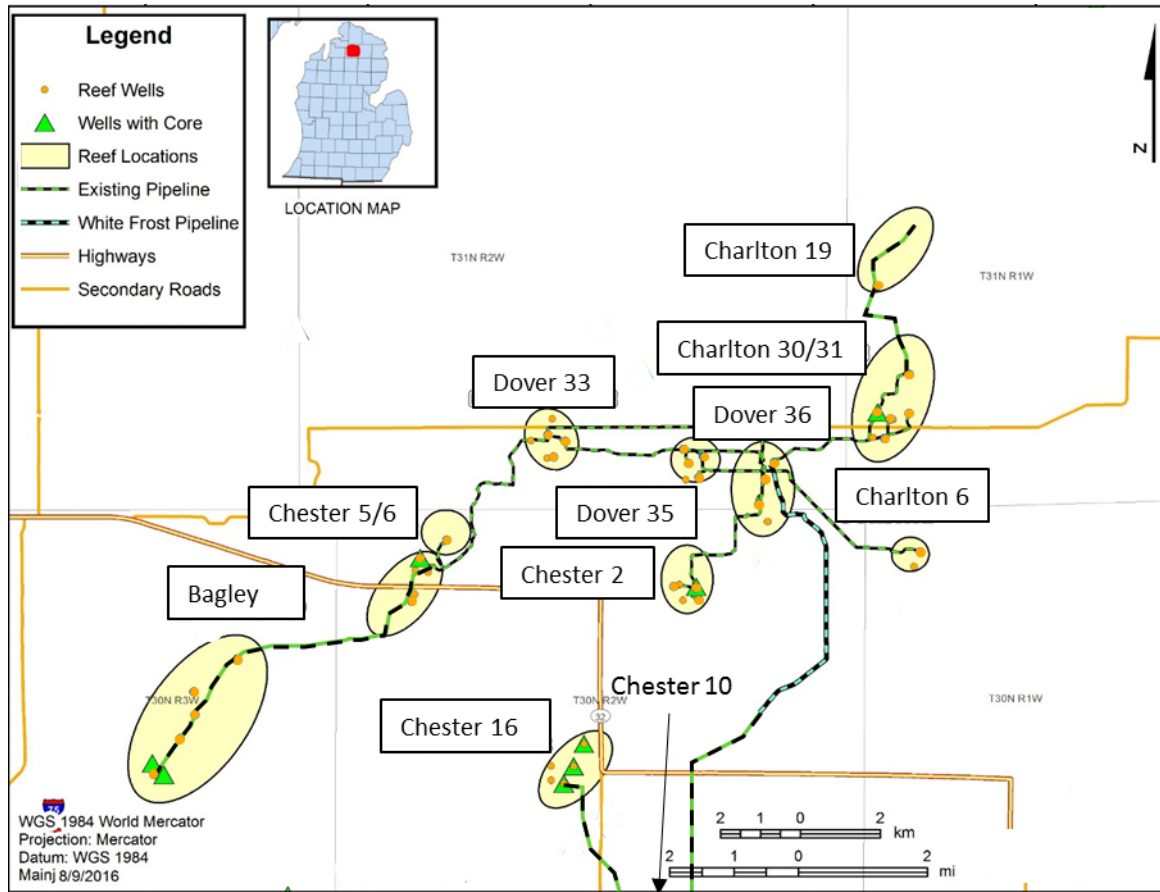


Figure 12: Location of active reefs operated by Core Energy.

### 2.3.2 CO<sub>2</sub> Production and Injection History

All of the active reefs have undergone primary production in the past. Core Energy maintains production records for all wells in the active reefs, including volumes of the following:

- oil produced,
- gas produced (commingled natural gas and CO<sub>2</sub>)
- water produced
- water injected (if applicable), and
- CO<sub>2</sub> injected.

Core Energy worked with Battelle to develop a baseline accounting as of December 31, 2017 of the CO<sub>2</sub> that has been injected since 1996. Since 1996, 2.11 million tonnes of CO<sub>2</sub> has been injected into the Core Energy reefs.

Core Energy is starting its mass balance accounting for CO<sub>2</sub> at zero. This means that the amount of CO<sub>2</sub> already in the system will ultimately be reflected in the mass balance calculation of the amount stored. Over time, the total amount stored will be roughly equal to the sum of CO<sub>2</sub>

from Chester 10 and the inventory of CO<sub>2</sub> produced through Dover 36 less any losses from equipment or subsurface leaks, which are expected to be minimal.

#### 2.4 Description of CORE Energy CO<sub>2</sub>-EOR and Ancillary Storage Project Facilities and the Injection Process

Core Energy operates an integrated facility that includes CO<sub>2</sub> capture, dedicated pipelines, injection and production wells, a central processing facility for fluids, and compressors. Figure 13 is a detailed flow chart with equipment names and meter numbers. The rest of this section will use Figure 13 to review the facilities and processes taking place at the Core Energy facility.

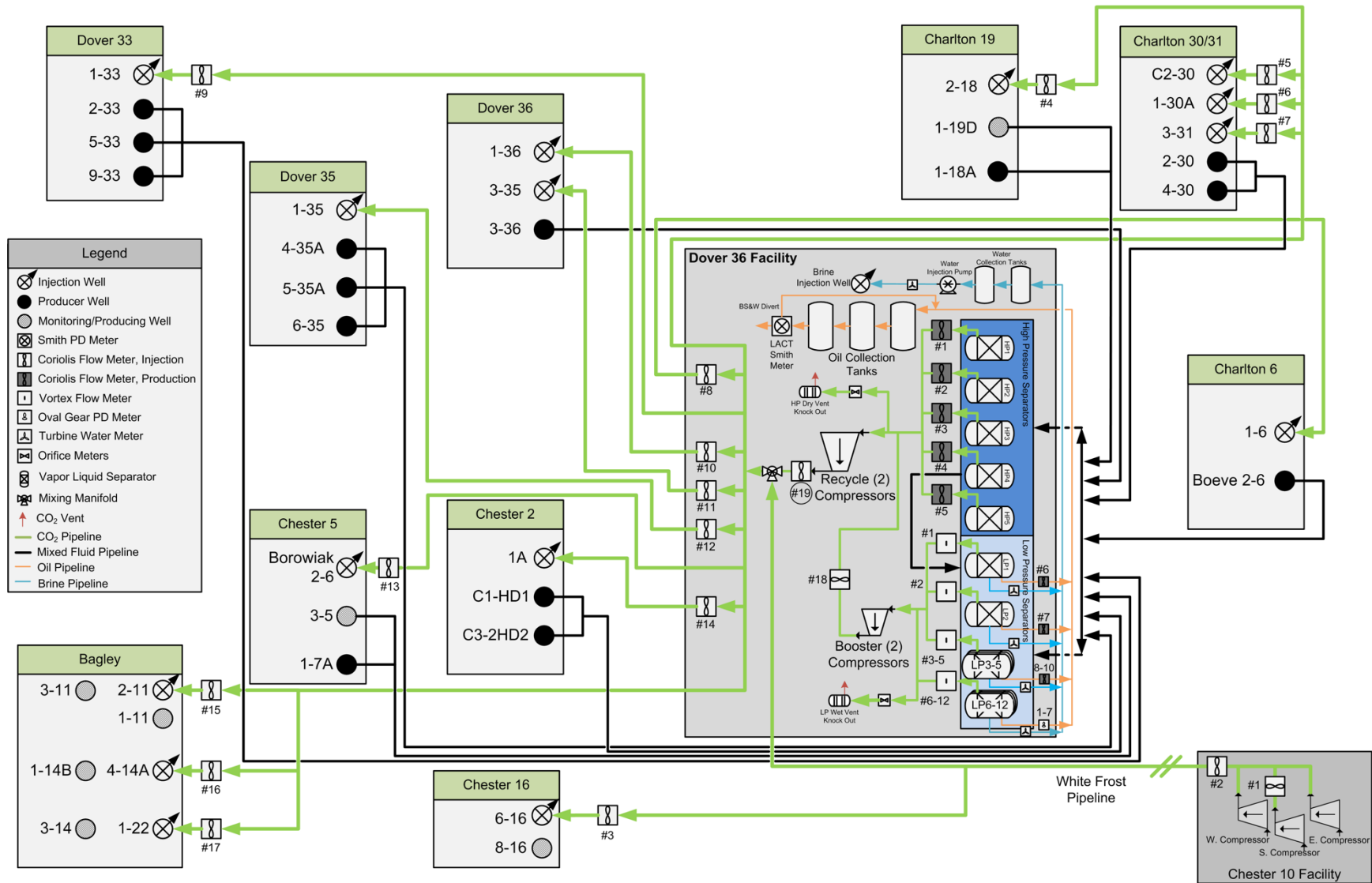


Figure 13 – Simplified Process Flow Diagram of Core Energy's EOR Facility

## 2.4.1 CO<sub>2</sub> Capture

Core Energy captures CO<sub>2</sub> at two locations:

- Chester 10 Facility (shown in bottom right corner of Figure 13): This facility captures CO<sub>2</sub> from a natural gas processing facility that treats gas produced from the Antrim Shale. Core Energy has the right to capture up to 100% of the CO<sub>2</sub> that would normally be vented from the natural gas plant. Core has made investments to expand capture operations over time and plans to make additional investments in the future. It currently captures between 300,000 to 350,000 tonnes of new CO<sub>2</sub> per year. Also, there is potential to capture an additional 100,000 tonnes per year, resulting in net potential 450,000 tonnes of new CO<sub>2</sub> per year. It is expected that the natural gas processing plant will continue operations for at least 10 to 20 years but continued operations depend on market conditions. Core currently has three compressor units at this facility, with the mass of all new CO<sub>2</sub> measured using Coriolis mass flow meter number 2 (Figure 13).
- Dover 36 Facility (large rectangular box in Figure 13): This facility is co-located along with the Dover 36 reef. This facility contains the main Recycle Compressor along with capture equipment which captures CO<sub>2</sub> from various high-pressure (HP) and low-pressure (LP) fluid separators that treat the fluids from the production wells. Core Energy currently captures ~300,000 tonnes of gas per year at the Dover 36 Facility. This gas consists of CO<sub>2</sub> (~95% by wt.) with small quantities of hydrocarbon gas which is recompressed and sent back to various EOR reefs. The mass of this gas is measured using Coriolis mass flow meter number 19.

## 2.4.2 CO<sub>2</sub> Distribution and Injection

Core Energy maintains about 80 miles of pipelines that are used to move CO<sub>2</sub>, produced fluids, and oil. A diagram of the pipeline network and locations of 10 EOR reefs is shown in Appendix II.

A portion of CO<sub>2</sub> from the Chester 10 Facility delivered via the White Frost Pipeline can be withdrawn directly for injection into Chester 16 reef (measured using Coriolis mass flow meter number 3); the remainder of the CO<sub>2</sub> from Chester 10 flows to the Dover 36 Facility, where it mixes with CO<sub>2</sub> from the Recycle Compressor at the Mixing Manifold. From the Mixing Manifold, Core can re-arrange various piping and valves to direct CO<sub>2</sub> to any one of the reefs.

Dedicated Coriolis mass flow meters are attached to each injection well at the EOR reefs. Some of the meters are located at the Dover 36 Facility while others are located directly at the wellhead. These meters are numbered 3 through 17 (Figure 13) for the 15 injection wells at 10 EOR reefs. It is important to note that Core can change the operational configuration of wells whereby an injector well may become a producer or monitoring well, or a producer well may be converted to an injector well. If in future, a producer well is reconfigured to be an injector well, Core will install a Coriolis or other suitable flow meter to measure the quantity of CO<sub>2</sub> being injected into that well and will indicate such changes in the annual reporting.



### 2.4.3 Produced Fluids Handling and Processing

Table A-1 in Appendix I lists the active wells, of which 20 are “producers”. These 20 wells are further indicated by status as a current producer (PR), a shut-in producer (SI-P) or an observation (OBS) well. Generally, at least one production well is located in each reef. For the new reefs, the production wells will be connected to pipelines for produced fluids once they start producing. For the other reefs, all produced fluids from the reefs flow directly to dedicated separators at central processing facilities.

Core Energy currently has a network of 5 HP separators and 12 LP separators at the Dover 36 Facility. Product streams from reefs that are producing oil under high pressure (> 340 psi) are first sent to an HP separator; product streams from reefs that are producing under low pressure (<340psi) are sent to one of the LP separators. The remaining liquid product stream (containing mostly oil and brine) from an HP separator is further sent to an LP separator for separation and stripping of any entrained gas. The produced gas that is separated in the HP separator is sent to the Recycle Compressor, while the gas separated from the LP separator is first sent to a Booster Compressor prior to being sent to the Recycle Compressor.

The produced gas which primarily consists of CO<sub>2</sub> (>95% by wt) is separated from the produced fluid and flows through a Coriolis mass flow meter at each of the HP separators before being sent to the Recycle Compressor (meters numbered 1 through 5). The bulk of the produced gas is captured in the HP separators (> 90% by wt). Meanwhile, the produced gas that is separated at the LP separator, flows through a Vortex type flow meter. The system of Coriolis mass flow meters (attached to the HP separators) and Vortex flow meters (attached to the LP separators) measures the mass of recycle gas produced from each operational reef. Additionally, one Coriolis mass flow meter (number 18) measures the mass of all recycle gas captured at the LP separators while another (number 19) measures the total quantity of produced gas that is produced by all operational EOR reefs.

Brine is separated by the LP separators. The collected brine is sent to a brine disposal well located onsite at the Dover 36 Facility.

Oil is gathered in collection tanks before flowing through a LACT meter for offsite sales. A small amount of CO<sub>2</sub> remains entrained in the oil after the CO<sub>2</sub> separation process, which bleeds off as the oil moves through the LP meters into a temporary storage/gathering tanks. Core hired an external engineering firm to conduct a survey in 2011 to determine the amount of CO<sub>2</sub> entrained in oil and developed a volumetric factor to quantify this loss for purposes of the mass balance. That factor is 16.84 standard cubic feet (scf) per barrel of oil. This translates into roughly 150 tons per year at current operations levels. Because the oil is blended in the gathering tank, Core Energy believes this factor applies uniformly to all oil.

While rare, operational outages periodically occur, which forces produced gas to be vented to the atmosphere. Core has orifice type flow meters installed at its Wet and Dry Vent locations to measure the mass of recycle gas that is vented. Looking back for the last 12 months (May 17 to April 18), a small volume of CO<sub>2</sub> was vented during eight (8) of those months (roughly 50 tons). The volume of CO<sub>2</sub> vented represents less 0.0174% of the produced volume.

#### 2.4.4 Data Collection

The system of flow metering at the Dover 36 Facility is centrally tied to a Core Energy HMI computer system. Coriolis mass flow meters that are located at the reef-site locations (at injection wellheads) typically have data-loggers which collect and store injection data. The HMI system records continuous production and injection data files on a per-minute basis for each day of operations. Operators typically record totalizer readings from injection and production parameters at 9 AM each day for the previous operational day. Additionally, there are daily site visits to the wellsites where operators record well data (e.g., tubing pressure, casing pressures, and wellhead temperatures). Together, these data streams provide accurate accounting of all CO<sub>2</sub> being acquired (from the Chester 10 Facility), injected into EOR reefs, and recycled at the Dover 36 Facility.

The method used when estimating the volume of CO<sub>2</sub> “lost” due to an interruption in data collection or mechanical failure of a meter (equipment) is to use the most recent daily volume of CO<sub>2</sub> associated with the meter and calculate the proportionate volume of “lost” CO<sub>2</sub> based on the number of hours involved in the data gap or until the meter was repaired. Core Energy has well and facility data in three forms: 1) Paper copies (scanned to server), 2) Keyed in data from paper copies into database, and 3) Automated capture of limited set of data that was recently instrumented (Fall of 2016).

Subsequent sections of this Plan, Section 5.5 and Section 6, provide a more detailed explanation for how this data and other means will be used as baseline data for comparison to detect possible surface leakage.

#### 2.4.5 Existing Wells

Core Energy operates 16 injection wells (1 of which is a shut-in injector) and 20 production/observation wells. These wells are listed in Appendix I.

Well status is discussed in Section 4.1.

Wells are configured as each EOR project is developed (see Table 1). Mechanical integrity for injection wells is monitored through daily readings of casing pressure, quarterly fill-up tests and mandatory mechanical integrity tests (MIT) every five years. All injection wells utilize a corrosion inhibited packer fluid in the annular space between the tubing string and casing, above the required isolation packer. Corrosion coupons are placed at various nodes in the system as a way to monitor metal loss.

Maps showing the locations of the wells in each reef are provided in Figure 12. In general, the basic open-hole geophysical logs (e.g. gamma ray, density, resistivity, neutron porosity, photoelectric) are available for most of the wells in the active reefs. A sonic log is available for approximately half of the wells. Cement-bond logs are sparingly available.

## 2.5 Core Energy Procedures for CO<sub>2</sub>- EOR Facility Modification

Core Energy plans to continue routine business operations, which may include securing additional CO<sub>2</sub>; modifying, adding, or closing wells; adding or closing reefs, and adding new facility equipment and pipelines. These modifications represent a continuation of the basic integrated current configuration and MRV approach and not a material change that triggers a revised plan (see 40CFR Part 98.448(d)). Therefore, Core Energy intends to indicate such changes in the annual monitoring report rather than submitting new MRV plans. The monitoring report would demonstrate how the change is a continuation of the existing EOR Facility and would also include any new site characterization, risk assessment, monitoring, and mass balance information as is already included for the existing EOR Facility. The existing provisions for the MRV would continue to apply. Each of these potential changes is discussed in more detail below.

### 2.5.1 New Sources of CO<sub>2</sub>

Core Energy is considering the addition of new equipment to capture additional CO<sub>2</sub> from the adjacent natural gas processing plant through its Chester 10 Compression Facility. It is also exploring the potential to obtain additional CO<sub>2</sub> through nearby sources that are in development.

In the event new sources of CO<sub>2</sub> are added, the amount of CO<sub>2</sub> would be measured using flow meters and added to the reported amount of CO<sub>2</sub> received onsite as indicated in Section 7. Injected CO<sub>2</sub> from these sources would be measured using flow meters and added to the reported amount of CO<sub>2</sub> injected as indicated in Section 7.

### 2.5.2 Adding New Wells

In order to add any new injection wells, Core Energy would have to work with the US EPA (or if Michigan gains primacy for Class II, MDEQ/OGMD) to obtain the permits and from MDEQ/OGMD to obtain permits for any new production wells. Such wells would be sited, completed, and operated in the same manner as the existing wells, under the oversight of the US EPA and/or MDEQ. The existing modeling and learned transferable principles would be combined with reef characteristics to determine location and operational plans for such wells. Well numbers and information would be included in the annual statement.

### 2.5.3 Abandoning Existing Wells

Core Energy follows the UIC Class II requirements and/or the MDEQ/OGMD requirements for closing wells. Any wells closed within a reporting year would be noted in the annual statement.

### 2.5.4 Changing the status of Existing Wells

Core Energy may change the status of an existing well from producer to injector or vice versa. In such situations, Core Energy will work with US-EPA and/or MDEQ/OGMD to obtain the necessary permits and will indicate the status change in the annual statement.

### 2.5.5 Acquiring New Reefs

Core Energy is looking to expand into new reefs based on their potential development value, which is a reflection of past operational history and current ownership structures as well as other factors. Based on the modeling and history of reef development in the area, Core Energy does not anticipate that past operations will preclude any reef from being selected as an expansion candidate. As part of the permitting process, Core Energy will conduct a site characterization, determine the boundaries of the reef, and assess the Area of Review (AoR) of at least ¼ mile around the reef to determine if there are any old wellbores that need to be remediated or closed and whether there are any other impediments to the successful implementation of CO<sub>2</sub> EOR on that reef. All potential new reefs are located in the MMA as indicated in Section 3.2 and would be moved into the AMA as indicated in Section 3.1 if they are developed by Core Energy.

### 2.5.6 Abandoning Existing Reefs

Core Energy will follow the requirements for closing wells and will follow any contractual or permit requirements for abandoning a reef. Core Energy will prepare a closure report for any abandoned reefs that assesses the amount of CO<sub>2</sub> that will be incidentally stored in that reef after closure and serving as the foundation for removing that reef and the related CO<sub>2</sub> from the active MRV reporting program.

### 2.5.7 Adding New Facility Equipment

Core Energy may add new equipment that could have an impact on the mass balance. This might include additional compressors, processing equipment, and/or other equipment. These changes would be noted in the annual statement and CO<sub>2</sub> losses from this equipment would be calculated as in Section 7 and the results included in the mass balance.

### 2.5.8 Acquiring New Pipeline Routes

Core Energy may build additional pipelines to connect new wells to the Core Energy Facility or to connect fill up reefs to production facilities. These changes would be noted in the annual statement and CO<sub>2</sub> losses from this pipeline would be calculated as in Section 7 and the results included in the mass balance.

## 3. Delineation of the Monitoring Area

### 3.1 Active Monitoring Area

Due to the highly compartmentalized nature of the Niagaran reefs, the Active Monitoring Area (AMA) is defined by the boundary of the Unit Area of each individual reef/field as established in the Order by the Supervisor of Wells for the MDEQ authorizing each EOR project. The following factors are considered in defining the boundaries:

- CO<sub>2</sub> injected into a reef remains contained in the reef because of the efficient seals along the edges and overlying the reef

- The edge of the reef is typically defined using 3D seismic data. Where 3D seismic data is not available, reef edges are approximated using all wells surrounding and penetrating a reef, along with analog reef geometry.
- Stored CO<sub>2</sub> will remain within a reef and will not migrate over geologic time, as is demonstrated by the long history of oil and gas production occurring within a reef. Just as the oil and/or gas were trapped in and contained by the reef, the same would be true for the CO<sub>2</sub>.
- Free-phase CO<sub>2</sub> is contained within the reefs and will remain there after injection ceases and wells are shut-in or closed
- MDEQ rules state that an operator must demonstrate that the reservoir is wholly contained in the Unit Area before an EOR project is authorized.

### 3.2 Maximum Monitoring Area

The maximum monitoring area (MMA) for the MRV Plan, based on the anticipated future of expansion to conduct CO<sub>2</sub> EOR operations in reefs within the NNPRT, extends geologically along the northern edge of the Michigan Basin. The NNPRT extends as a band of reefs from Lake Huron (Presque Isle County) to Lake Michigan (Manistee County), of which there are prospective CO<sub>2</sub> EOR reefs in every labeled county shown in Figure 14. In accordance with § 98.448-449, the actual MMA will extend for ½ mile beyond the reefs. The red dashed line in Figure 14 encompasses the half mile buffer to the north and south of the reefs in the MMA.

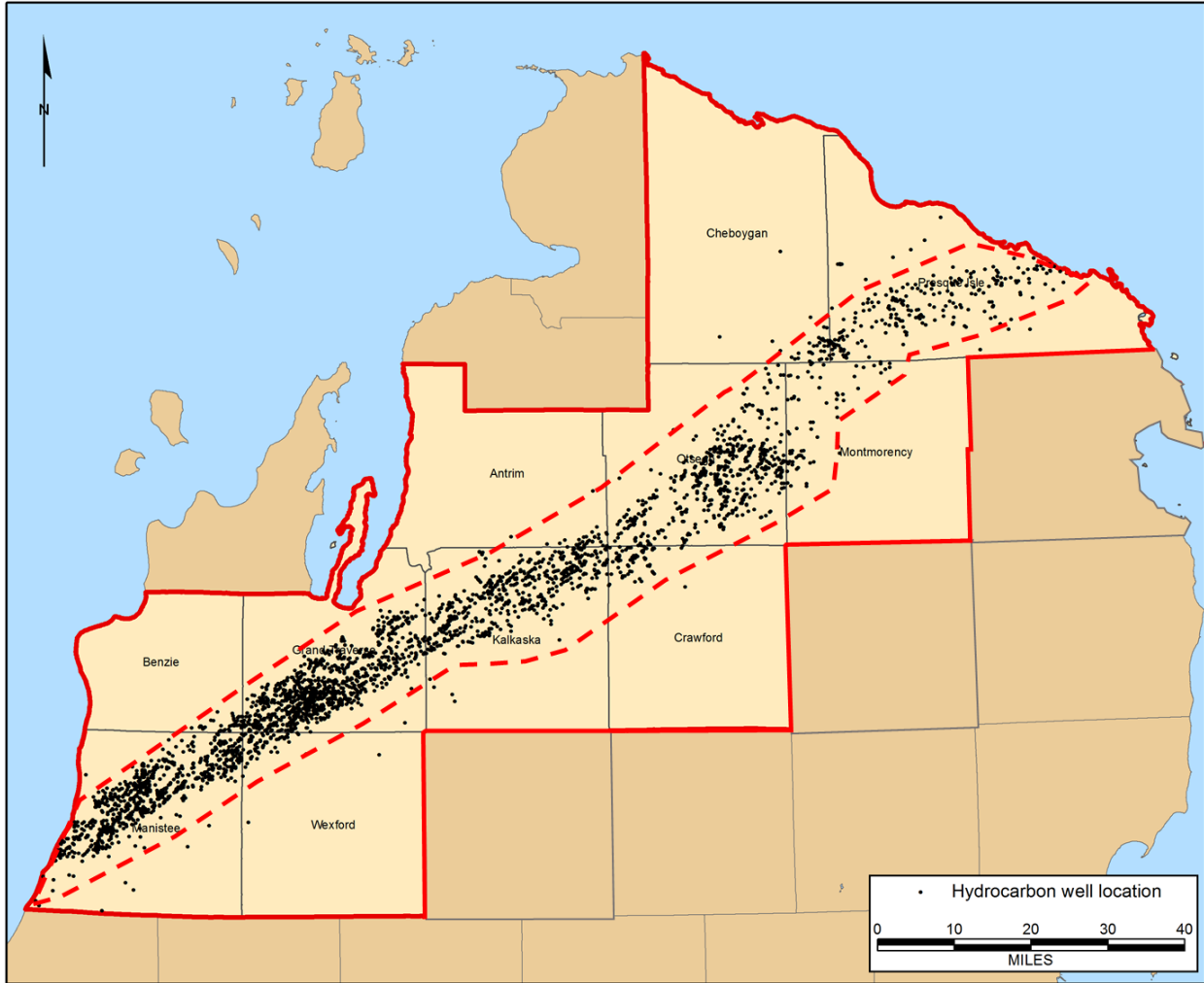


Figure 14 Areal Extent of Maximum Monitoring Area includes the hydrocarbon bearing pinnacle reefs in the NNPR

The reefs that are currently undergoing CO<sub>2</sub> EOR in Otsego County and all of the reefs in the NNPR that would be suitable CO<sub>2</sub> EOR targets in the future are found at the same place within Michigan's geological stratigraphic column. The reefs are always contained below the B-Salt and A2-Carbonate and above the White Niagaran (see Figure 15).



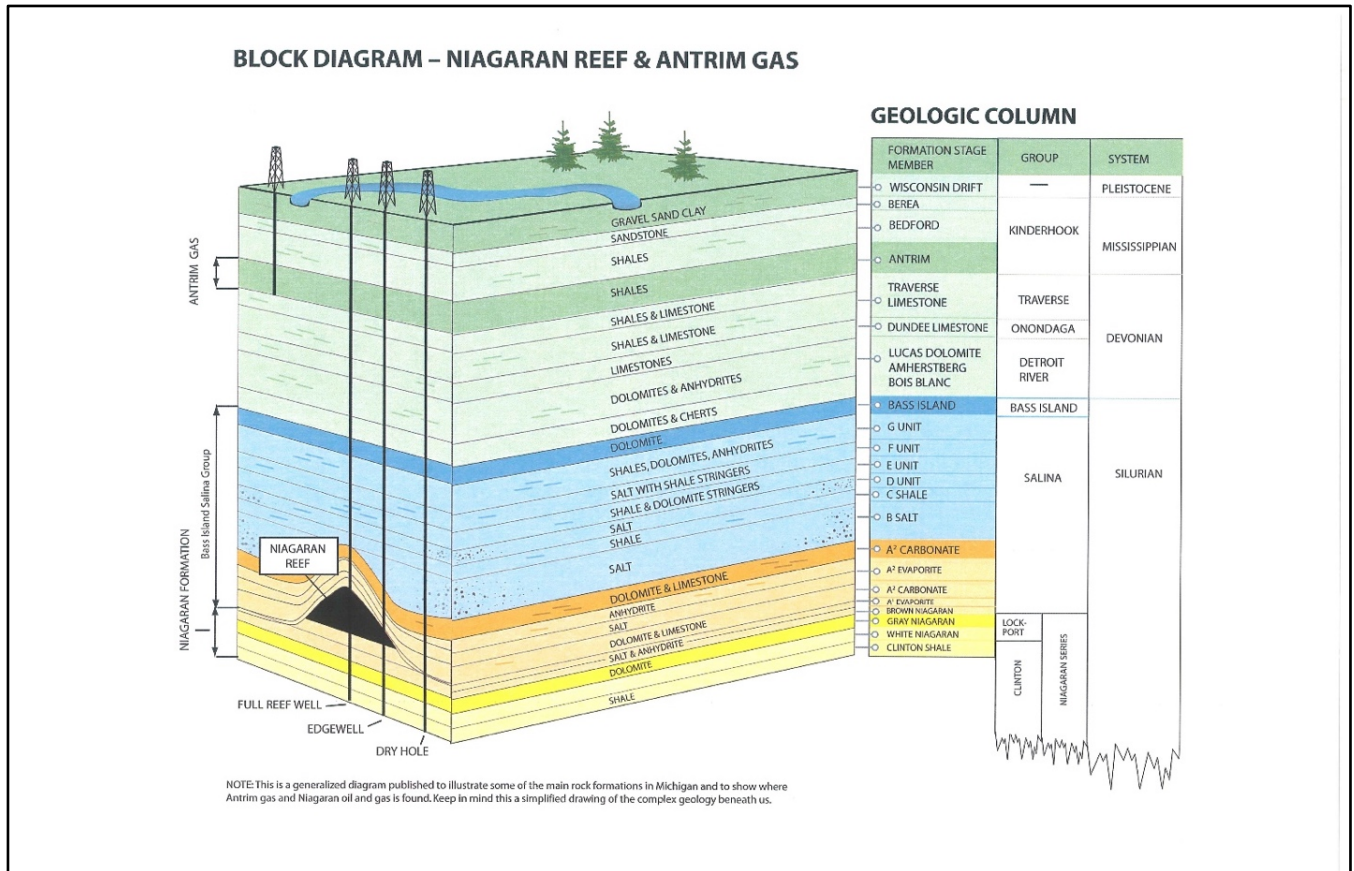


Figure 15 Michigan Stratigraphic Column

The potential risk of leakage is consistent from reef-to-reef in the MMA for several reasons. The hydrocarbon bearing reefs that Core Energy will develop are always found in the same geologic setting within the Michigan Basin. They are isolated, self-contained reservoirs, and the risk associated with leakage pathways are the same from reef-to-reef. Further, any reef added to Core Energy’s EOR operations would first be screened for suitability for EOR operations and would then have to undergo the Michigan unitization process by MDEQ. New wells or well changes would go through the state (MDEQ) and federal (US EPA) permitting requirements.

### 3.3 Monitoring Timeframes

Core Energy’s primary purpose for injecting CO<sub>2</sub> is to produce oil that would otherwise remain trapped in the reservoir and not, as in UIC Class VI, “specifically for the purpose of geologic storage.”<sup>1</sup> During a Specified Period, Core Energy will have a subsidiary purpose of establishing the long-term containment of a measurable quantity of CO<sub>2</sub> in the reefs that it operates. The Specified Period will be shorter than the period of production from the Core Energy facility. At the conclusion of the Specified Period, Core Energy will submit a request for discontinuation of reporting. This request will be submitted when Core Energy can provide a demonstration that current monitoring and model(s) show that the cumulative mass of CO<sub>2</sub> reported as sequestered during the Specified Period is not expected to migrate in the future in a manner likely to result in

<sup>1</sup> EPA UIC Class VI rule, EPA 75 FR 77291, December 10, 2010, section 146.81(b).



surface leakage. It is expected that it will be possible to make this demonstration within three years after injection for the Specified Period ceases. The demonstration will rely on three principles: 1) the amount of CO<sub>2</sub> stored in properly abandoned reefs will be considered unlikely to migrate to the surface, 2) the continued process of fluid management during the years of CO<sub>2</sub> EOR operation after the Specified Period will contain injected fluids in the reefs, and 3) that the cumulative mass reported as sequestered during the Specified Period is a fraction of the theoretical storage capacity of the reefs in the field. See 40 C.F.R. § 98.441(b)(2)(ii).

#### 4. Evaluation of Leakage Pathways

Knowledge gained through the long history of oil and gas production in the Niagaran reefs coupled with the regional geological characterization conducted by Battelle for the MRCSP were used to identify and assess potential pathways for leakage of CO<sub>2</sub> to the surface. The following potential pathways are reviewed:

- Existing wellbores
- Faults and fractures
- Natural and induced seismic activity
- Lateral migration outside of a reef
- Diffuse leakage through the seal
- Pipeline/surface equipment

##### 4.1 Existing Wellbores

Wellbores that penetrate the reef constitute the most likely pathway for leakage, however this risk is assessed as very small because of the well construction specifications implemented by Core Energy. Wells are constructed with four strings of casing (i.e. conductor, surface, intermediate and total depth string), three of which are cemented in place; the surface casing is cemented all the way to the surface. Additionally, all wells have tubing strings run to near the permitted injection zones. Injection wells require a packer attached to the tubing string, located no more than 100 feet (30 m) above the permitted injection zone and mechanical integrity on injection wells must be established and maintained. Core Energy adheres to all regulatory requirements of the state and federal agencies charged with oversight as they relate to well drilling, completion and operation as means to maintain mechanical integrity and prevent wellbore leakage. Though previously drilled wells and plugged/abandoned wells may be thought to have a higher risk for leakage pathways than newly drilled wells, all wells within a defined AoR for a project are evaluated. All wells in northern Michigan have been ranked based on age, status, and depth (penetrating seal). It was concluded that wells which penetrated the seals were ranked with high integrity because they were more recent and adhered to regulatory requirements. Figure 16 shows all the well rankings in Otsego County (green is high integrity) and the number of wells which penetrate each reef.

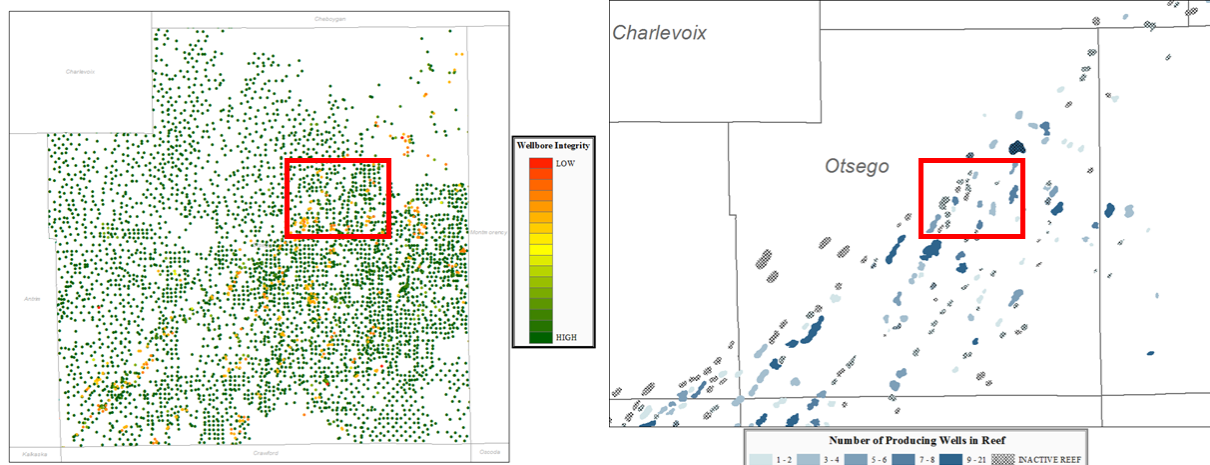


Figure 16: Wellbore integrity ranking (left) of all wells in Otsego County showing dominantly high integrity and the number of wells which penetrate each reef (blue) showing few seal penetrations within the Core Energy reef area (red)

MRCSP's a systematic wellbore integrity evaluation in seven fields in the Michigan Basin which were actively being used for CO<sub>2</sub> EOR also included cement plugs. In this study, cement plugs were analyzed and ranked based on depth, number of plugs, thickness, and age. It was concluded that plugged wells which penetrated the reefs and nearby off reef locations had sufficient plug placement and thickness to prevent leakage.<sup>2</sup>

Leakage through wellbore cement was also researched in the NNPRT by analyzing several cement bond logs in the region. Cement was categorized based on the bond index. Cement with 80 to 100% bond was considered sufficient, 60 to 80% was intermediate, and less than 60% was not ideal. Wells which penetrated the reef were shown to have at least 50 feet of sufficient cement bond within the seal, which by industry standards is sufficient (Figure 17). Several wells were also tested for sustained casing pressure after being exposed to CO<sub>2</sub> and did not demonstrate any sustained casing pressure which would be caused by leakage through a cement annulus.

<sup>2</sup> Haagsma, A. , Weber, S. , Moody, M. , Sminchak, J. , Gerst, J. and Gupta, N. (2017), Comparative wellbore integrity evaluation across a complex of oil and gas fields within the Michigan Basin and implications for CO<sub>2</sub> storage. Greenhouse Gas Sci Technol, 7: 828-842. doi:[10.1002/ghg.1620](https://doi.org/10.1002/ghg.1620)

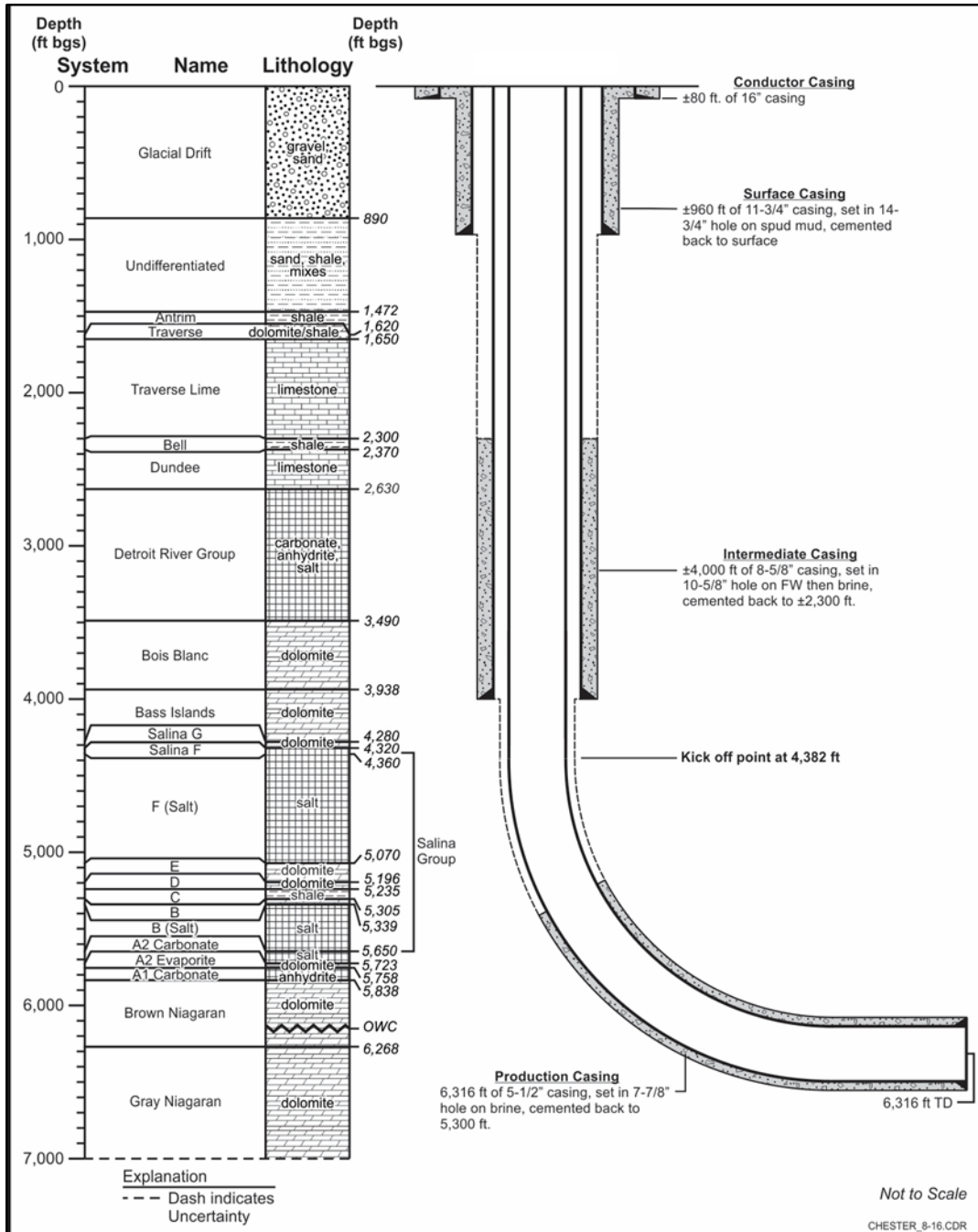


Figure 17: Example of well construction for a Core Energy well showing intervals of cement over crucial formations.

Overall, wellbore integrity studies and the oil and gas history demonstrate that while leakage through a wellbore is possible, the wells have been constructed ideally to prevent such leakage. Core Energy also conducts routine monitoring of active wellbores by performing bottom hole pressure measurements and wellhead inspections.

### 4.1.1 Future Wells

The highly-compartmentalized nature of the NNPRT reefs and the state requirements for drilling wells in active and new reefs will prevent new wells from posing a threat of leakage. As discussed in section 2.1, the structure of each reef ensures that they are separated from each other and that there is no fluid communication. This means that any well drilled in the MMA that does not intersect or pass through a reef, even if drilled to a depth deeper than that of the NNPRT reefs, is not a potential leakage pathway. Additionally, because reefs undergoing CO<sub>2</sub> EOR have to be unitized prior to commencing EOR operations, Core Energy controls all the pertinent rights that would preclude (or allow) for a well to be drilled within its unit, thus, no well could be drilled within the unit boundary of an active EOR project.

### 4.2 Faults and Fractures

Basement crustal features such as the Mid-Michigan Rift/geophysical anomaly and the Grenville Front (Figure 18) may affect formation thickness and the tectonic movement of Paleozoic structures in the sedimentary rock section. Many ancient faults and folds in the Paleozoic section are parallel or perpendicular to the basement features. There are fewer identified faults in the northern most counties of Michigan than there are in southern Michigan, making the NNPRT an ideal location for CO<sub>2</sub>-EOR. The faults in northern Michigan are deeper features and do not influence the integrity of the caprocks for the reefs.

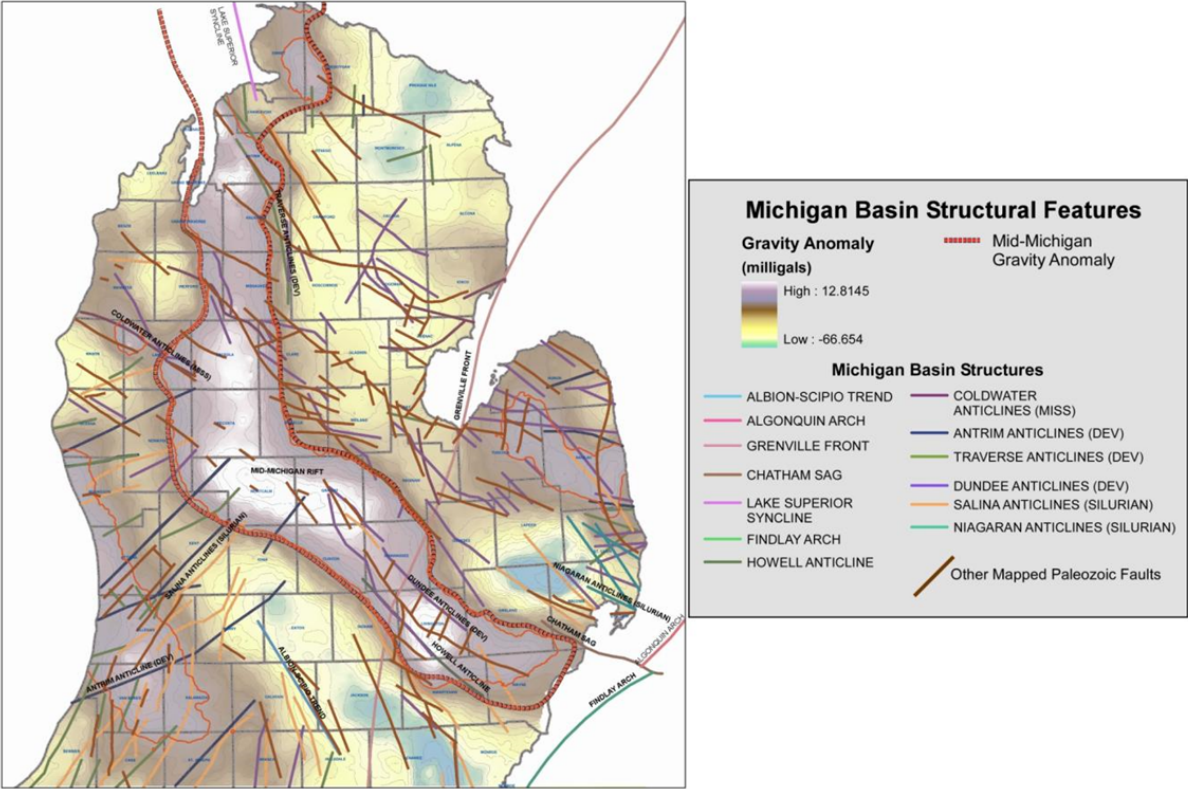


Figure 18: Michigan Basin structural feature



### 4.3 Natural and Induced Seismic Activity

Michigan Basin is structurally stable with few known faults. There are no recorded seismic events in northern Michigan and risk of seismic activity is low with a 0 to 4% chance of a seismic event in northern Michigan and no recorded seismic events (Figure 19A). Nearby 2D and 3D seismic data confirm there are no major structural features around the sites of interest (Figure 19B).

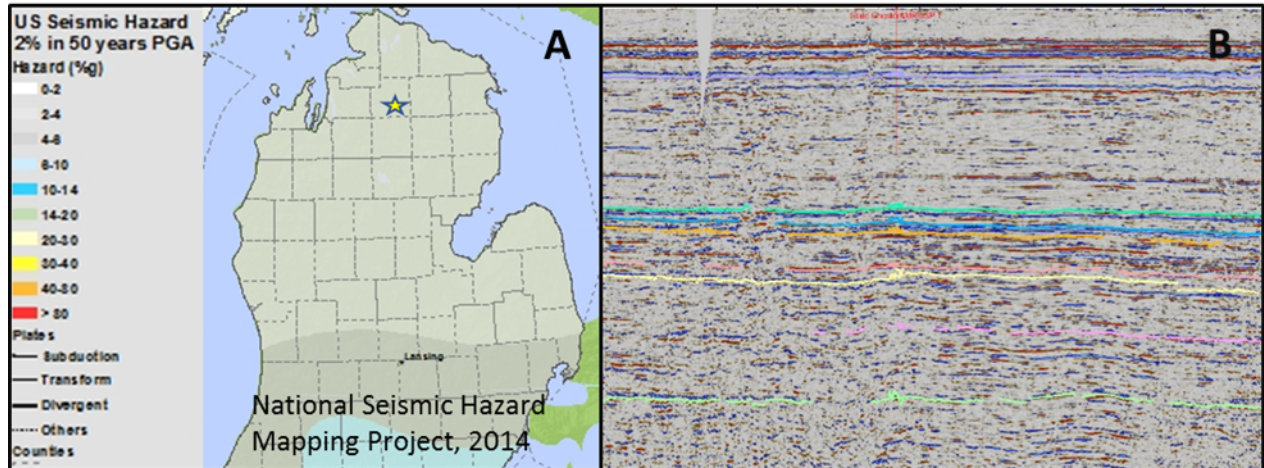


Figure 19: US seismic hazard map (A) with example 2D seismic line (B) showing low risk for seismic activity and no major structural features.

### 4.4 Lateral Migration Outside of a Reef

It is highly unlikely that injected CO<sub>2</sub> will migrate outside of the boundaries of a reef due to the following factors:

- 1) The containment provided by the inherent reef geology consisting of non-porous salts and evaporites along the flanks and overlying the reef structure. This containment is believed to effectively isolate the individual reefs resulting in closed reservoir dynamics observed over the course of MRCSP CO<sub>2</sub> injection (see section 2.1)
- 2) Operational procedures at Core Energy, which monitor injection and production volumes from well-managed wells.
- 3) Periodic material balance associated with the measured reservoir fluid amounts, which has helped correlate and reconfirm that no CO<sub>2</sub> has been lost to the surroundings from the reef thus far.

Containment is also validated by the numerical modeling exercises (both analytical and dynamic numerical models) undertaken for each of the reefs of interest aimed at investigating reef response and CO<sub>2</sub> migration over time.

#### 4.5 Diffuse Leakage through the Seal

Diffuse leakage through the seal, overlying Salina group, is highly unlikely. The seal is composed of several hundred feet of salt, shale, and tight carbonate. Oil and gas production also confirms the successful trapping of fluids in the reefs over geologic time. Additional pressure monitoring and geomechanical modeling of the seals in several reefs confirmed the efficiency and integrity of the confining system.

The fracture gradient is 0.8 psi/ft which is approximately 4130 psi at a depth of 5162 ft (shallowest perforation in Core Energy reefs). The coordinating wellhead (surface) pressure equates to 1761 psi. The maximum pressure tubing can experience is 1400 psi, based on the pressure that can be delivered from the injection compressors. Thus, the fracture pressure is higher than can physically be realized within the well and there is no risk of fracturing the seals. Further, each CO<sub>2</sub> injection well is assigned a maximum surface injection pressure as a part of the US EPA permitting process, whose purpose is to ensure that the reservoir fracture pressure is not exceeded.

Additionally, geomechanical analyses were conducted using wireline logs and core tests for select reefs. Analytical techniques were used to estimate changes in minimum horizontal stress,  $\sigma_h$ , caused by changes in pressure and temperature during CO<sub>2</sub> injection and to determine whether the stress state compromises the ability of reservoirs for safe and effective CO<sub>2</sub> storage. It was found that fracturing of the reservoir or caprock is not likely as long as the injection pressure is maintained below the UIC permit pressure limit.

#### 4.6 Pipeline/surface equipment

Leakage through pipelines and surface equipment is a potential risk. Core Energy uses its routine maintenance and daily inspection procedures to minimize this risk. Further, it will deploy three approaches to calculate the amounts of CO<sub>2</sub> lost through pipelines and surface equipment: 1) following GHGRR Subpart W methods for estimating fugitive and vented emissions, 2) using direct metering to measure specific venting events as discussed in Section 2.4.3, and 3) in the event an extreme event were to occur, using engineering best practices to estimate a loss.

### 5. Monitoring

This section describes the general approach to monitoring at the Core Energy facility and indicates how data will be collected for this MRV plan.

#### 5.1 General Monitoring Procedures

As part of its ongoing operations, Core Energy monitors and collects flow, pressure, and gas composition data from each reef in the central HMI computer system.

As indicated in Figure 13 Core Energy uses Coriolis mass flow meters for all measurements included in the mass balance (Section 7) and also uses Vortex flow meters for some operational monitoring. Fluid composition will be determined, at a minimum, quarterly, consistent with EPA

GHGRP's Subpart RR, section 98.447(a). All meter and composition data are documented, and records will be retained for the Specified Period. Quarterly composition analysis will be done at meter #2 at Chester 10 Facility for pure CO<sub>2</sub> gas and at meter #19 at Dover 36 Facility for combined recycle gas. If any other combined recycle gas processing facilities are added, as indicated in Section 2.5, similar Coriolis mass flow meters will be installed and quarterly composition analyses will be conducted. Such new meters would be included in the monitoring report and Section 7 calculations. If not done on a routine basis, Core will use initial baseline data or last available quarter composition analysis as continuation of reporting quarter, with justification as to why analysis was not done/deemed necessary. All composition analysis will be on % wt. basis of CO<sub>2</sub> in gas stream.

Core Energy has invested in Micro Motion Coriolis Mass Flow Meters throughout its operations. These meters are designed to retain calibration. The meters have no moving parts and a non-intrusive measuring sensor. As a result, there are no probes or detectors that come into direct contact with process fluids. The benefit of this design is that there are no bearings or rotors to wear, turbines to be deformed, electrodes to coat, or degradation of orifices to be concerned about. The manufacturer reports that "It has been our experience, and that of our customers, that Coriolis meters do not shift or lose their calibration during the life of the meter.

When calibration issues arise, the focus of the problem is normally traceable to the flowmeter installation or a characteristic of the process that was not previously taken into consideration." As a result, there are no prevailing industry standard(s) for meter calibration for these meters.

Core Energy observes trend data from the meters and has on occasion sent meters back to the company for recalibration but this does not occur routinely. This type of meter would have to be severely abused (serious mechanical damage, overheating beyond metal plasticity limits) to change calibration. These types of abuses do not happen during normal operations. Therefore, Core Energy considers this approach to be consistent with EPA GHGRP's Subpart RR, section 98.444(e)(3). These meters will be maintained, operated continually, and will feed data directly to the central HMI computer system. The meters meet the industry standard for meter accuracy and calibration frequency. The level of precision and accuracy for these meters currently satisfies the requirements for reporting in existing UIC permits.

Core Energy contracts with a third party firm that specializes in GHG Reporting Rule compliance to determine Core Energy's emissions using the Subpart W methodology. This results in an annual Subpart W report for Core Energy. Based on the results of this report to date, Core Energy does not meet the threshold for reporting its emissions to EPA through the EGRT system. Core Energy tracks its Subpart W emissions internally and will use these calculations, as specified the Subpart RR, for determining the mass of CO<sub>2</sub> stored.

## 5.2 CO<sub>2</sub> Received

Core Energy measures the volume of received CO<sub>2</sub> using Coriolis mass flow meters at the Chester 10 Facility and, as indicated in section 2.4.1, the Dover 36 Facility. As indicated in Section 2.5, any new recycle gas processing would be measured using Coriolis mass flow meters. No CO<sub>2</sub> is received in containers.



### 5.3 CO<sub>2</sub> Injected into the Subsurface

Injected CO<sub>2</sub> will be metered using the Coriolis mass flow meters dedicated to each injection well at a reef.

### 5.4 CO<sub>2</sub> Produced, Entrained in Products, and Recycled

For purposes of reporting under Subpart RR, Core energy will measure the mass of CO<sub>2</sub> produced through separators using Coriolis mass flow meters #19.

For any new production facilities added, as indicated in Section 2.5, the mass of CO<sub>2</sub> produced would similarly be measured using Coriolis mass flow meters.

CO<sub>2</sub> is produced as entrained or dissolved CO<sub>2</sub> in produced oil. As the oil passes through low-pressure separation to a gathering tank, a small amount of CO<sub>2</sub> is released. Core Energy has determined the emission factor of 16.84 scf/barrel conservatively estimates this amount (see Section 2.4.3), which is about 150 tonnes per year and will use this to determine the amount entrained as part of the CO<sub>2</sub> produced calculation.

### 5.5 CO<sub>2</sub> Emitted by Surface Leakage

Core Energy uses an event-driven process to assess, address, track, and if applicable quantify potential CO<sub>2</sub> leakage to the surface. Core Energy will reconcile the internal Subpart W report and results from any event-driven quantification to assure that surface leaks are not double counted.

The monitoring program for event-driven incidents has been designed to meet two objectives, in accordance with the leakage risk assessment in Section 4: 1) to detect problems before CO<sub>2</sub> leaks to the surface; and 2) to detect and quantify any leaks that do occur. This section discusses how this monitoring will be conducted and used to quantify the volumes of CO<sub>2</sub> leaked to the surface.

#### 5.5.1 Monitoring for potential Leakage from the Injection/Production Zone:

Core Energy routinely tracks and reports on a daily basis, the following surface data for all wells: Injection Rate (MCF), Production Rates (BO, BW, MCF), Tubing Pressure (psig), Casing Pressure (psig), Wellhead Temperatures (°F) and Runtime (Hours). Where there is instrumentation, data are collected more frequently but in the oilfield it is normal and customary for data to be reduced to daily volumes and/or averages. Core utilizes this data primarily for operational oversight and monitoring of EOR projects, but also intends to use this data to determine when further investigation of potential CO<sub>2</sub> leakage is warranted.

Core utilizes modeling, analog performance, operational practice, and historical project performance; bounded by permit conditions that take into account reservoir characteristics (e.g. injection pressure, injectant density, fracture gradient) to develop targeted daily/monthly injection rates, pressures and volumes. If injection rate or pressure significantly deviate from that which is targeted, it generates a flag and alerts operational personnel to investigate and resolve the matter. Operational and engineering personnel will collectively work to resolve these flagged events. Data flags and operational investigations do not mean that leakage of CO<sub>2</sub> has occurred, rather they are

an indication that the injection rate and pressure are not conforming to the targeted values. In most cases, the flagged events result in an easy fix (e.g. pressure gauge failure and subsequent replacement) and pose no threat of CO<sub>2</sub> leakage. However, in those rare cases whereby flagged events cannot be easily resolved, a more thorough and detailed investigation would be initiated, garnering wider Company or industry support as needed. Whenever any investigation identifies that CO<sub>2</sub> leakage has occurred, the volume of CO<sub>2</sub> that has escaped from the closed system will be quantified using operational and engineering judgement and included in the annual RR reporting.

Similarly, Core uses the collected data along with modeling, analogs and project performance to forecast produced volumes (i.e. oil, water, CO<sub>2</sub>) and composition. If producing wells do not have individual separation vessels and meters, they are individually well tested at least quarterly (more frequently if overall project production or individual well pressure data warrant it). The production data is reviewed at least monthly and if there is a significant deviation from past performance or forecast, operational and engineering personnel investigate further. If the cause of the deviation cannot be understood and resolved quickly, a more thorough and detailed investigation would be initiated, garnering wider Company or industry support as needed. Whenever any investigation identifies that CO<sub>2</sub> leakage has occurred, the volume of CO<sub>2</sub> that has escaped from the closed system will be quantified using operational and engineering judgement and included in the annual RR reporting.

Again, because of the unique geology of the NNPRT, to date, there has never been a case whereby leakage was suspected to have occurred in the EOR flood zone. In the very rare event that CO<sub>2</sub> leakage may be suspected in the EOR flood zone, Core would deploy methods to quantify the volume of CO<sub>2</sub> involved. With respect to tracking reservoir pressure, episodic surveys are conducted, on a field-by-field or well-by-well basis to gather information about reservoir pressure and other parameters (e.g. kh, skin). Because of the heterogeneity of these carbonate pinnacle reefs, it is not feasible to let injection wells fall-off or producing wells build-up for periods long enough to reach static conditions, thus, the bottom hole pressure measured in an injection well can be very significantly higher than that measured in a producing well over the typical survey duration (e.g. 3 to 7 days). Therefore, over time, well pressure survey histories are developed for both injection and production wells, that yield general performance behavior and characteristics for each well (field). Then, if a survey is run and its results diverge from this survey history in a statistically significant way, it triggers a deeper evaluation to discern what may be taking place and causing the anomaly. For example if injection wells in a field, over time, yield similar pressure survey results and then suddenly a survey yields an anomalous and lower result, then further evaluation is done to discern what may be causing the change (e.g. net CO<sub>2</sub> in reservoir declined considerably since last survey and/or an injection well was shut-in or its injection rate reduced, then the measured pressure would be expected to be lower than previous surveys).

If leakage in the flood zone were detected, Core Energy would use an appropriate method to quantify the involved volume of CO<sub>2</sub>. This might include use of material balance equations based on known injected quantities and monitored pressures in the injection zone to estimate the volume of CO<sub>2</sub> involved.

A subsurface leak might not lead to a surface leak. In the event of a subsurface leak, Core Energy would determine the appropriate approach for tracking subsurface leakage to determine and quantify leakage to the surface. To quantify leakage to the surface, Core Energy would estimate the relevant parameters (e.g., the rate, concentration, and duration of leakage) to quantify the leak volume. Depending on specific circumstances, these determinations may rely on engineering estimates.

#### 5.5.2 Monitoring of Wellbores:

Core Energy monitors wells through continual pressure monitoring in the injection zone (as described in Section 5.1), monitoring of the annular pressure in wellheads, and routine maintenance and inspection. At any time, in the case of an injection well, where there is a loss of MIT, the well must be and is shut-in until such time the wellbore is repaired. Upon completion of the workover, a new MIT is performed under the oversight of the EPA. The results of the MIT along with workover information are supplied to the EPA and if all is in order, they issue a letter authorizing injection to be resumed. Under no circumstances is injection commenced until such time the letter is in hand.

Leaks from wellbores would be detected through the follow-up investigation of pressure anomalies and visual inspection.

Anomalies in injection zone pressure may not indicate a leak, as discussed above. However, if an investigation leads to a work order, field personnel would inspect the equipment in question and determine the nature of the problem. If it is a simple matter, the repair would be made and the volume of leaked CO<sub>2</sub> would be included in the internal Subpart W report for the Core Energy Facility. If more extensive repair were needed, Core Energy would determine the appropriate approach for quantifying leaked CO<sub>2</sub> using the relevant parameters (e.g., the rate, concentration, and duration of leakage).

Anomalies in annular pressure or other issues detected during routine maintenance inspections would be treated in the same way. Field personnel would inspect the equipment in question and determine the nature of the problem. For simple matters the repair would be made at the time of inspection and the volume of leaked CO<sub>2</sub> would be included in the internal Subpart W report for the Core Energy Facility. If more extensive repairs were needed, the well would be shut in until repairs could be completed and Core Energy would determine the appropriate approach for quantifying leaked CO<sub>2</sub> using the relevant parameters (e.g., the rate, concentration, and duration of leakage).

In the event CO<sub>2</sub> is lost during a repair, the most recent daily volume of CO<sub>2</sub> would be prorated against the number of hours that the failure caused CO<sub>2</sub> to leak from the system. It should be noted that when doing workovers, the wells are always “killed” by using appropriate density fluid and the wells are “dead” (no CO<sub>2</sub> flow), thus, leakage has not occurred during workovers to wells to date. In the rare and unlikely event surface leakage does occur during a workover, an estimate of the volume would be made using engineering and operational judgements.

## 5.6 Mass of CO<sub>2</sub> Emissions from Equipment Leaks and Vented Emissions of CO<sub>2</sub> from Surface Equipment Located Between the Injection Flow Meter and the Injection Wellhead

Core Energy evaluates and estimates leaks from equipment, the CO<sub>2</sub> content of produced oil, and vented CO<sub>2</sub>, using the procedures in 40 CFR Part 98 Subpart W. Core Energy will use this method for reporting under Subpart RR.

## 5.7 Mass of CO<sub>2</sub> Emissions from Equipment Leaks and Vented Emissions of CO<sub>2</sub> from Surface Equipment Located Between the Production Flow Meter and the Production Wellhead

Core Energy evaluates and estimates leaks from equipment, the CO<sub>2</sub> content of produced oil, and vented CO<sub>2</sub>, using the procedures in 40 CFR Part 98 Subpart W. It also measures CO<sub>2</sub> emissions from dry and wet vents attached to the separators. Both of these measurements will be included under Subpart RR.

## 5.8 Demonstration that Injected CO<sub>2</sub> is not expected to Migrate to the Surface

At the end of the Specified Period, Core Energy intends to cease injecting CO<sub>2</sub> for the ancillary purpose of establishing the long-term storage of CO<sub>2</sub> in the Core Energy Facility. After the end of the Specified Period, Core Energy anticipates that it will submit a request to discontinue monitoring and reporting. The request will demonstrate that the amount of CO<sub>2</sub> reported as stored "is not expected to migrate in the future in a manner likely to result in surface leakage" ( §98.441).

At that time, Core Energy will be able to support its request with years of data collected during the Specified Period as well as two to three (or more, if needed) years of data collected after the end of the Specified Period. This demonstration will provide the information necessary for the EPA Administrator to approve the request to discontinue monitoring and reporting including:

- i. An assessment of injection data for each reef indicating the total volume of injected and stored CO<sub>2</sub> as well as the actual surface injection pressures;
- ii. An assessment of the CO<sub>2</sub> leakage detected, if any, including discussion of the estimated amount of CO<sub>2</sub> leaked and the distribution of emissions by leakage pathway; and
- iii. An assessment of reservoir pressure that demonstrates the reservoir pressure in a reef is either too low to enable flow to the surface (i.e., reef has been blown down) or that the reservoir pressure is stable enough to demonstrate that the CO<sub>2</sub> is contained within the reef and not expected to migrate in a manner to create a potential leakage pathway.

## 6. Determination of Baselines for Monitoring CO<sub>2</sub> Surface Leakage

Core Energy will use the results from daily monitoring of field conditions and operational data, as well as routine testing and maintenance information to monitor for surface leakage.

As indicated in sections 2.4.4. and 5, Core Energy uses onsite management and an automatic data system to conduct its EOR operations. Core Energy will use data from these efforts to identify and investigate variances from expected performance that could indicate CO<sub>2</sub> leakage. Below is a description of how this data will be used to determine when further investigation of potential CO<sub>2</sub> leakage is warranted.

- **Visual Inspections:** Operations personnel make daily rounds of the facilities and wells, providing a visual inspection of equipment used in the operations (e.g. vessels, piping, valves, wellheads). Making these rounds provide opportunity to identify issues early and address them proactively, which may preclude leaks from happening and/or minimize any CO<sub>2</sub> leakage. If an identified issue cannot be resolved by the person who first observes it, a work order will be generated to resolve the matter. Each event will be documented, include an estimate of the amount of CO<sub>2</sub> leaked and included in the annual RR reporting. Records for such events will be kept on file for a minimum of three years.
- **Injection Well Surveillance:** Core establishes target rates and pressures for all injection wells based on various parameters (e.g. CO<sub>2</sub> availability, field performance, delivery agreements, permit conditions). When a statistically significant deviation occurs that is outside of the established over or under range of the targeted values, it triggers further investigation to determine if the variance poses a leak threat. If investigation of an event identifies that a leak has occurred, those events will be documented, include an estimate of the amount of CO<sub>2</sub> leaked and included in the annual RR reporting. Records for such events will be kept on file for a minimum of three years.
- **Production Well Surveillance:** Core establishes a forecast for producing wells and projects, estimating the volumes of fluids (e.g. oil, CO<sub>2</sub>, water) that are likely to be produced over a period of time. Evaluation of the produced volumes along with other data (e.g. pressure, composition) informs operational decisions for how to manage a project and aid in identifying possible issues that may involve CO<sub>2</sub> leakage. These evaluations can direct engineering and/or operational personnel to investigate matters further, which can lead to work orders being issued to work on wells and/or surface equipment involved in a CO<sub>2</sub> EOR project. If investigation of an event identifies that a leak has occurred, those events will be documented, include an estimate of the amount of CO<sub>2</sub> leaked and included in the annual RR reporting. Records for such events will be kept on file for a minimum of three years.
- **Mechanical Integrity Testing (MIT):** Each CO<sub>2</sub> injection well has a permit condition whereby mechanical integrity has to be established and maintained. This involves the regular monitoring of the tubing-casing annular pressure and conducting annular fill-up tests. Core operational personnel monitor the pressure and conduct the tests in accordance with the permit conditions. In the event a loss of mechanical integrity occurs, the injection well is immediately shut-in and an investigation is initiated to determine what caused the loss of mechanical integrity. If investigation of an event identifies that a leak has occurred, those events will be documented, include an estimate of the amount of CO<sub>2</sub> leaked and included in the annual RR reporting. Records for such events will be kept on file for a minimum of three years.

## 7. Site Specific Considerations for the Mass Balance Equation

The Core Energy facility is small relative to many other EOR operations. It operates a current total of 15 injection, 14 production, and 7 monitoring/production wells located in 10 reefs. Core Energy also has 2.11 million metric tonnes of CO<sub>2</sub> inventory that will be reflected, over time, in the mass balance equation. To account for the site conditions and complexity Core Energy proposes the following modifications for using the equations in Subpart RR §98.443.

### 7.1. Mass of CO<sub>2</sub> Received

Core Energy will use equation RR-1 as indicated in Subpart RR §98.443 to calculate the mass of CO<sub>2</sub> received from the Chester 10 Facility and all recycle gas (currently from Dover 36 Facility but to include other new recycling facilities as indicated in Section 2.5.). In the annual monitoring report, Core Energy will track the current and cumulative volume of Dover 36 Facility CO<sub>2</sub> and indicate when it has reached 2,110,000 metric tonnes of working inventory; at that time, it will stop reporting the amount from Dover 36 under RR-1 / RR-3. In the future, any additional new sources of CO<sub>2</sub> will be added in the same manner.

$$CO_{2T,r} = \sum_{p=1}^4 (Q_{r,p} - S_{r,p}) * C_{CO_2,p,r} \quad \text{Equation RR-1}$$

where:

CO<sub>2T,r</sub> = Net annual mass of CO<sub>2</sub> received through flow meter r (metric tons).

Q<sub>r,p</sub> = Quarterly mass flow through a receiving flow meter r in quarter p at standard conditions (metric tons).

S<sub>r,p</sub> = Quarterly mass flow (metric tons) through a receiving flow meter r that is redelivered to another facility without being injected into a site well in quarter p

C<sub>CO<sub>2</sub>,p,r</sub> = Quarterly CO<sub>2</sub> concentration measurement in flow for flow meter r in quarter p (wt. percent CO<sub>2</sub>, expressed as a decimal fraction).

p = Quarter of the year.

r = Receiving flow meters.

Core Energy will sum to total Mass of CO<sub>2</sub> Received using equation RR-3 in §98.443

$$CO_2 = \sum_{r=1}^R CO_{2T,r} \quad \text{Equation RR-3}$$

where:

CO<sub>2</sub> = Total net annual mass of CO<sub>2</sub> received (metric tons).

CO<sub>2T,r</sub> = Net annual mass of CO<sub>2</sub> received (metric tons) as calculated in Equation RR-1 for flow meter r.

r = Receiving flow meter.

## 7.2 Mass of CO<sub>2</sub> Injected into the Subsurface

Core Energy will use equation RR-4 as indicated in Subpart RR §98.443 to calculate the mass of CO<sub>2</sub> injected into the subsurface at each of the ten reefs. Core proposes to use a method to calculate “C<sub>CO<sub>2</sub>,p,u</sub>” that uses a weighted average concentration that reflects the different CO<sub>2</sub> concentrations in the different sources of CO<sub>2</sub> as explained below.

$$CO_{2,u} = \sum_{p=1}^4 Q_{p,u} * C_{CO_2,p,u}$$

Equation RR-4

where:

CO<sub>2,u</sub> = Annual CO<sub>2</sub> mass injected (metric tons) as measured by flow meter u.

Q<sub>p,u</sub> = Quarterly mass flow rate measurement for flow meter u in quarter p (metric tons per quarter).

C<sub>CO<sub>2</sub>,p,u</sub> = Quarterly CO<sub>2</sub> concentration average measurement in flow for all injection flow meters (wt. percent CO<sub>2</sub>, expressed as a decimal fraction) as determined from Equation A below.

p = Quarter of the year.

u = Injection Flow meter.

For the weighted average concentration, C<sub>CO<sub>2</sub></sub>, Equation A indicates the current calculation using CO<sub>2</sub> from Chester 10 Facility and Dover 36 Facility. If new facilities are added, the weighted concentration average would be modified to include them in the same manner.

$$Concentration\ Average = \frac{Q_{p,CH10} * C_{CO_2,p,CH10} + Q_{p,D36} * C_{CO_2,p,D36}}{Q_{p,CH10} + Q_{p,D36}}$$

Equation A

Where:

Q<sub>p,CH10</sub> = Quarterly mass flow rate measurement of pure CO<sub>2</sub> (from Chester 10 Facility at flow meter #2) in quarter p (metric tons per quarter).

Q<sub>p,D36</sub> = Quarterly mass flow rate measurement of recycle gas (from Dover 36 Facility at flow meter #19) in quarter p (metric tons per quarter).

C<sub>CO<sub>2</sub>,p,CH10</sub> = Quarterly CO<sub>2</sub> concentration of pure CO<sub>2</sub> (from Chester 10 Facility at flow meter #2) in quarter p (wt. percent CO<sub>2</sub>, expressed as a decimal fraction).

C<sub>CO<sub>2</sub>,p,D36</sub> = Quarterly CO<sub>2</sub> concentration of recycle gas (from Dover 36 Facility at flow meter #19) in quarter p (wt. percent CO<sub>2</sub>, expressed as a decimal fraction).



Core Energy will aggregate injection data using equation RR-6:

$$CO_{2i} = \sum_{u=1}^U CO_{2,u} \quad \text{Equation RR-6}$$

where:

$CO_{2i}$  = Total annual  $CO_2$  mass injected (metric tons) through all injection wells.

$CO_{2,u}$  = Annual  $CO_2$  mass injected (metric tons) as measured by flow meter u.

### 7.3 Mass of $CO_2$ Produced

Core Energy uses Coriolis mass flow meters to measure  $CO_2$  in produced fluids and an emissions factors based on past testing to determine  $CO_2$  entrained in oil. It will use equation RR-7 and RR-9 to report this data.

If new production facilities are added, as indicated in Section 2.5, the same approach will be applied.

$$CO_{2,w} = \sum_{p=1}^4 Q_{p,w} * C_{CO_2,p,w} \quad \text{Equation RR-7}$$

Where:

$CO_{2,w}$  = Annual  $CO_2$  mass produced (metric tons) through separator w.

$Q_{p,w}$  = Quarterly gas mass flow rate measurement for separator w in quarter p (metric tons).

$C_{CO_2,p,w}$  = Quarterly  $CO_2$  concentration of recycle gas (currently at Dover 36 Facility flow meter #19) for separator w in quarter p (wt. percent  $CO_2$ , expressed as a decimal fraction).

p = Quarter of the year.

w = Separator.

Core will aggregate production data using equation RR-9

$$CO_{2P} = \sum_{w=1}^W CO_{2,w} + X \quad \text{Equation RR-9}$$

Where:

$CO_{2P}$  = Total annual  $CO_2$  mass produced (metric tons) through all separators in the reporting year.

$CO_{2,w}$  = Annual  $CO_2$  mass produced (metric tons) through separator w in the reporting year.

w = Separator flow meter.

X = Entrained  $CO_2$  in produced oil (metric tons).

## 7.4 Mass of CO<sub>2</sub> emitted by Surface Leakage

Core Energy will calculate and report the total annual Mass of CO<sub>2</sub> emitted by Surface Leakage using an approach that is tailored to specific leakage events. As described in Sections 4 and 5.1.5-5.1.7, Core Energy is prepared to address the potential for leakage in a variety of settings. Estimates of the amount of CO<sub>2</sub> leaked to the surface will likely depend on a number of site-specific factors including measurements, engineering estimates, and emission factors, depending on the source and nature of the leakage.

Core Energy's process for quantifying leakage will entail using best engineering principles or emission factors. While it is not possible to predict in advance the types of leaks that will occur, Core Energy describes some approaches for quantification in Section 5.1.5-5.1.7. In the event leakage to the surface occurs, Core Energy would quantify and report leakage amounts, and retain records that describe the methods used to estimate or measure the volume leaked as reported in the Annual Subpart RR Report. Further, Core Energy will reconcile the internal Subpart W report and results from any event-driven quantification to assure that surface leaks are not double counted.

Equation RR-10 in 48.433 will be used to calculate and report the Mass of CO<sub>2</sub> emitted by Surface Leakage:

$$CO_{2E} = \sum_{x=1}^X CO_{2,x} \quad \text{Equation RR-10}$$

where:

CO<sub>2E</sub> = Total annual CO<sub>2</sub> mass emitted by surface leakage (metric tons) in the reporting year.

CO<sub>2,x</sub> = Annual CO<sub>2</sub> mass emitted (metric tons) at leakage pathway x in the reporting year.

x = Leakage pathway.

## 7.5 Mass of CO<sub>2</sub> sequestered in subsurface geologic formations.

Core Energy will use equation RR-11 to determine the mass of CO<sub>2</sub> that is incidentally stored each year.

$$CO_2 = CO_{2I} - CO_{2P} - CO_{2E} - CO_{2FI} - CO_{2FP} \quad \text{Equation RR-11}$$

where:

CO<sub>2</sub> = Total annual CO<sub>2</sub> mass sequestered in subsurface geologic formations (metric tons) at the facility in the reporting year.

CO<sub>2I</sub> = Total annual CO<sub>2</sub> mass injected (metric tons) in the well or group of wells covered by this source category in the reporting year. CO<sub>2P</sub> = Total annual CO<sub>2</sub> mass produced (metric tons) net of of CO<sub>2</sub> entrained in oil in the reporting year.

CO<sub>2E</sub> = Total annual CO<sub>2</sub> mass emitted (metric tons) by surface leakage in the reporting year. CO<sub>2FI</sub> = Total annual CO<sub>2</sub> mass emitted (metric tons) from equipment leaks and vented emissions of CO<sub>2</sub> from equipment located on the surface, between the

flow meter used to measure injection quantity and the injection wellhead in the reporting year, calculated as provided in subpart W.

$CO_{2FP}$  = Total annual  $CO_2$  mass emitted (metric tons) from equipment leaks and vented emissions of  $CO_2$  from equipment located on the surface between the production wellhead and the flow meter used to measure production quantity in the reporting year, calculated as in Subpart W and including the metered  $CO_2$  measurements at the wet and dry vents attached to the separators.

## 7.6 Cumulative mass of $CO_2$ reported as sequestered in subsurface geologic formations

Core Energy will sum up the total annual volumes obtained using equation RR-11 in 98.443 to calculate the Cumulative Mass of  $CO_2$  Sequestered in Subsurface Geologic Formations.

## 8. Estimated Schedule for Implementation of MRV Plan

This plan will be effective as of January 1, 2018.

## 9. Quality Assurance Program

### 9.1 Monitoring

Core Energy will follow the requirements in 40 CFR part 98.444 as indicated in Sections 2, 5 and 7. As indicated in Section 5.1, Core Energy has invested in Micro Motion Coriolis Mass Flow Meters throughout its operations. These meters are designed to retain calibration. The meters have no moving parts and a non-intrusive measuring sensor. As a result, there are no probes or detectors that come into direct contact with process fluids. The benefit of this design is that there are no bearings or rotors to wear, turbines to be deformed, electrodes to coat, or degradation of orifices to be concerned about. The manufacturer reports that “It has been our experience, and that of our customers, that Coriolis meters do not shift or lose their calibration during the life of the meter. When calibration issues arise, the focus of the problem is normally traceable to the flow meter installation or a characteristic of the process that was not previously taken into consideration.” As a result, there are no prevailing industry standard(s) for meter calibration for these meters. Core Energy observes trend data from the meters and has on occasion sent meters back to the company for recalibration but this does not occur routinely. Core Energy considers this approach to be consistent with EPA GHGRP’s Subpart RR, section 98.444(e)(3). These meters will be maintained, operated continually, and will feed data directly to the central HMI computer system. The meters meet the industry standard for meter accuracy and calibration frequency. The level of precision and accuracy for these meters currently satisfies the requirements for reporting in existing UIC permits.

### 9.2 Procedures for estimating missing data.

In the event Core Energy is not able to collect data for the mass balance equations, it will follow the requirements in 40 CFR part 98.445 to provide missing data.

When estimating the volume of missing CO<sub>2</sub> data due to an interruption in data collection or mechanical failure of a meter (equipment) is to use the most recent daily volume of CO<sub>2</sub> associated with the meter and calculate the proportionate volume of “lost” CO<sub>2</sub> based on the number of hours involved in the data gap or until meter repaired.

### 9.3 MRV Plan Revisions

In the event there is a material change to the monitoring and/or operational parameters of the Core Energy CO<sub>2</sub> EOR operations that is not anticipated in this MRV plan, the MRV plan will be revised and submitted to the EPA Administrator within 180 days as required in §98.448(d).

## 10. Records Retention

Core Energy will maintain and submit records required under 40 CFR Part 98.3(g) and 40 CFR Part 98.447. Records will be maintained by Core Energy in electronic format at the Core Energy headquarters. In addition, Core Energy has well and facility data in three forms; A.) Paper copies (scanned to server), B.) Keyed in data from paper copies into database, and C.) Automated capture of limited set of data that was recently instrumented (Fall of 2016).

## 11. References

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# Appendix

## Appendix I: List of Wells

Table A-1. Core Energy Wells used for Monitoring and Accounting

Unit	Facility	API Permit	DEQ Permit	Well Name	Well Type	Well Status
<b>Dover 33 EOR Unit</b>	Dover 36 CPF	21-137-29565-00-00	29565	Lawnichak & Myszkiec 1-33	Injection	INJ
<b>Dover 33 EOR Unit</b>	Dover 36 CPF	21-137-00652-00-00	61209	Lawnichak 9-33	Oil	PR
<b>Dover 33 EOR Unit</b>	Dover 36 CPF	21-137-51603-00-00	51603	Lawnichak & Myszkiec 5-33 HD1	Oil	PR
<b>Dover 33 EOR Unit</b>	Dover 36 CPF	21-137-50985-04-00	55942	Lawnichak & Myszkiec 2-33 HD4	Oil	PR
<b>Bagley 11-14-23 EOR</b>	Dover 36 CPF	21-137-39758-01-00	39866	Wrubel 4-14A	Injection	INJ
<b>Bagley 11-14-23 EOR</b>	Dover 36 CPF	21-137-30536-00-00	30536	MBM 1-22	Injection	INJ
<b>Bagley 11-14-23 EOR</b>	Dover 36 CPF	21-137-38240-00-00	38240	Daughters of Friel 2-11	Injection	INJ
<b>Bagley 11-14-23 EOR</b>	Dover 36 CPF	21-137-37794-00-00	37794	Janik Mackowiac 1-11	Oil	OBS
<b>Bagley 11-14-23 EOR</b>	Dover 36 CPF	21-137-38286-00-00	38286	Janik Stevens 3-11	Oil	OBS
<b>Bagley 11-14-23 EOR</b>	Dover 36 CPF	21-137-39748-00-00	39748	Janik Strappazon 3-14	Oil	OBS
<b>Bagley 11-14-23 EOR</b>	Dover 36 CPF	21-137-38859-02-00	39897	Glasser 1-14B	Oil	OBS
<b>Charlton 19 Unit (EOR)</b>	Dover 36 CPF	21-137-42766-00-00	42766	El Mac Hills 2-18	Injection	INJ
<b>Charlton 19 Unit (EOR)</b>	Dover 36 CPF	21-137-40911-04-00	57261	El Mac Hills 1-19D	Oil	SI-P
<b>Charlton 19 Unit (EOR)</b>	Dover 36 CPF	21-137-41801-01-00	61197	El Mac Hills 1-18A	Oil	PR
<b>Charlton 30/31 EOR Unit</b>	Dover 36 CPF	21-137-30203-00-00	30203	State Charlton C2-30	Injection	INJ
<b>Charlton 30/31 EOR Unit</b>	Dover 36 CPF	21-137-59048-00-00	59048	State Charlton & Larsen 3-31	Injection	INJ
<b>Charlton 30/31 EOR Unit</b>	Dover 36 CPF	21-137-29989-00-00	29989	State Charlton 1-30A	Injection	INJ
<b>Charlton 30/31 EOR Unit</b>	Dover 36 CPF	21-137-57916-00-00	57916	State Charlton 4-30	Oil	PR
<b>Charlton 30/31 EOR Unit</b>	Dover 36 CPF	21-137-31287-00-00	31287	State Charlton 2-30	Oil	PR
<b>Charlton 6 EOR Unit</b>	Dover 36 CPF	21-137-35209-00-00	35209	Zeimet-Higgins & St Charlton 1-6	Injection	INJ
<b>Charlton 6 EOR Unit</b>	Dover 36 CPF	21-137-59086-00-00	59086	State Charlton & Boeve 2-6	Oil	PR
<b>Chester 2 EOR Unit</b>	Dover 36 CPF	21-137-29430-00-00	29430	Wolf, Carl 1A	Injection	INJ
<b>Chester 2 EOR Unit</b>	Dover 36 CPF	21-137-29958-01-00	29958	Wolf, Carl et al C1-HD1	Oil	PR

<b>Chester 2 EOR Unit</b>	Dover 36 CPF	21-137- 60596-01-00	60596	Cargas 3-2 HD2	Oil	PR
<b>Chester 5 EOR Unit</b>	Dover 36 CPF	21-137- 59237-00-00	59237	Borowiak 2-6	Injection	INJ
<b>Chester 5 EOR Unit</b>	Dover 36 CPF	21-137- 58926-00-00	58926	Butler 3-5	Injection	SI-I
<b>Chester 5 EOR Unit</b>	Dover 36 CPF	21-137- 29265-01-00	60833	Piasecki 1-7A	Oil	PR
<b>Dover 35 EOR Unit</b>	Dover 36 CPF	21-137- 29236-00-00	29236	Salling Hanson Trust 1-35	Injection	INJ
<b>Dover 35 EOR Unit</b>	Dover 36 CPF	21-137- 37324-01-00	59238	Pomarzynski et al 5-35A	Oil	SI-P
<b>Dover 35 EOR Unit</b>	Dover 36 CPF	21-137- 29947-01-00	29995	Salling Hanson Trust 4-35A	Oil	PR
<b>Dover 35 EOR Unit</b>	Dover 36 CPF	21-137- 57787-00-00	57787	Pomarzynski et al 6-35	Oil	PR
<b>Dover 36 EOR Unit</b>	Dover 36 CPF	21-137- 29348-00-00	29348	Kubacki State 3-35	Injection	INJ
<b>Dover 36 EOR Unit</b>	Dover 36 CPF	21-137- 29235-00-00	29235	Kubacki State 1-36	Injection	INJ
<b>Dover 36 EOR Unit</b>	Dover 36 CPF	21-137- 52719-00-00	52719	Dover State 36 Unit 3-36	Oil	PR
<b>Chester 16 EOR Unit</b>	Dover 36 CPF	21-137- 61189-00-00	61189	Chester 16 Unit 6-16 Pilot	Injection	INJ
<b>Chester 16 EOR Unit</b>	Dover 36 CPF	21-137- 61186-00-00	61186	Chester 16 Unit 8-16	Oil	OBS



Table A-2. Summary of Niagaran Wells by Reef With Listing of Depth, Completion Date, and Wireline Log Inventory used for Geologic Characterization

Source: Michigan DEQ Oil and Gas Well Database ([http://michigan.gov/deq/0,1607,7-135-3311\\_4111\\_4231-97870--,00.html](http://michigan.gov/deq/0,1607,7-135-3311_4111_4231-97870--,00.html))

Note: CAL=CALIPER; GR=GAMMA RAY; NPFI=NEUTRON POROSITY; RHOB=DENSITY; PE=PHOTOELECTRIC; SON=SONIC; RES=RESISTIVITY; CBL=CEMENT BOND LOG; CBIL= circumferential borehole image log (acoustic image log); NEUTRON= neutron log reported in neutron units; PNC=Pulsed Neutron Capture log.

(a) Indicates currently active (not plugged/abandoned) producing well.

(b) Indicates currently active (not plugged/abandoned) injection well.

(c) Deviated well; total depth amsl will be determined after acquiring deviation survey.

Reef	Well Permit No.	Well Name	Well No.	Total Depth, ft		Date Completed	Wireline Logs
				bgs	amsl		
Bagley	29074	Yule King Tree	1-15	6135	- 4815	1/14/1973	CAL,GR,NPFI,RHOB,RES
	29085	Alan Gornick	1-23	6177	- 4867	1/18/1973	CAL,GR,NPFI,RHOB
	29249	Alan Gornick	1-14	6165	- 4869	11/23/1973	CAL,GR,NPFI,RHOB
	30536 <sup>(a)</sup>	MBM	1-22	6013	- 4689	10/24/1975	CAL,GR,NPFI,RHOB,RES
	37794 <sup>(a)</sup>	Janik & Mackowiac	1-11	6326	- 5021	9/11/1984	CAL,GR,NPFI,RHOB,RES,PNC
	38240 <sup>(b)</sup>	Daughters of Friel	2-11	6250	- 4739	10/30/1984	CAL,GR,NPFI,RHOB,RES
	38286 <sup>(a)</sup>	Janik & Stevens	3-11	6045	- 4676	11/2/1984	CAL,GR,NPFI,RHOB,RES
	38859	Glasser	1-14A	6115	- 4811	3/2/1986	CAL,GR,NPFI,RES
	38923	Yule King Tree	1-14	6024	- 4725	10/17/1985	CAL,GR,NPFI,RES,PNC

Reef	Well Permit No.	Well Name	Well No.	Total Depth, ft		Date Completed	Wireline Logs
				bgs	amsl		
	39554	Stevens and State Bagley	1-22	6295	- 4975	1/13/1986	CAL,GR,NPHI,RHOB,RES
	39748 <sup>(a)</sup>	Janik & Strappazon	3-14	6000	- 4706	2/24/1986	CAL,GR,NPHI,RHOB,RES
	39758	Wrubel	4-14	6140	(c)	3/9/1986	CAL,GR,NPHI,RHOB,RES
	39850	Glasser	1-14A	6367	- 4839	3/12/1986	CAL,GR,NPHI,RHOB,RES
	39866 <sup>(a)</sup>	Wrubel	4-14A	6191	- 4822	4/21/1986	CAL,GR,NPHI,RHOB,RES
	39897 <sup>(a)</sup>	Glasser	1-14B	6130	- 4752	5/7/1986	CAL,GR,NPHI,RES,PNC
	55307	Stevens and State Bagley	1-22A	6270	- 4910	1/9/2003	CAL,GR,NPHI,RHOB,RES
Charlton 6	28895	Zeimet & Higgins	1-6	6008	- 4724	6/21/1972	CAL,GR,NPHI,RHOB,RES
	35209 <sup>(b)</sup>	Zeimet, Higgins & State Charlton	1-6	5975	- 4745	12/10/1981	CAL,GR,NPHI,RHOB,PE,RES
	59086 <sup>(a)</sup>	State Charlton & Boeve	2-6	6202	- 4796	6/19/2008	CAL,GR,NPHI,RHOB,RES,PE
Charlton 19	40911	El Mac Hills	1-19	5675	- 4552	3/9/1988	CAL,GR,NPHI,RHOB,RES,SON
	41801	El Mac Hills	1-18A	5466	- 4341	2/24/1989	CAL,GR,NPHI,RHOB,RES,PNC
	42766 <sup>(b)</sup>	El Mac Hills	2-18	5555	(c)	2/5/1990	CAL,GR,NPHI,RHOB,RES,PNC
	54416	El Mac Hills	1-19A	5433	- 4297	6/22/2001	Not Logged
	54582	El Mac Hills	1-19B	5421	(c)	6/27/2001	Not Logged
	54583	El Mac Hills	1-19C	5321	- 4246	7/1/2001	Not Logged
	57261 <sup>(a)</sup>	El Mac Hills	1-19D	5495	- 4335	12/21/2005	CAL,GR,NPHI,RHOB,RES,SON,PNC
Charlton 30-31	29073	Salling Hanson et al	1-31	5770	- 4645	1/9/1973	CAL,GR,NPHI,RHOB,SON,RES
	30195	State Charlton "C"	1-30	5679	- 4497	3/21/1975	CAL,GR,NPHI,RHOB,RES

Reef	Well Permit No.	Well Name	Well No.	Total Depth, ft		Date Completed	Wireline Logs
				bgs	amsl		
	32605	State Charlton "C"	3-30	5746	- 4563	12/16/1978	CAL,GR,NPHI,RHOB,RES
	29989 <sup>(b)</sup>	State Charlton	1-30A	5650	- 4582	12/24/1974	CAL,GR,NPHI,SON,RES
	30203 <sup>(b)</sup>	State Charlton "C"	2-30	6255	- 4588	4/22/1975	CAL,GR,NPHI,RHOB,RES
	31287 <sup>(a)</sup>	State Charlton	2-30	5660	- 4517	12/7/1976	CAL,GR,NPHI,SON,RES
	57916 <sup>(a)</sup>	State Charlton	4-30	5800	- 4599	11/30/2006	CAL,GR,NPHI,RHOB,PE,RES
	59048 <sup>(b)</sup>	State Charlton & Larsen	3-31	5800	- 4689	7/7/2008	CAL,GR,NPHI,RHOB,PE,RES
Chester 2	28459	Cargas, Perry J	1	6005	- 4762	10/4/1971	CAL,GR,NPHI,RHOB,SON,RES
	28706	Finnegan, Bernard et al	1	6051	- 4818	1/6/1972	CAL,GR,NPHI,RES
	29677	Wolf, Carl	1-B	5847	- 4568	6/27/1974	CAL,GR,NPHI,RHOB,RES
	31646	Cargas, Perry J	1-2A	5990	- 4745	9/9/1977	CAL,GR,NPHI,RHOB,RES
	29430 <sup>(b)</sup>	Wolf, Carl	1-A	5973	- 4710	12/2/1973	CAL,GR,NPHI,RHOB,RES
	29958 <sup>(a)</sup>	Wolf, Carl et al "C"	1	5806	- 4536	12/9/1974	CAL,GR,NPHI,RHOB,RES
	29958-01 <sup>(a)</sup>	Wolf, Carl et al "C"	1 HD1	6570	- 4509	10/9/2001	CAL,GR,CBL
	60596 <sup>(a)</sup>	Cargas, Perry J	3-2 HD-1	6962	- 4556	10/9/2012	CAL,GR,NPHI,RHOB,RES,SON,PNC
Chester 5-6	29067	Borowiak	1-6	6022	- 4673	1/11/1973	CAL,GR,NPHI,SON,RES
	29234	Borowiak	1-5	5725	- 4409	4/13/1973	CAL,GR,NPHI,SON,RES
	29254	Kosiara	2-7	5750	- 4398	5/24/1973	CAL,GR,SON,RES
	29265	Piasecki	1-7	5770	- 4416	5/4/1973	CAL,GR,NPHI,SON,RES,PNC

Reef	Well Permit No.	Well Name	Well No.	Total Depth, ft		Date Completed	Wireline Logs
				bgs	amsl		
	31515	Piasecki, John State Chester	1-7	5800	- 4462	6/1/1977	CAL,GR,NPHI,RHOB,RES
	32207	Kosiara, Josephine	2-7A	5881	(c)	3/20/1978	CAL,GR,NPHI,RHOB,RES
	38424	Gottloeb	1-8	6080	(c)	11/21/1984	CAL,GR,NPHI,RHOB,PE,RES
	40169	Nienaber	2-5	5985	- 4633	12/16/1986	CAL,GR,NPHI,RHOB,PE,RES
	58926 <sup>(b)</sup>	Butler	3-5	5897	- 4585	5/1/2008	CAL,GR,NPHI,RHOB,RES,CBIL,CRA
	59237 <sup>(b)</sup>	Borowiak	2-6	6100	- 4751	7/25/2008	CAL,GR,NPHI,RHOB,PE,RES,CBIL,CBL
Chester 16	28159	Gaylord Mortgage	1-16	6210	- 4873	1/4/1971	CAL,GR,NPHI,RHOB,RES,SNP
	28433	Veraghen, Martin G	4-21	6303	- 4972	8/13/1971	CAL,GR,NPHI,RHOB,RES,SNP,SON
	28511	Gaylord Mortgage	2-16	6250	- 4907	9/4/1971	CAL,GR,NPHI,RES,SNP,SON
	28743	Veraghen & Rypkowski	5-21	6350	- 5037	3/29/1972	CAL,GR,NPHI,RES,SNP,SON
	28796	Gaylord Mortgage	3-16	6222	- 4896	8/22/1972	CAL,GR,NPHI,RES,SNP
	28798	Dreffs	4-16	6265	- 4913	3/13/1972	RES,SNP, SON
	28918	Veraghen & Dreffs	6-21	6318	- 4995	7/20/1972	CAL,GR,RES,SNP,SON
	61186	Chester	8-16	6455	- 5020	2/26/2017	CAL,GR,NPHI,RES,RHOB,SON
	61189***	Chester	6-16	6697	- 5061	12/23/2016	CAL,GR,NPHI,RES,RHOB,SON,PNC
Dover 33	29565 <sup>(b)</sup>	Lawnichak & Myszkier	1-33	5675	- 4528	5/20/1974	CAL,GR,NPHI,RES,RHOB,SON,PNC
	29781	Lawnichak & Myszkier	3-33	5625	- 4404	8/16/1974	CAL,GR,NPHI,RES
	29809	Koblinski & Fisher	1-28	5514	- 4397	8/22/1974	CAL,GR,NPHI,RES,SNP

Reef	Well Permit No.	Well Name	Well No.	Total Depth, ft		Date Completed	Wireline Logs
				bgs	amsl		
	29840	Kirt House	2-28	5475	- 4290	8/7/1974	CAL,GR,NPHI,RES,SON
	30392	Winter	2-33	5840	- 4560	8/9/1975	CAL,GR,NPHI,RES,SON
	31108	Amejka	2-34	5886	- 4657	9/5/1976	CAL,GR,NPHI,SON
	31228	Boughner State Dover	3-28	5520	- 4401	7/23/1977	CAL,GR,NPHI,SON
	31303	Thompson	1-33	5690	- 4540	11/22/1976	CAL,GR,NPHI,RES,RHOB
	32298	Boughner State Dover	4-28	5505	(c)	7/7/1978	CAL,GR,NPHI
	33830	Lawnichak & Myszkier	5-33	5775	- 4565	7/28/1980	CAL,GR,NPHI,RES,SON
	33937	Lawnichak & Myszkier	5-33A	5746	- 4536	8/4/1980	CAL,GR,NPHI,RES,SON
	35195	Winter	1-33	5740	- 4457	12/31/1982	CAL,GR,NPHI,RES,RHOB
	35584	Lawnichak & Morey	1-33	5703	- 4539	8/24/1982	CAL,GR,NPHI,RHOB
	50985	Lawnichak & Myszkier	2-33	5763	- 4597	11/22/1996	CAL,GR,NPHI,RHOB,PNC
	51601	Lawnichak & Myszkier	2-33 HD1	6990	- 4315	12/30/1996	CAL,GR,TDT
	51603	Lawnichak & Myszkier	5-33 HD1	6456	- 4354	2/2/1997	CAL,GR,PNC
	55479	Lawnichak & Myszkier	2-33 HD2	6138	(c)	8/21/2003	Not Logged
	55845	Lawnichak & Myszkier	2-33 HD3	7335	- 4368	9/23/2003	Not Logged
	55942	Lawnichak & Myszkier	2-33 HD4	7134	- 4348	12/29/2003	Not Logged
	61209	Lawnichak	9-33	6085	- 4677	12/3/2016	CAL,GR,NPHI,RES,RHOB,SON
□ ○ ☹	29374	Pomerzynski	2-35	5760	- 4619	9/27/1973	CAL,GR,NPHI,SON,RES

Reef	Well Permit No.	Well Name	Well No.	Total Depth, ft		Date Completed	Wireline Logs
				bgs	amsl		
	29947	Salling Hanson Trust	4-35	5564	- 4450	10/18/1974	CAL,GR,SON
	35941	Tinsey	1-35	5792	(c)	8/23/1982	CAL,GR,NPHI,RHOB,PE,RES
	37324	Pomerzynski et al	5-35	5715	- 4575	12/22/1983	CAL,GR,NPHI,RHOB,PE,RES
	37381	Taskey & Saddler Estate	1-35	5768	- 4615	2/14/1984	CAL,GR,NPHI,RHOB,RES
	29236 <sup>(b)</sup>	Salling & Hanson	1-35	5780	- 4656	5/25/1973	CAL,GR,NPHI,SON,RES
	29995 <sup>(b)</sup>	Salling Hanson Trust	4-35A	5715	- 4504	11/4/1974	CAL,GR,NPHI,SON,RES
	57787 <sup>(a)</sup>	"Pomarzynski"	6-35	5950	- 4688	11/30/2006	CAL,GR,NPHI,RHOB,PE,RES
	(59238) <sup>(a)</sup>	"Pomarzynski"	5-35A	5864	- 4437	8/24/2008	CAL,GR,NPHI
Dover 36	29303	Kubacki Cole	2-36	5765	- 4592	6/14/1973	CAL,GR,NPHI,SON,RES
	29664	Freese, Charles E III et al	1-2	5830	- 4614	4/8/1974	CAL,GR,NPHI,SON,RES
	29235 <sup>(b)</sup>	Kubacki & State Dover	1-36	5835	- 4683	4/29/1973	CAL,GR,NPHI,SON,RES
	29348 <sup>(b)</sup>	Kubacki State	3-35	6431	(c)	7/6/1973	CAL,GR,NPHI,SON,RES
	52719 <sup>(a)</sup>	Dover 36 Unit	3-36	5700	- 4533	7/31/1998	CAL,GR,NPHI,RHOB,PE,RES

Source: [Michigan DEQ Oil and Gas Well Database](#)

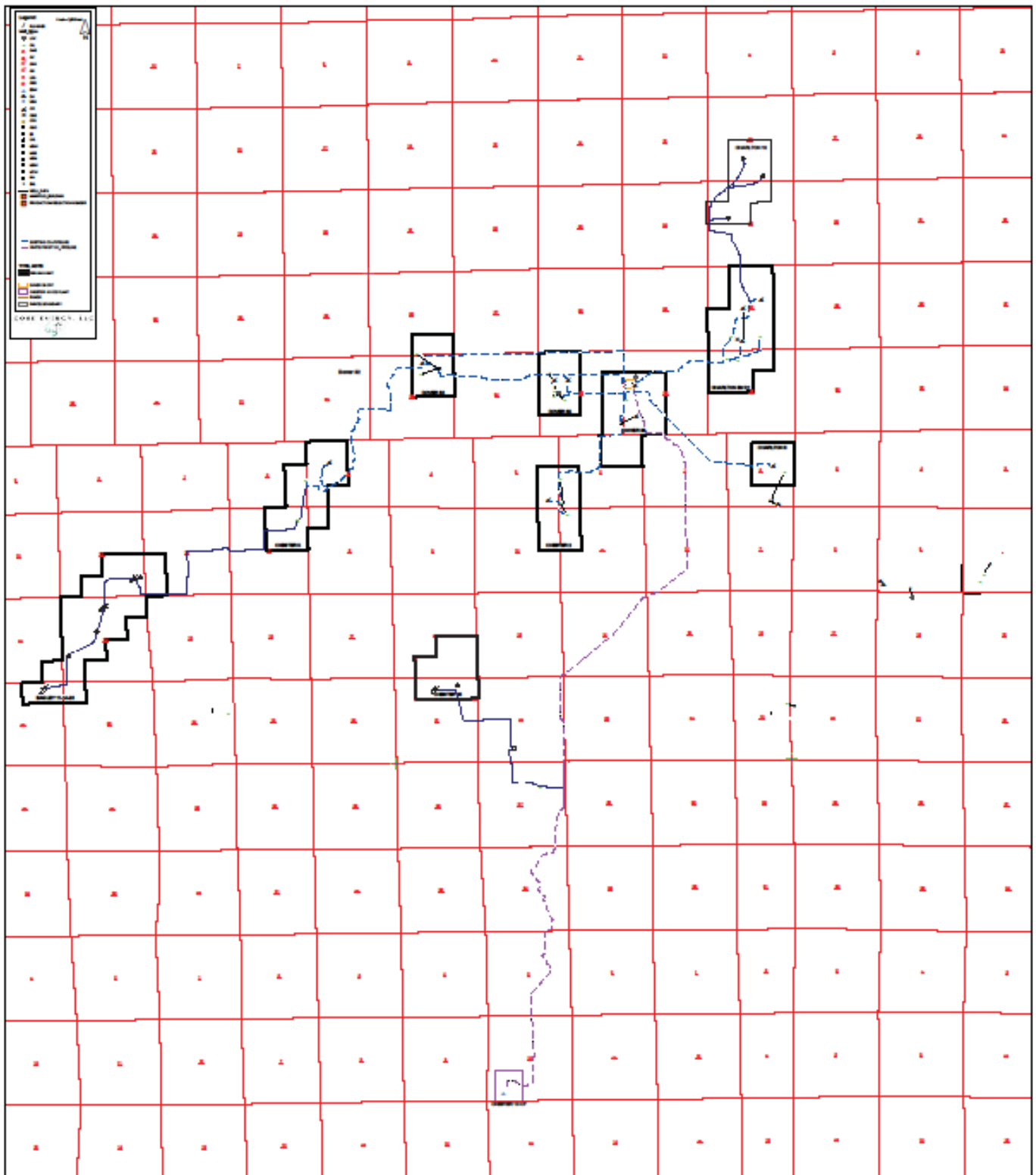
Note: CAL=CALIPER; GR=GAMMA RAY; NPHI=NEUTRON POROSITY; RHOB=DENSITY; PE=PHOTOELECTRIC; SON=SONIC; RES=RESISTIVITY; CBL=CEMENT BOND LOG; CBIL= circumferential borehole image log (acoustic image log); NEUTRON= neutron log reported in neutron units; PNC=Pulsed Neutron Capture log.

(a) Indicates currently active (not plugged/abandoned) producing well.

(b) Indicates currently active (not plugged/abandoned) injection well.

(c) Deviated well; total depth amsl will be determined after acquiring deviation survey.

## Appendix II: Map of Core Energy pipelines





**Request for Additional Information: Core Energy Subpart RR MRV Plan  
August 30, 2018**

Instructions: Please enter responses into this table. Any long responses, references, or supplemental information may be attached to the end of the table as an appendix. Supplemental information may also be provided in a resubmitted MRV plan.

No.	MRV Plan		EPA Questions	Responses
	Section	Page		
1.	2 and 2.1	7-8	<p>MRV Plan: [Pg 7] The NNPRT consists of closely spaced but highly-compartmentalized pinnacle reefs located, on average, about 6,000 feet below the ground surface (bgs) but can range from 3,000 to 8,000 feet.</p> <p>[Pg 8] The pinnacle reefs range from 2000 feet to more than 6000 feet deep;</p> <p>Is there a reason the reefs are listed as having two different depth ranges?</p>	<p>This is a typo that has been corrected in Section 2 of the final MRV plan.</p>
2.	2.2	18	<p>MRV plan: When a reef is abandoned, Core Energy typically recovers as much CO<sub>2</sub> as it can through well blown down, which reduces pressure to roughly 500 psi.</p> <p>In the GHGRP, the term blowdown is typically used in the context of venting natural gas or CO<sub>2</sub> to the atmosphere. The above statement from the MRV plan does not refer to venting to the atmosphere. Therefore, it would be helpful to explain what is meant by “blow down” in this context (or to use an alternative term). How is the CO<sub>2</sub> collected when the well is blown down?</p>	<p>The term “blown down” has been replaced with language that describes the process involved in recovering a portion of injected CO<sub>2</sub> when a reef is abandoned.</p>

No.	MRV Plan		EPA Questions	Responses
	Section	Page		
3.	3.2	28	<p>MRV Plan: The maximum monitoring area (MMA) for the MRV Plan, based on the anticipated future of expansion to conduct CO<sub>2</sub> EOR operations in reefs within the Northern Niagaran Pinnacle Reef Trend (NNPRT), extends geologically along the northern edge of the Michigan Basin (see Figure 14).</p> <p>40 CFR 98.449 defines “maximum monitoring area” as the area that must be monitored under this regulation and is defined as equal to or greater than that area expected to contain the free phase CO<sub>2</sub> plume until the CO<sub>2</sub> plume has stabilized plus an all-around buffer zone of at least one-half mile. Given this, does the defined MMA include a buffer zone from each of the outermost reefs (reefs that are next to the MMA boundary) that have potential for CO<sub>2</sub> EOR? This should be more clearly stated to be consistent with Subpart RR requirements.</p>	<p>The MMA does include a buffer of ½ mile around the range of reefs. The language in Section 3.2 has been modified to more clearly indicate that this is the case.</p>
4.	4.0	30	<p>For the Existing Wellbore Section and potential leakage pathways: Is there any risk of leakage from future wells drilled in the MMA that would be used for EOR and/or target a different formation? A brief explanation would be helpful.</p>	<p>No, there is no risk of leakage from future wells drilled in the MMA because of the highly-compartmentalized nature of the pinnacle reefs and control of rights for reefs within active EOR projects. A new section 4.1.1 has been added to the MRV plan to explain this more fully in the context of new wells.</p>
5.	4.1	31	<p>MRV Plan: In addition to analyzing wellbore integrity, cement plugs were also analyzed and ranked based on depth, number of plugs, thickness, and age.</p> <p>Was this data on the cement plugs from the state and what area did it cover?</p>	<p>These records come from MDEQ and cover a broad region. The MRV plan has been updated to include the reference to the technical study reporting the results of the cement plug assessment and to describe the study scope and methodology.</p>

No.	MRV Plan		EPA Questions	Responses
	Section	Page		
6.	5.5	37, 38, 39, 44	<p>MRV plan: [Pg 37] Core Energy will reconcile the Subpart W report and results from any event-driven quantification to assure that surface leaks are not double counted.</p> <p>[Pg 38] If it is a simple matter, the repair would be made and the volume of leaked CO<sub>2</sub> would be included in the 40 CFR Part 98 Subpart W report for the Core Energy Facility.</p> <p>[Pg 39] For simple matters the repair would be made at the time of inspection and the volume of leaked CO<sub>2</sub> would be included in the 40 CFR Part 98 Subpart W report for the Core Energy Facility.</p> <p>[Pg 39] Core Energy evaluates, and estimates leaks from equipment, the CO<sub>2</sub> content of produced oil, and vented CO<sub>2</sub>, using the procedures in 40 CFR Part 98 Subpart W. In the past, the amount of CO<sub>2</sub> leaked has been too small to meet the threshold for reporting.</p> <p>[Pg 44] Further, Core Energy will reconcile the Subpart W report and results from any event-driven quantification to assure that surface leaks are not double counted.</p> <p>The plan states that the facility is currently not reporting under Subpart W because it does not meet the reporting threshold, but there are several statements in the plan referring to a Subpart W report. Do these statements merely refer to the use of Subpart W calculation methods in Subpart RR? This should be clarified.</p>	<p>Core Energy contracts with a third party engineering firm to use the Subpart W method to determine annual emissions as specified in that subpart. To date, the mass of emissions has not been large enough to trigger the reporting requirement. Core Energy will use this method as specified in Subpart RR. The MRV plan has been updated to clarify the process it undergoes to calculate emissions using the Subpart W methodology and how that will be used in the Subpart RR reporting process.</p>

No.	MRV Plan		EPA Questions	Responses
	Section	Page		
7.	5.5	39	<p>MRV Plan: It should be noted that when doing workovers, the wells are always “killed” by using appropriate density fluid and the wells are “dead” (no CO<sub>2</sub> flow), thus, leakage, is very rare during workovers to wells.</p> <p>What is the basis for this statement? For example, is there historical data to support this? If so, an explanation and/or short discussion would be helpful. Information on the quantity of leakage that has occurred (e.g., based on experience) would be helpful as well.</p>	The basis of the statement is from Core Energy’s prescribed best practices and experience in the field, whereby no loss of well control incidents have been experienced. The language in the MRV plan has been updated to reflect this history.
8.	6.0	40	<p>MRV Plan: Core Energy will develop the necessary system guidelines to capture the information that is relevant to identify possible CO<sub>2</sub> leakage.</p> <p><b>Section 6</b> needs more explanation. There is no mention of historical data and how it will be compared to the data collected during Subpart RR reporting moving forward. The wording in this section implies that the operational information has not been recorded in the past. However, parts of <b>Sections 2, 4 and 5</b> indicate that data have been gathered and used in the development and operation of the existing facilities (i.e. first sentence of <b>Section 4</b>). The dataset gathered to date, along with an explanation on the approach for obtaining this information, would apply for <b>Section 6</b>. Additionally, some discussion on why the data listed in <b>Section 6</b> will be collected (or references to previous sections) and how it will be used would be helpful.</p>	Based on the risk assessment and operational procedures no surface leakage is anticipated. Therefore, baseline for detecting surface leakage address observed signs of surface leakage and operational data anomalies. Section 6 of the MRV plan has been updated to indicate the strategy Core Energy will use to compare actual performance to baselines to assess potential surface leakage.
9.	7.2	42	For Equation A “Concentration” is misspelled.	Corrected
10.	7.3	43	Equation RR-7 is listed as modified, but it is not modified. This may be left over from a previous version of the MRV Plan.	Corrected

No.	MRV Plan		EPA Questions	Responses
	Section	Page		
11.	7.3	44	<p>In the MRV Plan for Equation RR-8: <math>C_{CO_2,p,w}</math> = Quarterly CO<sub>2</sub> concentration of recycle gas (currently at Dover 36 Facility flow meter #19) for separator w in quarter p (wt. percent CO<sub>2</sub>, expressed as a decimal fraction)</p> <p>Equation RR-8 is used for calculating mass for each gas-liquid separator that utilizes a volumetric flow meter. This is appropriate for the Vortex flow meters, however, <math>C_{CO_2,p,w}</math> should be in volume percent CO<sub>2</sub>, not weight percent.</p>	Addressed by updating Section 7.3 in the MRV plan.
12.	7.3	44	<p>In the MRV Plan Equation RR-9 is given as:</p> $CO_{2P} = \sum_{w=1}^W CO_{2,w}$ <p>This is a modified version of equation RR-9 as it is listed in Subpart RR as CO<sub>2</sub> Entrained in Oil is not included. Equation RR-9 in Subpart RR:</p> <div style="border: 1px solid black; padding: 5px; width: fit-content; margin: 10px auto;"> <math display="block">CO_{2P} = (1+X) * \sum_{w=1}^W CO_{2,w} \quad (\text{Eq. RR-9})</math> </div> <p>Modifying Equation RR-9 (or any equation) from that published in the rule is problematic. Moreover, X is a required data reporting element in the reporting form (see 40 CFR 98.446(f)(5)), that will result in a validation error if not entered. Based on the discussion at page 24 of the MRV plan, it appears that the value for X has been estimated. Thus, it seems that X could be included in Equation RR-9 (i.e., without modifying the equation) and the facility's objectives regarding the calculation of site-specific variables for the mass balance equation (40 CFR 98.448(a)(5)) could be accounted for in the application of Equation RR-11 (see discussion below).</p>	Section 7.3 of the MRV plan has been updated to include "x" CO <sub>2</sub> entrained in oil.

No.	MRV Plan		EPA Questions	Responses
	Section	Page		
13.	7.5	45	<p>MRV Plan: <b>Rather than modifying the equation, Core Energy proposes to determine <math>CO_{2FI}</math> for use in equation RR-11 in 98.443 as be equal to the difference between the amount of <math>CO_2</math> received (in section 7.1, equation RR3) and the amount of <math>CO_2</math> injected (in section 7.2, equation RR6). This calculation is more accurate than measuring the amount of <math>CO_2</math> entrained in oil and using Subpart W results.</b></p> <p><math>CO_{2FI}</math> = Total annual <math>CO_2</math> mass emitted (metric tons) from equipment leaks and vented emissions of <math>CO_2</math> from equipment located on the surface, <b>which will be calculated as RR-3 - RR-6.</b></p> <p><math>CO_{2FP}</math> = Total annual <math>CO_2</math> mass emitted (metric tons) from equipment leaks and vented emissions of <math>CO_2</math> from equipment located on the surface between the production wellhead and the flow meter used to measure production quantity as in Subpart W. Note: <b>This calculation is subsumed in the calculation of <math>CO_{2FI}</math> and will be reported as zero.</b></p> <ol style="list-style-type: none"> <li>As stated above for Equation RR-9, modifying Equation RR-11 from that published in the rule is also problematic. However, site-specific variables can be calculated for the mass balance equation at Equation RR-11 (see 40 CFR 98.448(a)(5)). Also note that there are corresponding data reporting elements in the reporting form for <math>CO_2</math> emitted from equipment leaks and vented emissions (see 40 CFR 98.446(f)(3)(i) and (ii)).</li> <li>There appears to be a typo in the underlined text.</li> </ol>	<p>These comments have been addressed in an updated section 7.5 in the MRV plan that removes the modification thereby also addressing the typo.</p>

No.	MRV Plan		EPA Questions	Responses
	Section	Page		
14.	7.5	45	<p>MRV Plan: Currently there is a difference of roughly 13,000 tonnes per year <u>between between</u> these two values. Of this, roughly 7,000 tonnes is explained by the calculations conducted in accordance with GHG Reporting Rule Subpart W and an additional 150 tonnes is explained by the entrained oil factor. Rather than attempting to directly measure the balance, Core Energy will <u>Use</u> the entire difference as losses from equipment and entrained in oil.</p> <p>Typos in this section of text are underlined.</p>	Corrected



**Core Energy**

Northern Niagaran Pinnacle Reef Trend (NNPRT)  
CO<sub>2</sub> Monitoring, Reporting, and Verification (MRV) Plan

August, 2018

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## Introduction

Core Energy LLC (Core Energy) operates an integrated carbon dioxide (CO<sub>2</sub>) capture and enhanced oil recovery (EOR) facility in the Northern Niagaran Pinnacle Reef Trend (NNPRT) in Michigan. The Core Energy facility includes equipment to capture CO<sub>2</sub> from various sources, dedicated pipelines, a set of subsurface geologic reef formations, and equipment to process oil.

Core Energy joined the Midwest Regional Carbon Sequestration Partnership (MRCSP) in 2005 and has worked closely with the research team to advance the technical understanding of the reefs and the regional geology in the context of ongoing EOR operations. This research demonstrates that CO<sub>2</sub>-EOR results in incidental CO<sub>2</sub> storage in the reefs at the end of the CO<sub>2</sub>-EOR life cycle. Core Energy intends to inject CO<sub>2</sub> with a secondary purpose of establishing long-term containment of a measurable quantity of CO<sub>2</sub> in subsurface geological formations in the NNPRT for a term referred to as the “Specified Period.”

The MRCSP regional geologic characterization indicates that there is potential capacity for hundreds of millions tonnes of CO<sub>2</sub> through ancillary CO<sub>2</sub> EOR storage in the NNPRT. This potential far exceeds the amount of CO<sub>2</sub> available for EOR and, ultimately, ancillary storage capacity. This means that Core Energy anticipates being limited by the amount of available CO<sub>2</sub> in the future rather than by the amount of economically viable CO<sub>2</sub> EOR opportunity. In addition, the nature of the reef geology, as described in Section 2, provides operational flexibility that is much like buffer storage capacity. As a result, Core Energy anticipates continuing its business practice of capturing as much CO<sub>2</sub> as it can while the Antrim Shale play is still active and storing it within the reef system to support its EOR operations. Since it began operations, Core Energy has developed an inventory of anthropogenic CO<sub>2</sub> that is in circulation within the existing reef structures. Calculation of this inventory of working CO<sub>2</sub> is discussed further in Section 2.

During the Specified Period, Core Energy will utilize the working inventory of CO<sub>2</sub> through capture at the Dover 36 Facility and combine it with new CO<sub>2</sub> captured through the Chester 10 Facility. Over time, the mass balance calculation of stored CO<sub>2</sub> will reflect the existing inventory of CO<sub>2</sub> plus the new CO<sub>2</sub>, as discussed in Sections 2, 5, and 7. Core Energy plans to further expand the amount of CO<sub>2</sub> introduced to the field if new sources become available. This additional amount would also be reflected in the mass balance calculation of stored CO<sub>2</sub>.

Core Energy developed this monitoring, reporting, and verification (MRV) plan in accordance with 40 CFR §98.440-449 (Subpart RR) to provide for the monitoring, reporting and verification of the quantity of CO<sub>2</sub> sequestered at the Core Energy facility during the Specified Period. This plan describes how CO<sub>2</sub> EOR and ancillary storage take place in the reefs and how Core Energy will apply the requirements in 40 CFR §98.440-449 (Subpart RR) to calculate the annual amount of CO<sub>2</sub> stored throughout the entire Core Energy CO<sub>2</sub> EOR facility

In accordance with Subpart RR, flow meters are used to quantify the mass of CO<sub>2</sub> received, injected, produced, contained in products, and lost through venting or leakage. If leakage is detected, the mass of leaked CO<sub>2</sub> will be quantified using three approaches. First, Core Energy follows the procedures in 40 CFR §98.230-238 (Subpart W) to quantify fugitive emissions, planned and unplanned releases of CO<sub>2</sub>, and other surface releases from equipment. Second,

Core uses orifice type flow meters installed at its Wet and Dry Vent locations to measure the mass of recycle gas that is vented. And finally, Core Energy's risk-based monitoring program uses surveillance techniques in the subsurface and above ground to detect CO<sub>2</sub> leaks from potential subsurface leakage pathways. The CO<sub>2</sub> mass data, including CO<sub>2</sub> mass at different points in the injection and production process, equipment leaks, and surface leaks, will be used in the mass balance equations included in 40 CFR §98.440-449 (Subpart RR) to calculate the mass of CO<sub>2</sub> stored on an annual and cumulative basis.

**This MRV plan contains 12 sections:**

- Section 1 contains general facility information.
- Section 2 presents the project description. This section describes the geologic setting, reservoir modeling of the reefs, the operational history in the area, and the Core Energy facility operations.
- Section 3 describes the monitoring area for the Core Energy facility.
- Section 4 presents the evaluation of potential pathways for CO<sub>2</sub> leakage to the surface and demonstrates that the potential for leakage through pathways other than the man-made well bores and surface equipment is minimal.
- Section 5 describes Core Energy's risk-based monitoring process.
- Section 6 describes the baselines against which monitoring results will be compared to assess whether changes indicate potential leaks.
- Section 7 describes Core Energy's approach to determining the mass of CO<sub>2</sub> stored using the mass balance equations in 40 CFR §98.440-449, Subpart RR of the Environmental Protection Agency's (EPA) Greenhouse Gas Reporting Program (GHGRP).
- Section 8 presents the schedule for implementing the MRV plan.
- Section 9 describes the quality assurance program to ensure data integrity.
- Section 10 describes Core Energy's record retention program.
- Section 11 contains References.
- Section 12 contains Appendices.

**Technical Notes:**

1. Unless otherwise stated, this document uses the term "tonnes" to indicate metric tons (MT).

2. All calculations and reporting will be done on a metric ton basis (1000 kgs to 1 MT). Anytime CO<sub>2</sub> numbers are reported on a volume basis, Core Energy will utilize a conversion factor of 0.019 million cubic feet (MMCF), or 19,000 cubic feet, of CO<sub>2</sub> per metric ton of CO<sub>2</sub>. This translates to approximate conversion between weight basis to volume basis of CO<sub>2</sub> at 60° F, 1 atm (~1.87 kg/m<sup>3</sup> density).

**1. Facility Information**

- i) Reporter number – 545462
- ii) US Environmental Protection Agency (USEPA) (Region V) administers the Underground Injection Control (UIC) program for all classes of injection wells in Michigan. The Michigan Department of Environmental Quality (MDEQ) Oil, Gas and Minerals Division (OGMD) administers the statutes and rules subject to Part 615, Supervisor of Wells, of the Natural Resources and Environmental Protection Act, 1994, PA 451, as amended (NREPA). The injection wells operated by Core Energy are permitted as UIC Class II wells by US EPA and all wells (including production, injection and monitoring wells) are regulated by OGMD.
- iii) As of April 2018, there are 36 active wells penetrating the Niagaran reefs operated by Core Energy and there are additional wells that have been plugged and abandoned. A summary of these wells is included in Appendix I. Table A-1 indicates the active wells and includes the unit (reef), processing facility, API and MDEQ permit numbers, well name, depth and status. Table A-2 lists all wells that penetrate the reefs and includes reef, permit number, well name, well number, completion depth and date, type, and a wireline log inventory. Changes to the well inventory will be included in annual reporting.

**2. Project Description**

Core Energy operates in the upper north portion of Michigan in what is known as the Northern Niagaran Pinnacle Reef Trend (NNPRT). (Figure 1).

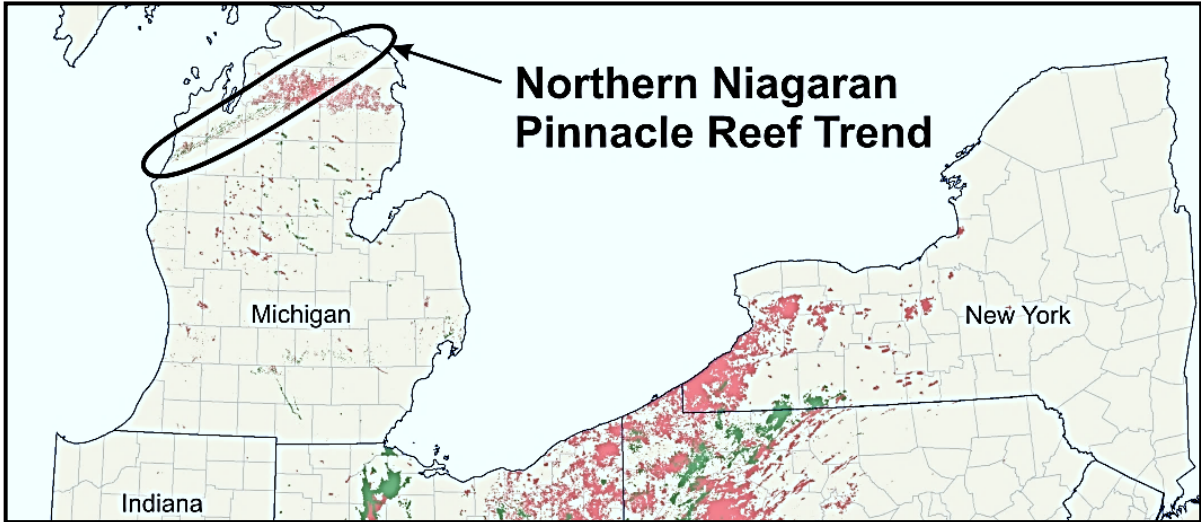


Figure 1 - General location of Core Energy operations

The NNPRT consists of closely spaced but highly-compartmentalized pinnacle reefs located, on average, about 6,000 feet below the ground surface (bgs) but can range from 3,000 to 8,000 feet. This formation began as a series of coral reefs that formed millions of years ago in a setting similar to what we now observe in the Bahamas or Great Barrier Reef.

Since the reefs formed, sediments and other debris were deposited in layers around and above the reefs, forming hard structures that are excellent for containing the oil and gas that collected in them when the ocean receded and the corals died. It is estimated that in northern Michigan alone, such reefs could sequester several hundred million tonnes of CO<sub>2</sub>.

Data was compiled for all reefs including data from ten cores and covering five Core Energy reefs: Bagley, Chester 16, Dover 33, Chester 2 and Chester 5. Core analyses included descriptions, photographs, porosity and permeability measurements, and advanced analyses in select cores. More than 40 additional Niagaran cores were collected in Otsego County with data available at the Michigan Geologic Repository for Research and Education (MGRRE).

Core Energy also collected 3D seismic data for nine reefs: Chester 16, Dover 33, Dover 35, Dover 36, Chester 2, Chester 5, Charlton 19, Charlton 30/31, and Charlton 6 (Figure 2). The data was used to identify the boundary of the reef edges and verify that there are no structural concerns in the area. Where 3D seismic data is not available, formation tops, thicknesses, and production are used along with nearby reefs to define the boundaries.

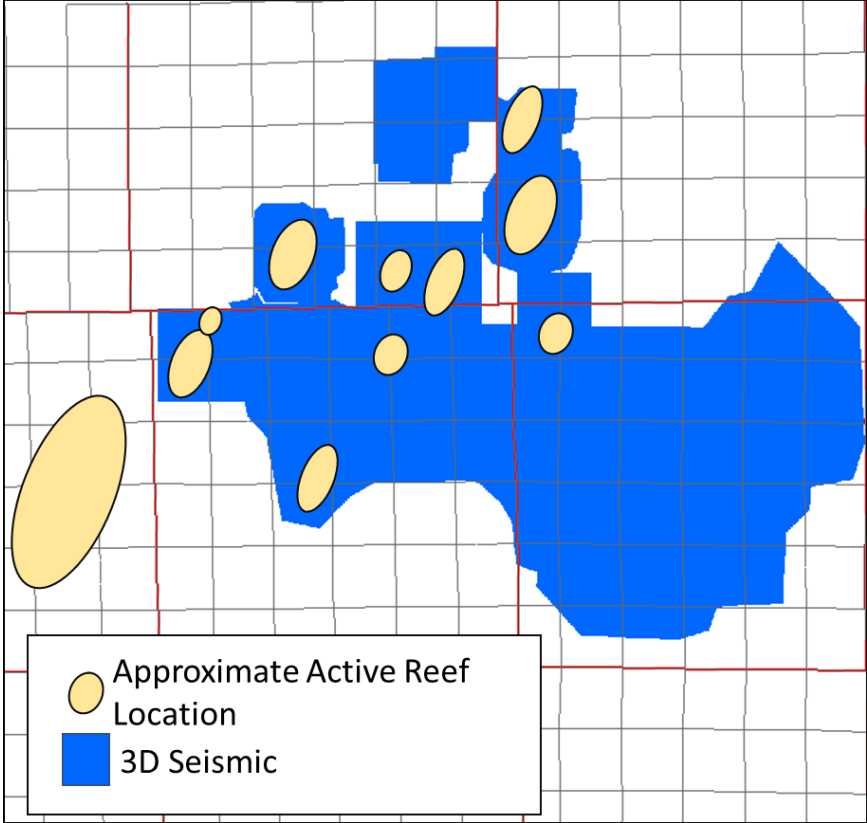


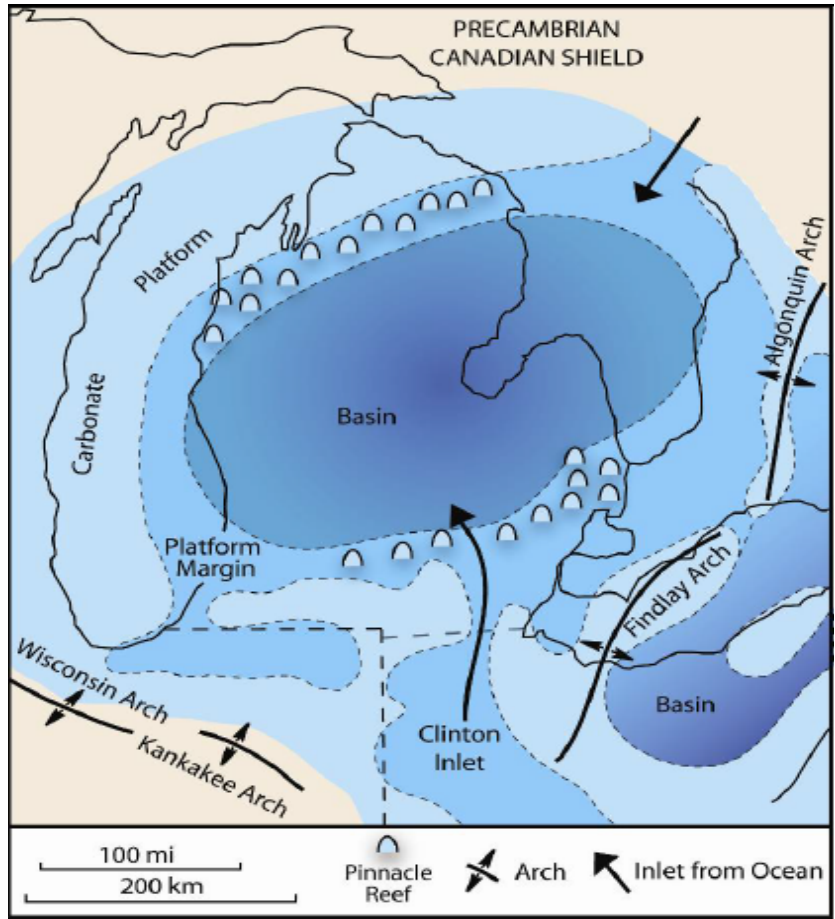
Figure 2: Map of approximate active reef locations (yellow) and 3D seismic (blue).



## 2.1 Geologic Setting

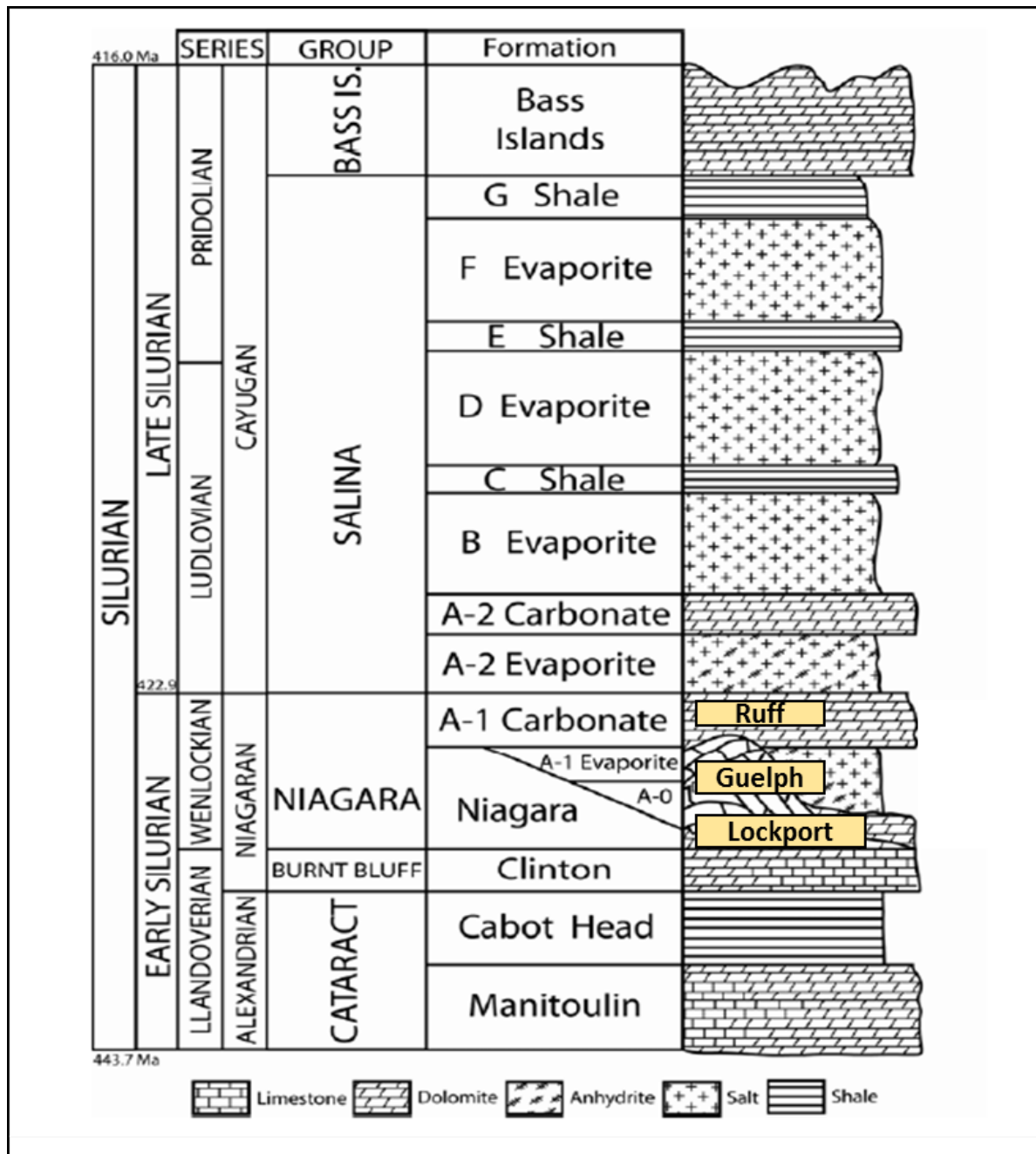
The NNPRT is part of an extensive paleo shallow shelf carbonate depositional system. The trend of pinnacle reefs forms a circular belt along the platform margin that rings the Michigan Basin (Figure 3). The pinnacle reefs range from 2000 feet to more than 6000 feet deep; most of the oil- and gas-producing reefs along the NNPRT are at depths of approximately 3500 to 5500 feet. While individual reef complexes are localized (averaging 50 to 400 acres in area), they may be up to 2000 acres in areal extent and 150 to 700 feet in vertical relief with the steeply dipping flanks. Reef height, pay thickness, burial depth, and reservoir pressure increase towards the basin center (Gill 1979). Currently, there are approximately 800 fields in the NNPRT and approximately 400 in the Southern Niagaran Pinnacle Reef Trend (SNPRT) of the Michigan Basin.

The NNPRT is generally divided in an updip direction into gas, oil, and water-saturated zones (Gill 1979). The reservoir facies primarily consist of porous and permeable dolomite and limestone. Some reefs are completely dolomitized, while others are essentially all limestone. Dolomitization of reefs increases as the reefs become shallower, and salt and anhydrite plugging of porosity occurs in the deeper reefs (Gill 1979). Effective porosity intervals for the reservoir range from only a few feet to several hundred feet from reef to reef. Porosity values extend to 35%, but typically average 3-12%; the best porosity and permeability are associated with dolomitized reef core and flank facies. The best reservoir rocks are characterized by well-developed inter-crystalline and vuggy porosity with average permeability values of 3 to 10 millidarcies. Secondary porosity can significantly enhance permeability within the reservoir.



Ritter (2008), modified from Briggs and Briggs (1974)  
 Figure 3: Carbonate platform and Basin setting during NNPRT development in Michigan.

The reef facies developed within the Niagara Group and includes the Lockport and Guelph lithostratigraphic formations (Figure 4). The Lockport Formation is characterized by two types of crinoidal wackestones: dolomitized and low-porosity, undolomitized (Charbonneau 1990). The Lockport reaches a thickness of approximately 500 feet near the basin margins, but thins and has a more reddish color toward the center of the Basin (Huh 1973; Huh et al. 1977; Charbonneau 1990). The Lockport is frequently referred to as the “White Niagaran” but grades upward into a gray argillaceous, nodular crinoidal wackestone. The Guelph Formation contains the informal “Gray Niagaran” and the “Brown Niagaran”. The Guelph “Brown Niagaran” consists of skeletal wackestones, packstones, grainstones, and boundstones/bindstones associated with the carbonate pinnacle reef buildups. It includes thin off-reef carbonate detrital/conglomerate lithofacies below the A-0 carbonate (Huh 1973). The Guelph Formation forms the core of the reservoir rocks associated with producing reefs.



Ritter (2008), modified from Cercone (1984).

Figure 4. Generalized Stratigraphic Column for the Silurian Section noting Niagaran reefs.

The seals for the Niagaran reefs consist of a series of evaporites and salt-plugged carbonates that encase the flanks of the reefs and form regional seals over the entire reef complex (see Figure 4). The A-1 and A-2 evaporites regionally transition from salt off the reefs to anhydrites over the tops of the reef. The A-1 evaporite generally thins or is not present over the tops of the reef but forms restricted seals along the flanks of the reefs. MRCSP studied five representative reefs in detail: Chester 16, Dover 33, Charlton 19, Bagley 11-14-23, and Chester 2. This study included acquiring a full suite of density and acoustic logs in order to characterize the rapid changes in the composition of the evaporites surrounding the reef flanks. These data enabled

the MRCSP to understand and map reservoir porosity, seal integrity, and seismic response and are discussed below.

The A-1 carbonate belongs to the Ruff Formation and overlies the A-1 evaporite. It is a light-brown to tan, fine to medium crystalline, laminated, dolomitic mudstone and stromatolitic or microbial laminated boundstones, which may show truncation surfaces and rip-up clasts (Huh 1973; Gill 1973; Ritter 2008). Laminated, dolomitic mudstones occur in inter-reef deposits and on the reef; dolomitic microbial boundstone facies unconformably overlie the Brown Niagaran skeletal deposits (Gill 1973). The A-1 carbonate generally seals the flanks of the reefs, but some reservoir zones within the carbonate can be developed on the crests of the reefs.

Figure 5 illustrates the internal structure and geometry of reefs as well as their development cycle. This knowledge is important for predicting areas of best reservoir within the reef. The building of a Niagaran reef was initiated by carbonate mud-rich bioherm accumulation in warm, calm, shallow waters. The bioherm grew as sea level rose, following the prime conditions where biohermal organisms thrive (Stage 1). As sea level continued to rise, the reef core developed, dominated by corals and stromatoporoids. The wind direction during time of reef building was important because it created asymmetry within the reef (Rine 2015). The windward direction developed reef rubble where pieces of the reef core broke off and reduced in size by wave water impact. The leeward side developed a muddy detrital grain apron as fine-grained material sloughed off the reef. (Stage 2). When relative sea level stabilized, stromatolitic algal caps formed over top of the reef and created an intertidal, depositional environment. Next, as sea level fell within the Michigan Basin, the reef complex was exposed (Stage 3), and the living reef was killed. Evaporites such as salt and anhydrites were deposited along the flanks of the reefs and diagenesis occurred within the reef core. As post-Niagaran sea level rose and fell, layers of carbonates and evaporites were deposited over the reef complex (Stage 4).

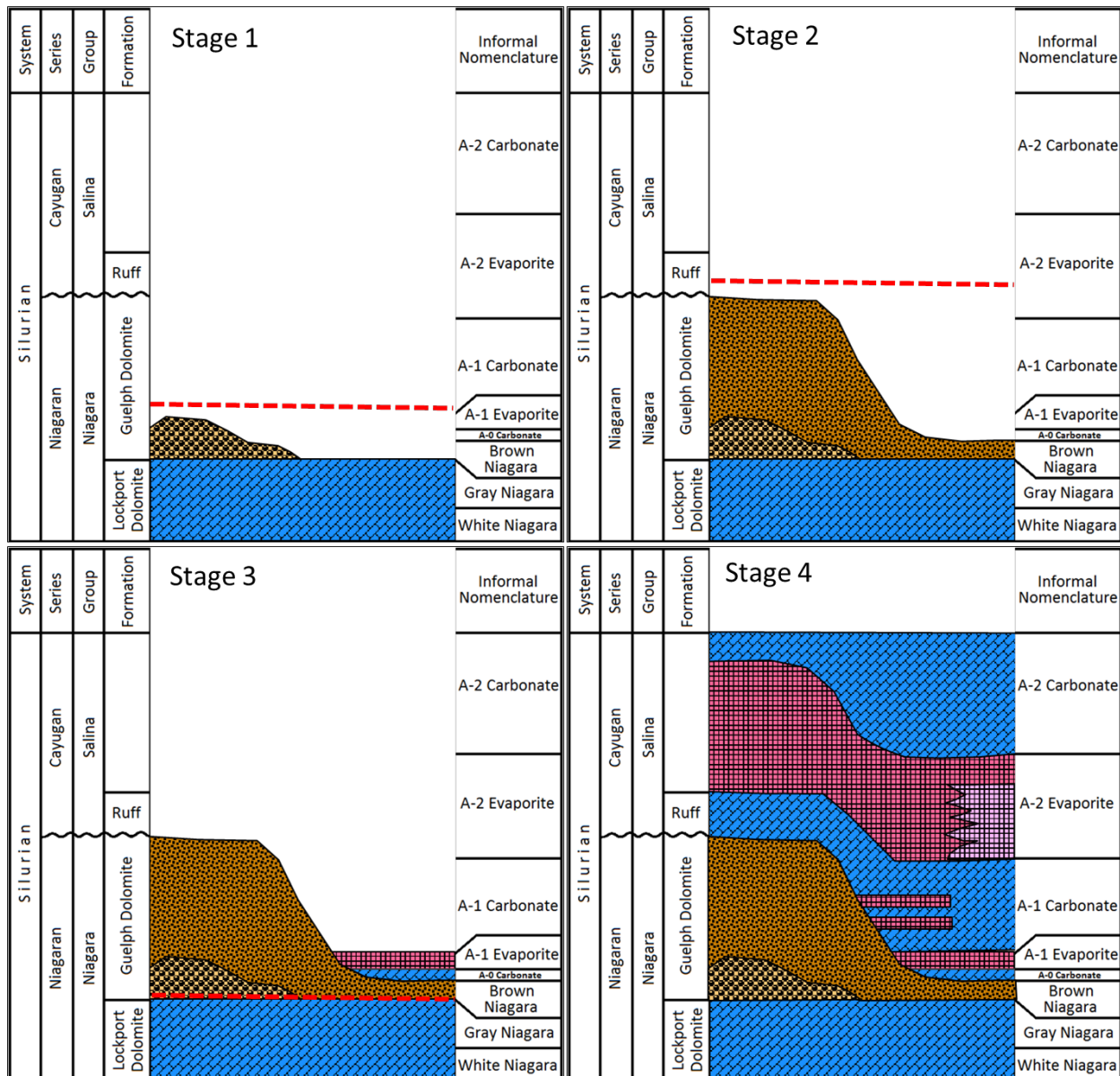


Figure 5: Simplified diagrams of the stages of Niagaran reef development. Red dashed line denotes approximate sea level relative to reef growth.

## 2.2 Reef Reservoir Characterization and Modeling

This subsection of the MRV plan describes the modeling that was developed to characterize the NNPRT reefs operated by Core Energy, Core Energy’s understanding of the behavior of EOR operations in the reefs as indicated by the models, and the procedures going forward to use and or expand the modeling to determine which new reefs to include in operations as well as the operations plans for those reefs.

Core Energy worked with MRCSP to model six representative reef reservoirs. The key objectives of this modeling were to develop a detailed understanding of each modeled reef as well as the predictability of internal reef architecture. The modeling was successful in achieving both aims. Going forward, Core Energy does not plan to develop detailed models for each new

reef but will draw on a set of transferable principles from existing modeling that can be applied in operations and improving CO<sub>2</sub> flood performance.

2.2.1 Model Development

MRCSP used Static Earth Models (SEMs) to integrate all available geologic and geophysical information into a single framework used to conceptualize CO<sub>2</sub> migration and retention in the subsurface (Figure 6). The SEMs also provide the basis for incorporating geologic information into dynamic models for the reservoirs. The building of SEMs was an iterative process with multiple stages of quality checks to develop an SEM most representative of geology and reservoir properties. To build SEMS and dynamic models, the following information was integrated by geologists and engineers:

- Reef geometry (seismic and/or production), well locations and construction, formation depth and thickness, and delineation of lithofacies
- Rock properties including porosity, permeability, and fluid saturations from core and wireline log data
- Fluid flow such as density and viscosity of fluids, relative permeability, capillary pressure, and fluid phase

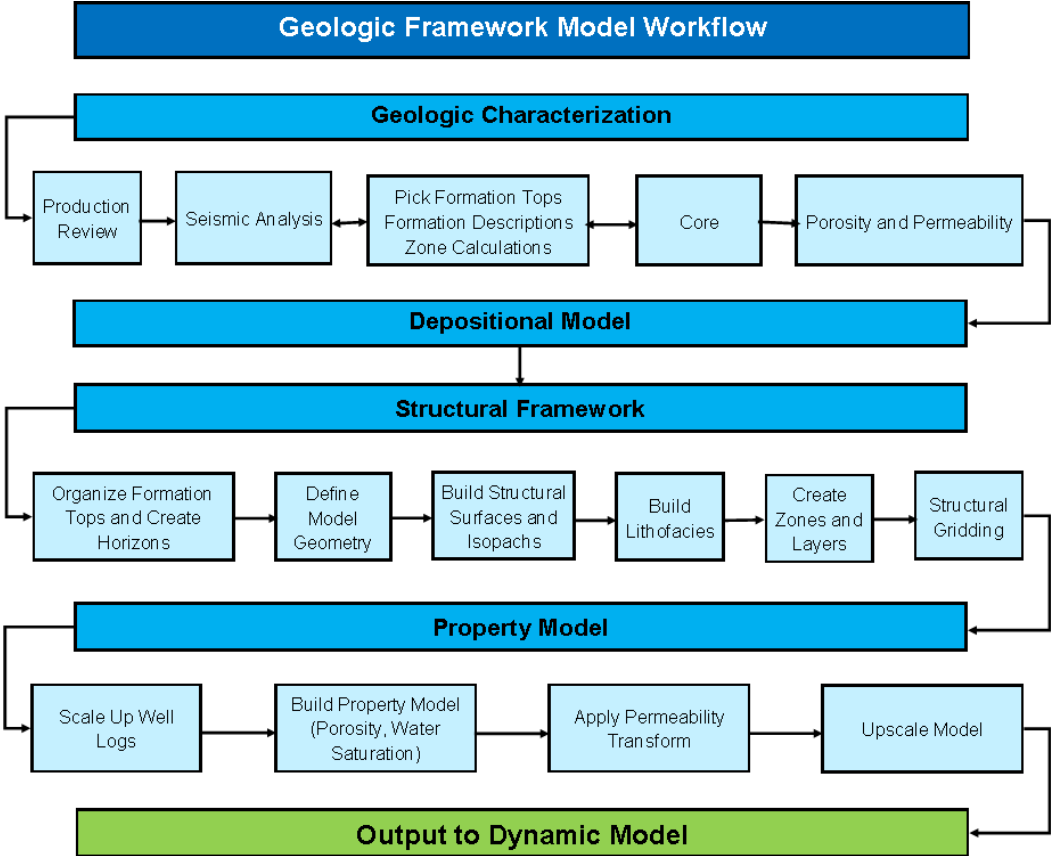


Figure 6: Typical geologic characterization and modeling workflow for reefs.



The modeling workflow began with geologic characterization of a reef which incorporated and integrated all information and data to develop a conceptual/depositional model. Figure 7 illustrates a 2D cross section through one such reef (Chester 16) with formations and reservoir flags. SEMs were then constructed using a conceptual geologic model, which allows for predictability of both vertical and horizontal lithofacies distributions by use of whole core and wireline log data. Figure 8 is an example 2D slice through a 3D SEM of Chester 16 (A) and Dover 33 (B) showing porosity distributions. Once SEMs were complete, they were outputted for dynamic modeling.

Dynamic modeling was used to history match with production records, simulate fluid flow and pressure changes, and assist with well design and CO<sub>2</sub>-EOR flood configuration design.

Basic geologic characterization is used to define the reef, describe formations, and identify reservoir and caprocks. Advanced geologic characterization and modeling are typically used to aid in planning or when a reef does not perform as expected. While Core Energy does not do the same level of characterization and modeling for each reef, lessons learned from advanced modeling show the predictability of internal reef architecture. Core Energy combines the knowledge gained from modeling regarding CO<sub>2</sub> flows within reef architecture along with the feedback from material balance and pressure monitoring and response to develop operational plans for CO<sub>2</sub> EOR.

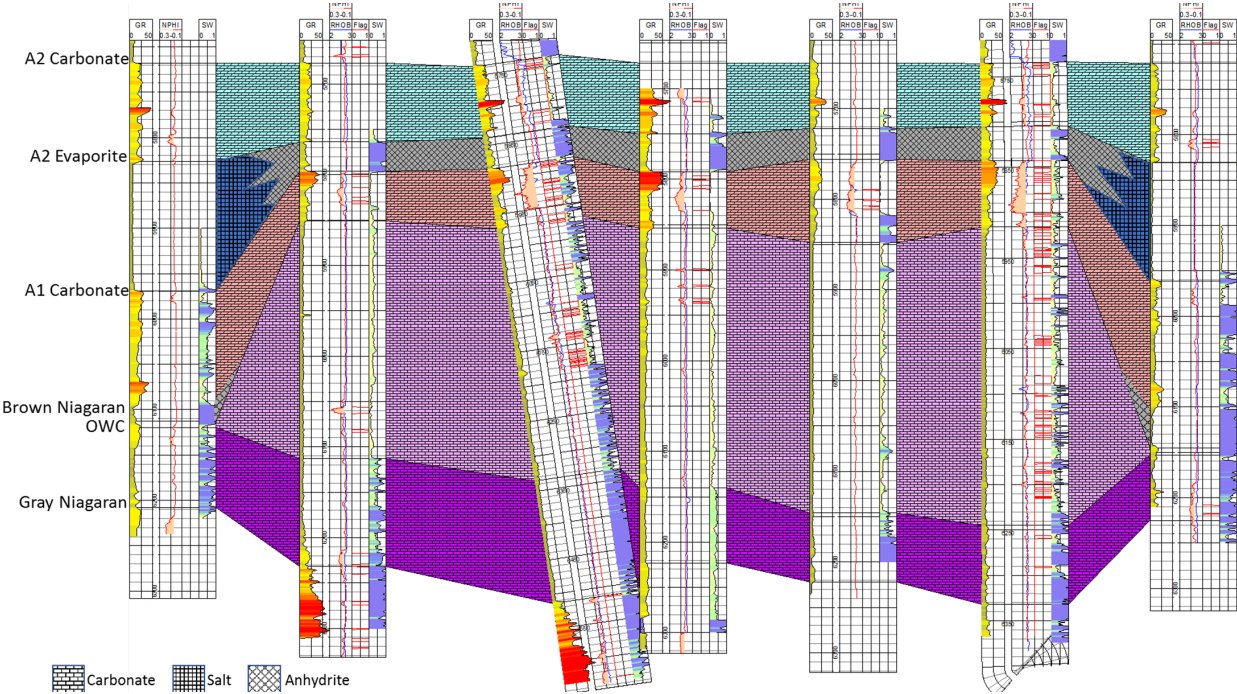


Figure 7: Example 2D conceptual model and geologic characterization of a reef.



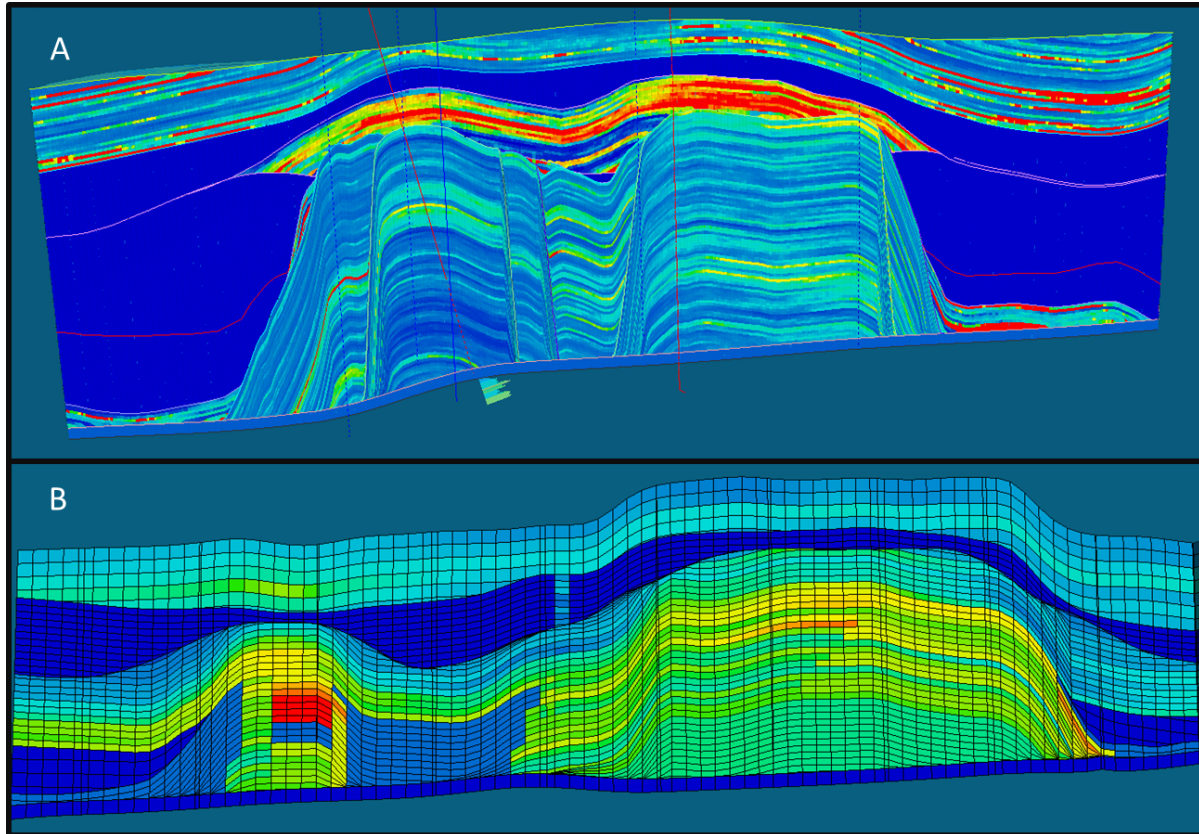


Figure 8. Example slice through a 3D SEM showing porosity distribution through Chester 16 (A) and Dover 33 (B)

Core Energy in collaboration with MRCSP has completed a significant amount of characterization and modeling on select reefs (Figure 9). To date, all 10 reefs have undergone basic geologic characterization to develop a 2D conceptual model of the reef. Five reefs have been developed into SEMs and taken into dynamic modeling. Even though the reefs have variable reservoir properties, there are predictable controls on reservoir performance such as amount of dolomitization, secondary porosity development, and salt plugging which can be identified through geologic characterization. For example, limestone reefs tend to have tighter porosity mid to lower reef with highest porosity and permeability in the upper reef and A1 Carbonate, as illustrated in Figure 8A with hotter colors for higher porosity. Dolomitized reefs tend to have more enhanced porosity throughout the reef due to secondary porosity development as illustrated in Figure 8B with hotter colors for higher porosity. The variability or heterogeneity in rock/facies type is related to a reef's location within the larger Michigan Basin geologic setting.

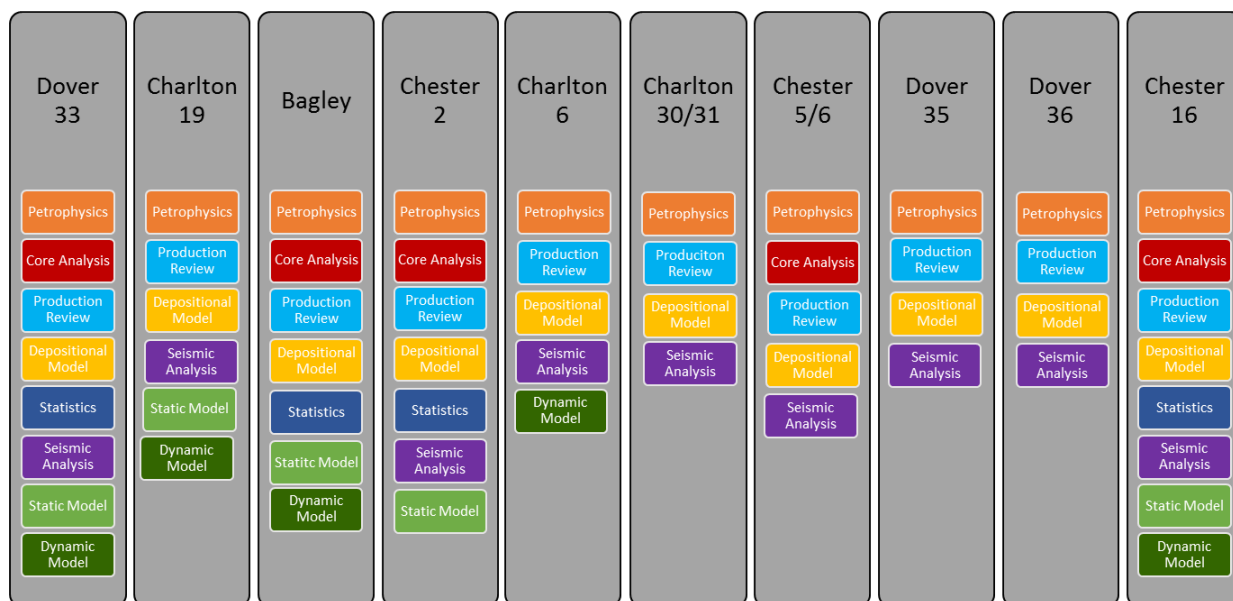


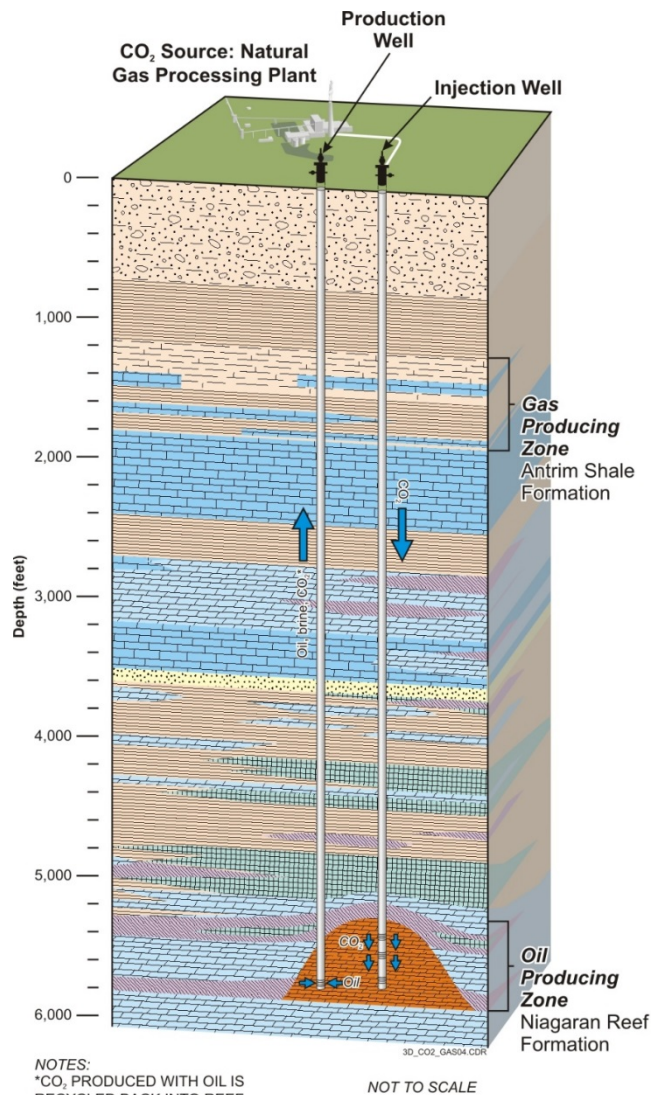
Figure 9: Analyses completed to date by reef.

## 2.2.2 Conceptual Understanding of CO<sub>2</sub> EOR in Reef Structures

The modeling and extensive history of oil and gas production in the NNPR have demonstrated the varying degree of compartmentalization of the reefs and the efficiency of the overlying evaporites and carbonates as seals. The reefs act as a closed reservoir system, which provides excellent conditions for CO<sub>2</sub>-EOR operations.

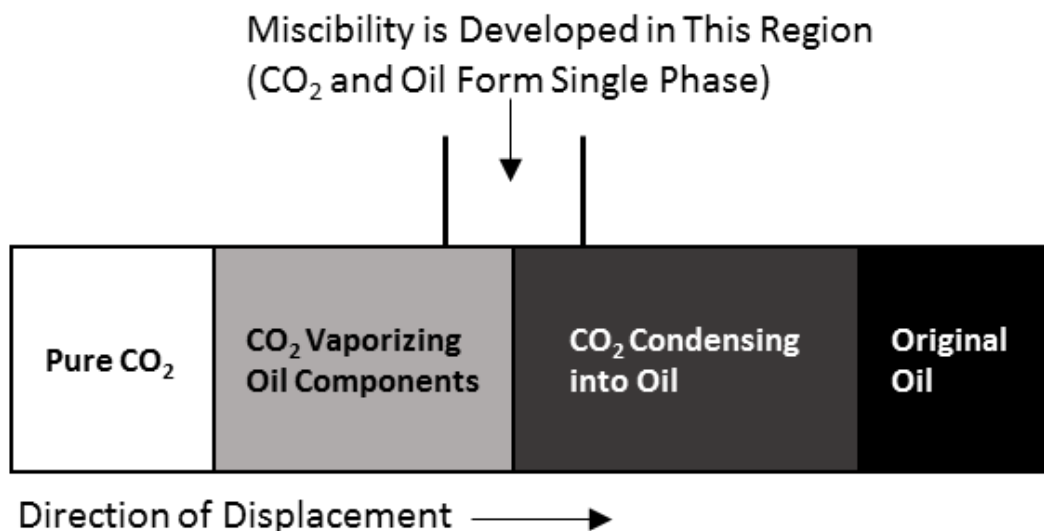
The discovery pressure in the oil-bearing NNPR reefs averages about 3,000 (psi). Primary production utilized this pressure to flow oil to the surface. Secondary production, using water flooding, was attempted but not widely used. Tertiary production, using CO<sub>2</sub> EOR, was initiated in the late 1990's and expanded by Core Energy as it started operations in 2003.

Core Energy typically initiates CO<sub>2</sub> EOR in reefs that have undergone primary and often secondary production and then "blown down" in preparation for closure. The typical average reservoir pressure is well below 500 psi in these reefs after blow down and there is significant voided pore space. As CO<sub>2</sub> is injected into the reefs, it contacts the oil trapped in the pore space while it simultaneously increases the reservoir pressure. As contact and pressure increase, the CO<sub>2</sub> eventually becomes miscible with the oil which allows it to flow towards a designed production well. Figure 10 illustrates the CO<sub>2</sub> - EOR process in a reef field for a CO<sub>2</sub> injection well and the associated production well. Note that the source of CO<sub>2</sub> is from the gas producing zone indicated at the top of the column.



NOTES:  
 \*CO<sub>2</sub> PRODUCED WITH OIL IS RECYCLED BACK INTO REEF.  
 ALL LOCATIONS ARE APPROXIMATE.  
 Figure 10: Simplified diagram illustrating CO<sub>2</sub>-EOR process in a reef.

Figure 11 shows a graphic representation of how CO<sub>2</sub> and oil become miscible. At either end of the image are pure CO<sub>2</sub> and original oil. As the two come into contact and pressure increases, CO<sub>2</sub> vaporizes oil and also condenses into it, forming a single-phase fluid mixture of CO<sub>2</sub> and oil. This mixture of CO<sub>2</sub> and oil, along with formation brine present in some cases, is then produced from the well.



From Zick, 1986

Figure 11: CO<sub>2</sub> Miscibility Diagram (SPE Monograph 22)

The Core Energy facility has significant operational flexibility due to the modular nature of the reefs and the diversity of their development status. The Core Energy reefs are isolated from each other, and each goes through a phase development maturation process that ranges from new or “fill up”, to operational, onto depleted.

New reefs are in the fill up stage in which the initial volume of CO<sub>2</sub> is being injected to raise reservoir pressure above the minimum miscibility pressure (~1190 psi MMP) of CO<sub>2</sub> in oil. Above this MMP, the CO<sub>2</sub> and oil become a single phase fluid and begin to flow to producer wells depending on the pressure gradient between the injection well and the producer wells. After the reef has been pressurized above the MMP (the fill-up phase), these reefs transition into the operational phase, which can last for many years.

Once a reef is determined to be operational, pipelines will be extended from the producing wells to a central processing facility, if they are not already in place. Based on the oil type and the temperature of the reservoirs, Core Energy found that conducting miscible CO<sub>2</sub> flooding is optimized at roughly 1,300 PSI.

Core has also tested the capacity to increase pressure above the optimal range and finds that while it has the headroom (available pore space) and ability to increase pressure to well above 1,300 psi, it does not have equipment that could raise pressure to levels near or above the fracture pressure.

When the bulk of economically available oil has been produced via EOR, the reef is considered depleted or nearing depletion. In depleted reefs, the economic return on CO<sub>2</sub> EOR is not as high as in the operational reefs. However, these reefs still have some oil left in place and can also effectively act as short-term storage for CO<sub>2</sub> in the system. When a reef is abandoned, Core Energy typically recovers as much CO<sub>2</sub> as it can through well blown down, which reduces pressure to roughly 500 psi. The amount of CO<sub>2</sub> which remains in the reef below blow down

pressure cannot be recovered and is essentially permanently stored under current technological conditions.

This development cycle for each reef, combined with operating multiple reefs at once, provides Core Energy with unique operational flexibility. At any time, the number of reefs and the diversity of their status enables Core to accept as much CO<sub>2</sub> as it can capture and then use it over time. This is especially important due to the depleting nature of their anthropogenic source of CO<sub>2</sub> (i.e. gas processing plants servicing the Antrim Shale production).

**2.3 Operational History of the Core Energy Reefs**

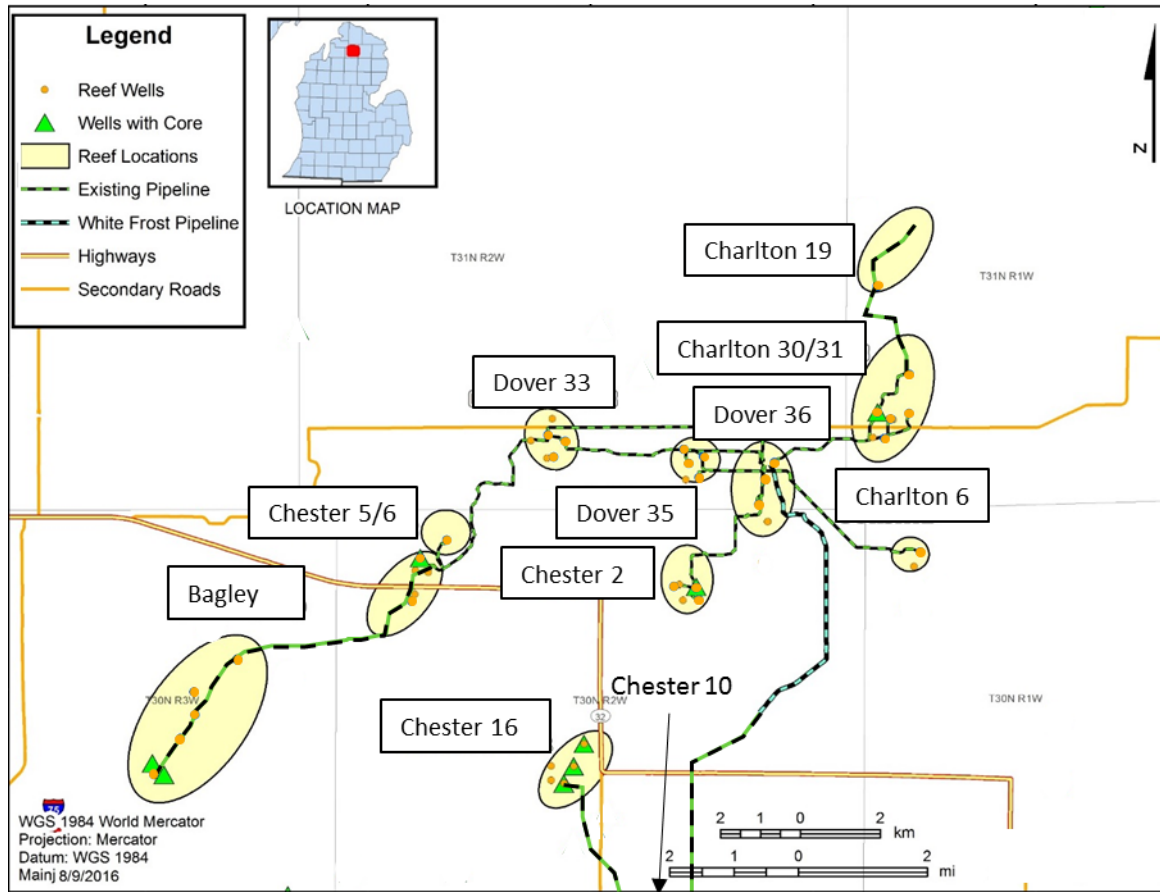
The NNPRT reefs, originally developed in the 1970-1980s, have undergone primary production and, in some cases, secondary recovery through water flood and other methods. Oil operations largely subsided in the early 1990s and then picked up sporadically towards the end of the decade. Core Energy entered the play in 2003, taking over two operating reefs and slowly expanding into eight additional reefs.

**2.3.1 Core Energy EOR Reef Complex Development**

Core Energy currently operates 10 active EOR reefs in Otsego County in northern Michigan. CO<sub>2</sub> EOR was initiated in each of these reefs at different times as indicated in Table 1. Figure 12 shows the location of each reef.

**Table 1: Active CO<sub>2</sub>-EOR reefs and date of initial flooding.**

Reef	Date CO <sub>2</sub> Flooding Initiated
Dover 33	1996
Dover 36	1997
Dover 35	2004
Charlton 30/31	2005
Charlton 6	2006
Chester 2	2009
Chester 5	2011
Charlton 19	2015
Bagley 11-14-23	2015
Chester 16	2017



**Figure 12: Location of active reefs operated by Core Energy.**

### 2.3.2 CO<sub>2</sub> Production and Injection History

All of the active reefs have undergone primary production in the past. Core Energy maintains production records for all wells in the active reefs, including volumes of the following:

- oil produced,
- gas produced (commingled natural gas and CO<sub>2</sub>)
- water produced
- water injected (if applicable), and
- CO<sub>2</sub> injected.

Core Energy worked with Battelle to develop a baseline accounting as of December 31, 2017 of the CO<sub>2</sub> that has been injected since 1996. Since 1996, 2.11 million tonnes of CO<sub>2</sub> has been injected into the Core Energy reefs.

Core Energy is starting its mass balance accounting for CO<sub>2</sub> at zero. This means that the amount of CO<sub>2</sub> already in the system will ultimately be reflected in the mass balance calculation of the amount stored. Over time, the total amount stored will be roughly equal to the sum of CO<sub>2</sub>



from Chester 10 and the inventory of CO<sub>2</sub> produced through Dover 36 less any losses from equipment or subsurface leaks, which are expected to be minimal.

#### 2.4 Description of CORE Energy CO<sub>2</sub>-EOR and Ancillary Storage Project Facilities and the Injection Process

Core Energy operates an integrated facility that includes CO<sub>2</sub> capture, dedicated pipelines, injection and production wells, a central processing facility for fluids, and compressors. Figure 13 is a detailed flow chart with equipment names and meter numbers. The rest of this section will use Figure 13 to review the facilities and processes taking place at the Core Energy facility.



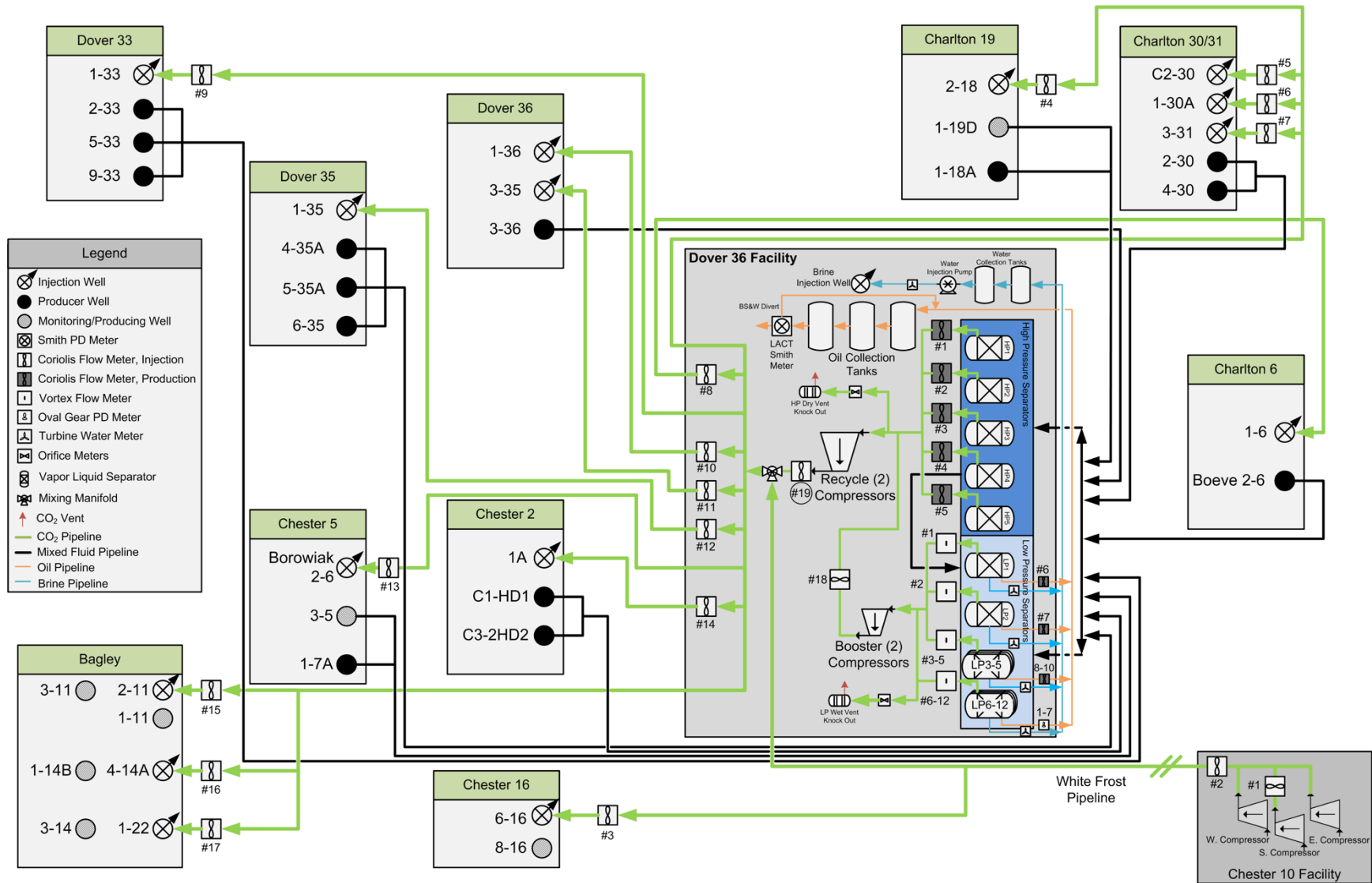


Figure 13 – Simplified Process Flow Diagram of Core Energy's EOR Facility

## 2.4.1 CO<sub>2</sub> Capture

Core Energy captures CO<sub>2</sub> at two locations:

- Chester 10 Facility (shown in bottom right corner of Figure 13): This facility captures CO<sub>2</sub> from a natural gas processing facility that treats gas produced from the Antrim Shale. Core Energy has the right to capture up to 100% of the CO<sub>2</sub> that would normally be vented from the natural gas plant. Core has made investments to expand capture operations over time and plans to make additional investments in the future. It currently captures between 300,000 to 350,000 tonnes of new CO<sub>2</sub> per year. Also, there is potential to capture an additional 100,000 tonnes per year, resulting in net potential 450,000 tonnes of new CO<sub>2</sub> per year. It is expected that the natural gas processing plant will continue operations for at least 10 to 20 years but continued operations depend on market conditions. Core currently has three compressor units at this facility, with the mass of all new CO<sub>2</sub> measured using Coriolis mass flow meter number 2 (Figure 13).
- Dover 36 Facility (large rectangular box in Figure 13): This facility is co-located along with the Dover 36 reef. This facility contains the main Recycle Compressor along with capture equipment which captures CO<sub>2</sub> from various high-pressure (HP) and low-pressure (LP) fluid separators that treat the fluids from the production wells. Core Energy currently captures ~300,000 tonnes of gas per year at the Dover 36 Facility. This gas consists of CO<sub>2</sub> (~95% by wt.) with small quantities of hydrocarbon gas which is recompressed and sent back to various EOR reefs. The mass of this gas is measured using Coriolis mass flow meter number 19.

## 2.4.2 CO<sub>2</sub> Distribution and Injection

Core Energy maintains about 80 miles of pipelines that are used to move CO<sub>2</sub>, produced fluids, and oil. A diagram of the pipeline network and locations of 10 EOR reefs is shown in Appendix II.

A portion of CO<sub>2</sub> from the Chester 10 Facility delivered via the White Frost Pipeline can be withdrawn directly for injection into Chester 16 reef (measured using Coriolis mass flow meter number 3); the remainder of the CO<sub>2</sub> from Chester 10 flows to the Dover 36 Facility, where it mixes with CO<sub>2</sub> from the Recycle Compressor at the Mixing Manifold. From the Mixing Manifold, Core can re-arrange various piping and valves to direct CO<sub>2</sub> to any one of the reefs.

Dedicated Coriolis mass flow meters are attached to each injection well at the EOR reefs. Some of the meters are located at the Dover 36 Facility while others are located directly at the wellhead. These meters are numbered 3 through 17 (Figure 13) for the 15 injection wells at 10 EOR reefs. It is important to note that Core can change the operational configuration of wells whereby an injector well may become a producer or monitoring well, or a producer well may be converted to an injector well. If in future, a producer well is reconfigured to be an injector well, Core will install a Coriolis or other suitable flow meter to measure the quantity of CO<sub>2</sub> being injected into that well and will indicate such changes in the annual reporting.

### 2.4.3 Produced Fluids Handling and Processing

Table A-1 in Appendix I lists the active wells, of which 20 are “producers”. These 20 wells are further indicated by status as a current producer (PR), a shut-in producer (SI-P) or an observation (OBS) well. Generally, at least one production well is located in each reef. For the new reefs, the production wells will be connected to pipelines for produced fluids once they start producing. For the other reefs, all produced fluids from the reefs flow directly to dedicated separators at central processing facilities.

Core Energy currently has a network of 5 HP separators and 12 LP separators at the Dover 36 Facility. Product streams from reefs that are producing oil under high pressure (> 340 psi) are first sent to an HP separator; product streams from reefs that are producing under low pressure (<340psi) are sent to one of the LP separators. The remaining liquid product stream (containing mostly oil and brine) from a HP separator is further sent to a LP separators for separation and stripping of any entrained gas. The produced gas that is separated in the HP separator is sent to the Recycle Compressor, while the gas separated from the LP separator is first sent to a Booster Compressor prior to being sent to the Recycle Compressor.

The produced gas which primarily consists of CO<sub>2</sub> (>95% by wt) is separated from the produced fluid and flows through a Coriolis mass flow meter at each of the HP separators before being sent to the Recycle Compressor (meters numbered 1 through 5). The bulk of the produced gas is captured in the HP separators (> 90% by wt). Meanwhile, the produced gas that is separated at the LP separator, flows through a Vortex type flow meter. The system of Coriolis mass flow meters (attached to the HP separators) and Vortex flow meters (attached to the LP separators) measures the mass of recycle gas produced from each operational reef. Additionally, one Coriolis mass flow meter (number 18) measures the mass of all recycle gas captured at the LP separators while another (number 19) measures the total quantity of produced gas that is produced by all operational EOR reefs.

Brine is also separated by the LP separators. The collected brine is sent to a brine disposal well located onsite at the Dover 36 Facility. Oil is gathered in collection tanks before flowing through a LACT meter for offsite sales. A small amount of CO<sub>2</sub> remains entrained in the oil after the CO<sub>2</sub> separation process, which bleeds off as the oil moves through the LP meters into a temporary storage/gathering tanks. Core hired an external engineering firm to conduct a survey in 2011 to determine the amount of CO<sub>2</sub> entrained in oil and developed a volumetric factor to quantify this loss for purposes of the mass balance. That factor is 16.84 standard cubic feet (scf) per barrel of oil. This translates into roughly 150 tons per year at current operations levels. Because the oil is blended in the gathering tank, Core Energy believes this factor applies uniformly to all oil.

While rare, operational outages periodically occur, which forces produced gas to be vented to the atmosphere. Core has orifice type flow meters installed at its Wet and Dry Vent locations to measure the mass of recycle gas that is vented. Looking back for the last 12 months (May 17 to April 18), a small volume of CO<sub>2</sub> was vented during eight (8) of those months. The volume of CO<sub>2</sub> vented represents only 0.0174% of the produced volume.

#### 2.4.4 Data Collection

The system of flow metering at the Dover 36 Facility is centrally tied to a Core Energy HMI computer system. Coriolis mass flow meters that are located at the reef-site locations (at injection wellheads) typically have data-loggers which collect and store injection data. The HMI system records continuous production and injection data files on a per-minute basis for each day of operations. Operators typically record totalizer readings from injection and production parameters at 9 AM each day for the previous operational day. Additionally, there are daily site visits to the wellsites where operators record well data (e.g., tubing pressure, casing pressures, and wellhead temperatures). Together, these data streams provide accurate accounting of all CO<sub>2</sub> being acquired (from the Chester 10 Facility), injected into EOR reefs, and recycled at the Dover 36 Facility.

The method used when estimating the volume of CO<sub>2</sub> “lost” due to an interruption in data collection or mechanical failure of a meter (equipment) is to use the most recent daily volume of CO<sub>2</sub> associated with the meter and calculate the proportionate volume of “lost” CO<sub>2</sub> based on the number of hours involved in the data gap or until the meter was repaired. Core Energy has well and facility data in three forms: 1) Paper copies (scanned to server), 2) Keyed in data from paper copies into database, and 3) Automated capture of limited set of data that was recently instrumented (Fall of 2016).

#### 2.4.5 Existing Wells

Core Energy operates 16 injection wells (1 of which is a shut-in injector) and 20 production/observation wells. These wells are listed in Appendix I.

Well status is discussed in Section 4.1.

Wells are configured as each EOR project is developed (see Table 1). Mechanical integrity for injection wells is monitored through daily readings of casing pressure, quarterly fill-up tests and mandatory mechanical integrity tests (MIT) every five years. All injection wells utilize a corrosion inhibited packer fluid in the annular space between the tubing string and casing, above the required isolation packer. Corrosion coupons are placed at various nodes in the system as a way to monitor metal loss.

Maps showing the locations of the wells in each reef are provided in Figure 12. In general, the basic open-hole geophysical logs (e.g. gamma ray, density, resistivity, neutron porosity, photoelectric) are available for most of the wells in the active reefs. A sonic log is available for approximately half of the wells. Cement-bond logs are sparingly available.

### 2.5 Core Energy Procedures for CO<sub>2</sub>- EOR Facility Modification

Core Energy plans to continue routine business operations, which may include securing additional CO<sub>2</sub>; modifying, adding, or closing wells; adding or closing reefs, and adding new facility equipment and pipelines. These modifications represent a continuation of the basic integrated current configuration and MRV approach and not a material change that triggers a revised plan (see 40CFR Part 98.448(d)). Therefore, Core Energy intends to indicate such

changes in the annual monitoring report rather than submitting new MRV plans. The monitoring report would demonstrate how the change is a continuation of the existing EOR Facility and would also include any new site characterization, risk assessment, monitoring, and mass balance information as is already included for the existing EOR Facility. The existing provisions for the MRV would continue to apply. Each of these potential changes is discussed in more detail below.

### 2.5.1 New Sources of CO<sub>2</sub>

Core Energy is considering the addition of new equipment to capture additional CO<sub>2</sub> from the adjacent natural gas processing plant through its Chester 10 Compression Facility. It is also exploring the potential to obtain additional CO<sub>2</sub> through nearby sources that are in development.

In the event new sources of CO<sub>2</sub> are added, the amount of CO<sub>2</sub> would be measured using flow meters and added to the reported amount of CO<sub>2</sub> received onsite as indicated in Section 7. Injected CO<sub>2</sub> from these sources would be measured using flow meters and added to the reported amount of CO<sub>2</sub> injected as indicated in Section 7.

### 2.5.2 Adding New Wells

In order to add any new injection wells, Core Energy would have to work with the US EPA (or if Michigan gains primacy for Class II, MDEQ/OGMD) to obtain the permits and from MDEQ/OGMD to obtain permits for any new production wells. Such wells would be sited, completed, and operated in the same manner as the existing wells, under the oversight of the US EPA and/or MDEQ. The existing modeling and learned transferable principles would be combined with reef characteristics to determine location and operational plans for such wells. Well numbers and information would be included in the annual statement.

### 2.5.3 Abandoning Existing Wells

Core Energy follows the UIC Class II requirements and/or the MDEQ/OGMD requirements for closing wells. Any wells closed within a reporting year would be noted in the annual statement.

### 2.5.4 Changing the status of Existing Wells

Core Energy may change the status of an existing well from producer to injector or vice versa. In such situations, Core Energy will work with US-EPA and/or MDEQ/OGMD to obtain the necessary permits and will indicate the status change in the annual statement.

### 2.5.5 Acquiring New Reefs

Core Energy is looking to expand into new reefs based on their potential development value, which is a reflection of past operational history and current ownership structures as well as other factors. Based on the modeling and history of reef development in the area, Core Energy does not anticipate that past operations will preclude any reef from being selected as an expansion candidate. As part of the permitting process, Core Energy will conduct a site characterization, determine the boundaries of the reef, and assess the Area of Review (AoR) of at least ¼ mile

around the reef to determine if there are any old wellbores that need to be remediated or closed and whether there are any other impediments to the successful implementation of CO<sub>2</sub> EOR on that reef. All potential new reefs are located in the MMA as indicated in Section 3.2 and would be moved into the AMA as indicated in Section 3.1 if they are developed by Core Energy.

### 2.5.6 Abandoning Existing Reefs

Core Energy will follow the requirements for closing wells and will follow any contractual or permit requirements for abandoning a reef. Core Energy will prepare a closure report for any abandoned reefs that assesses the amount of CO<sub>2</sub> that will be stored in that reef after closure and serving as the foundation for removing that reef and the related CO<sub>2</sub> from the active MRV reporting program.

### 2.5.7 Adding New Facility Equipment

Core Energy may add new equipment that could have an impact on the mass balance. This might include additional compressors, processing equipment, and/or other equipment. These changes would be noted in the annual statement and CO<sub>2</sub> losses from this equipment would be calculated as in Section 7 and the results included in the mass balance.

### 2.5.8 Acquiring New Pipeline Routes

Core Energy may build additional pipelines to connect new wells to the Core Energy Facility or to connect fill up reefs to production facilities. These changes would be noted in the annual statement and CO<sub>2</sub> losses from this pipeline would be calculated as in Section 7 and the results included in the mass balance.

## 3. Delineation of the Monitoring Area

### 3.1 Active Monitoring Area

Due to the highly compartmentalized nature of the Niagaran reefs, the Active Monitoring Area (AMA) is defined by the boundary of the Unit Area of each individual reef/field as established in the Order by the Supervisor of Wells for the MDEQ authorizing each EOR project. The following factors are considered in defining the boundaries:

- CO<sub>2</sub> injected into a reef remains contained in the reef because of the efficient seals along the edges and overlying the reef
- The edge of the reef is typically defined using 3D seismic data. Where 3D seismic data is not available, reef edges are approximated using all wells surrounding and penetrating a reef, along with analog reef geometry.
- Stored CO<sub>2</sub> will remain within a reef and will not migrate over geologic time, as is demonstrated by the long history of oil and gas production occurring within a reef. Just

as the oil and/or gas were trapped in and contained by the reef, the same would be true for the CO<sub>2</sub>.

- Free-phase CO<sub>2</sub> is contained within the reefs and will remain there after injection ceases and wells are shut-in or closed
- MDEQ rules state that an operator must demonstrate that the reservoir is wholly contained in the Unit Area before an EOR project is authorized.

### 3.2 Maximum Monitoring Area

The maximum monitoring area (MMA) for the MRV Plan, based on the anticipated future of expansion to conduct CO<sub>2</sub> EOR operations in reefs within the Northern Niagaran Pinnacle Reef Trend (NNPRT), extends geologically along the northern edge of the Michigan Basin (see Figure 14).

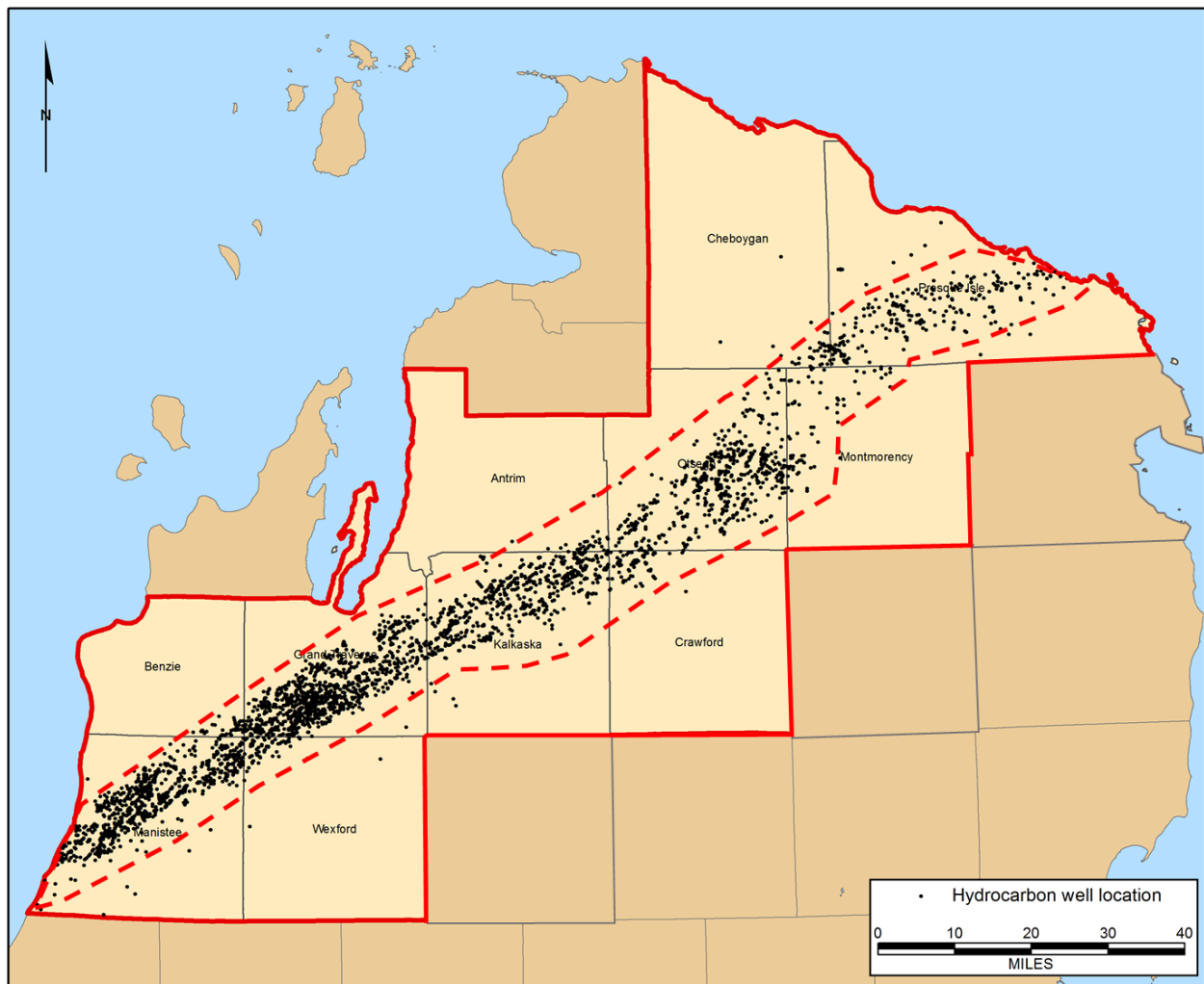


Figure 14 Areal Extent of Maximum Monitoring Area includes the hydrocarbon bearing pinnacle reefs in the NNPRT



The reefs that are currently undergoing CO<sub>2</sub> EOR in Otsego County and all of the reefs in the NNPR that would be suitable CO<sub>2</sub> EOR targets in the future are found at the same place within Michigan’s geological stratigraphic column. The reefs are always contained below the B-Salt and A2-Carbonate and above the White Niagaran (see Figure 15).

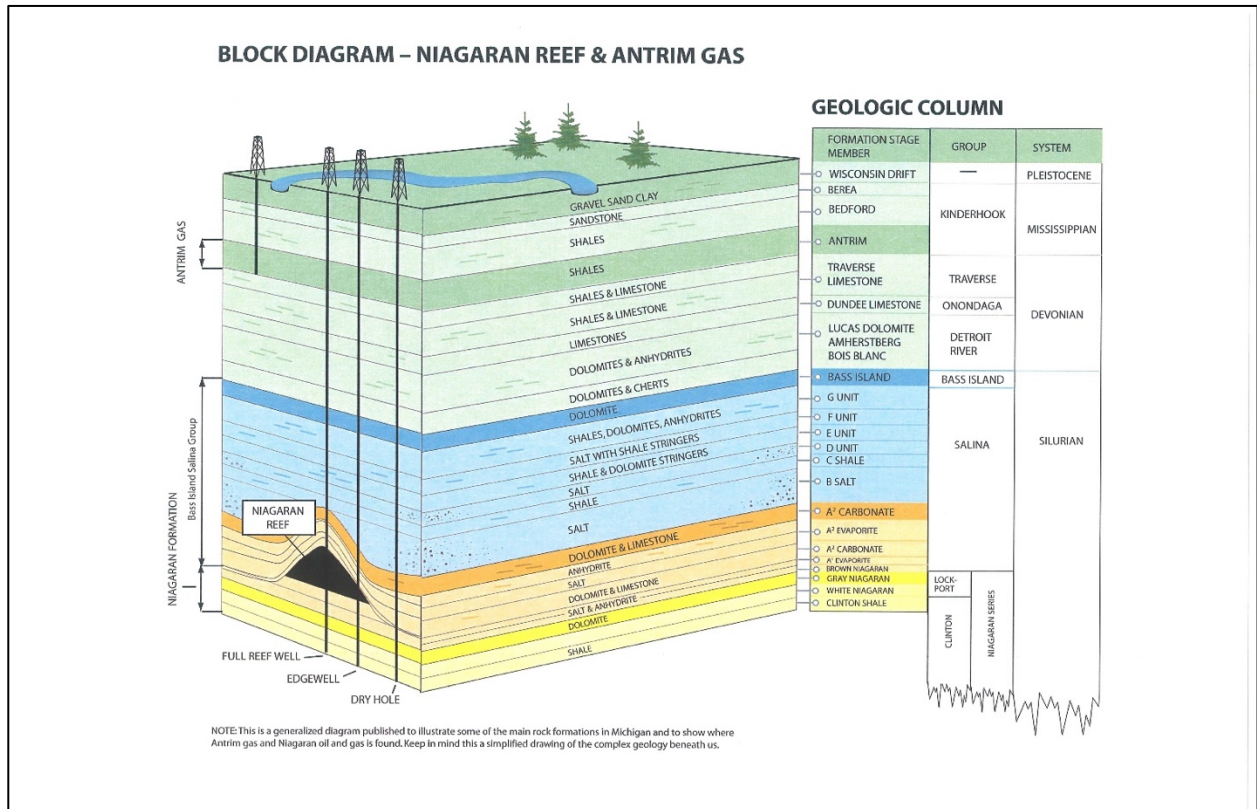


Figure 15 Michigan Stratigraphic Column

The potential risk of leakage is consistent from reef-to-reef in the MMA for several reasons. The hydrocarbon bearing reefs that Core Energy will develop are always found in the same geologic setting within the Michigan Basin. They are isolated, self-contained reservoirs, and the risk associated with leakage pathways are the same from reef-to-reef. Further, any reef added to Core Energy’s EOR operations would first be screened for suitability for EOR operations and would then have to undergo the Michigan unitization process by MDEQ. New wells or well changes would go through the state (MDEQ) and federal (US EPA) permitting requirements.

### 3.3 Monitoring Timeframes

Core Energy’s primary purpose for injecting CO<sub>2</sub> is to produce oil that would otherwise remain trapped in the reservoir and not, as in UIC Class VI, “specifically for the purpose of geologic storage.”<sup>1</sup> During a Specified Period, Core Energy will have a subsidiary purpose of establishing the long-term containment of a measurable quantity of CO<sub>2</sub> in the reefs that it operates. The Specified Period will be shorter than the period of production from the Core Energy facility. At

<sup>1</sup> EPA UIC Class VI rule, EPA 75 FR 77291, December 10, 2010, section 146.81(b).

the conclusion of the Specified Period, Core Energy will submit a request for discontinuation of reporting. This request will be submitted when Core Energy can provide a demonstration that current monitoring and model(s) show that the cumulative mass of CO<sub>2</sub> reported as sequestered during the Specified Period is not expected to migrate in the future in a manner likely to result in surface leakage. It is expected that it will be possible to make this demonstration within three years after injection for the Specified Period ceases. The demonstration will rely on three principles: 1) the amount of CO<sub>2</sub> stored in properly abandoned reefs will be considered unlikely to migrate to the surface, 2) the continued process of fluid management during the years of CO<sub>2</sub> EOR operation after the Specified Period will contain injected fluids in the reefs, and 3) that the cumulative mass reported as sequestered during the Specified Period is a fraction of the theoretical storage capacity of the reefs in the field. See 40 C.F.R. § 98.441(b)(2)(ii).

#### 4. Evaluation of Leakage Pathways

Knowledge gained through the long history of oil and gas production in the Niagaran reefs coupled with the regional geological characterization conducted by Battelle for the [MRCSP](#) were used to identify and assess potential pathways for leakage of CO<sub>2</sub> to the surface. The following potential pathways are reviewed:

- Existing wellbores
- Faults and fractures
- Natural and induced seismic activity
- Lateral migration outside of a reef
- Diffuse leakage through the seal
- Pipeline/surface equipment

##### 4.1 Existing Wellbores

Wellbores that penetrate the reef constitute the most likely pathway for leakage, however this risk is assessed as very small because of the well construction specifications implemented by Core Energy. Wells are constructed with four strings of casing (i.e. conductor, surface, intermediate and total depth string), three of which are cemented in place; the surface casing is cemented all the way to the surface. Additionally, all wells have tubing strings run to near the permitted injection zones. Injection wells require a packer attached to the tubing string, located no more than 100 feet (30 m) above the permitted injection zone and mechanical integrity on injection wells must be established and maintained. Core Energy adheres to all regulatory requirements of the state and federal agencies charged with oversight as they relate to well drilling, completion and operation as means to maintain mechanical integrity and prevent wellbore leakage. Though previously drilled wells and plugged/abandoned wells may be thought to have a higher risk for leakage pathways than newly drilled wells, all wells within a defined AoR for a project are evaluated. All wells in northern Michigan have been ranked based on age, status, and depth (penetrating seal). It was concluded that wells which penetrated the seals were ranked with high integrity because they were more recent and adhered to regulatory requirements. Figure 16 shows all the well rankings in Otsego County (green is high integrity) and the number of wells which penetrate each reef.

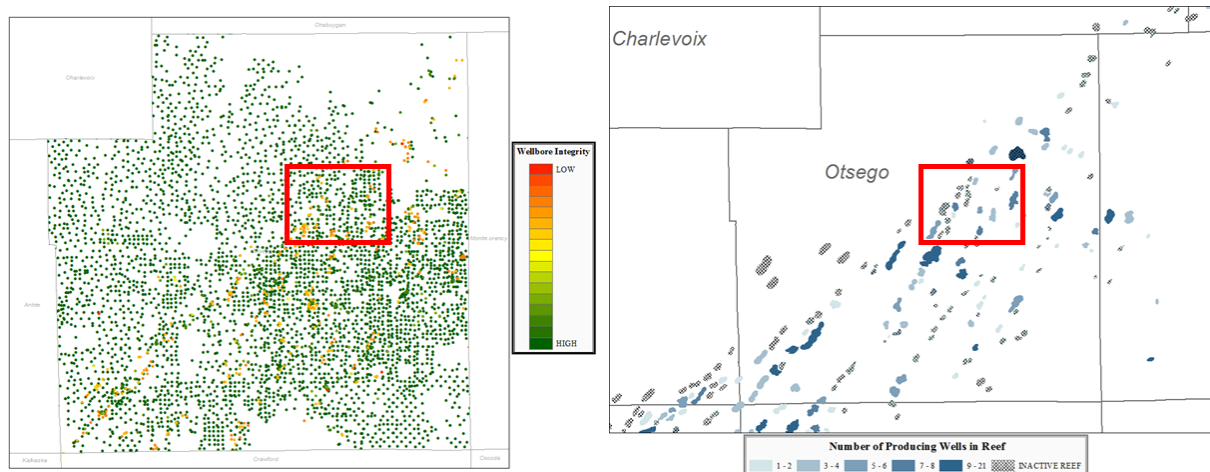


Figure 16: Wellbore integrity ranking (left) of all wells in Otsego County showing dominantly high integrity and the number of wells which penetrate each reef (blue) showing few seal penetrations within the Core Energy reef area (red)

In addition to analyzing wellbore integrity, cement plugs were also analyzed and ranked based on depth, number of plugs, thickness, and age. It was concluded that plugged wells which penetrated the reefs and nearby off reef locations had sufficient plug placement and thickness to prevent leakage.

Leakage through wellbore cement was also researched in the NNPRT by analyzing several cement bond logs in the region. Cement was categorized based on the bond index. Cement with 80 to 100% bond was considered sufficient, 60 to 80% was intermediate, and less than 60% was not ideal. Wells which penetrated the reef were shown to have at least 50 feet of sufficient cement bond within the seal, which by industry standards is sufficient (Figure 17). Several wells were also tested for sustained casing pressure after being exposed to CO<sub>2</sub> and did not demonstrate any sustained casing pressure which would be caused by leakage through a cement annulus.

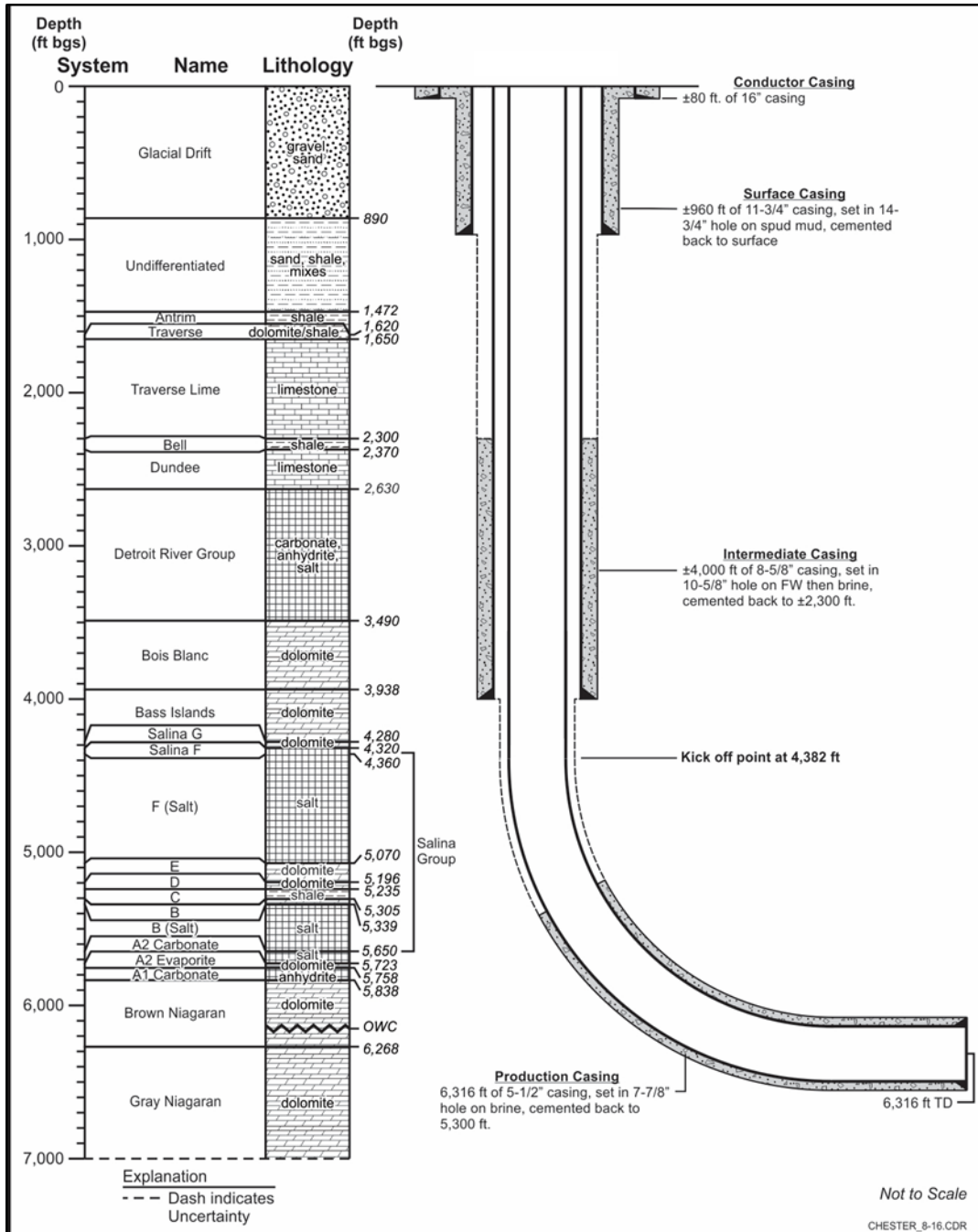


Figure 17: Example of well construction for a Core Energy well showing intervals of cement over crucial formations.

Overall, wellbore integrity studies and the oil and gas history demonstrate that while leakage through a wellbore is possible, the wells have been constructed ideally to prevent such leakage. Core Energy also conducts routine monitoring of active wellbores by performing bottom hole pressure measurements and wellhead inspections.

## 4.2 Faults and Fractures

Basement crustal features such as the Mid-Michigan Rift/geophysical anomaly and the Grenville Front (Figure 18) may affect formation thickness and the tectonic movement of Paleozoic structures in the sedimentary rock section. Many ancient faults and folds in the Paleozoic section are parallel or perpendicular to the basement features. There are fewer identified faults in the northern most counties of Michigan than there are in southern Michigan, making the NNPRT an ideal location for CO<sub>2</sub>-EOR. The faults in northern Michigan are deeper features and do not influence the integrity of the caprocks for the reefs.

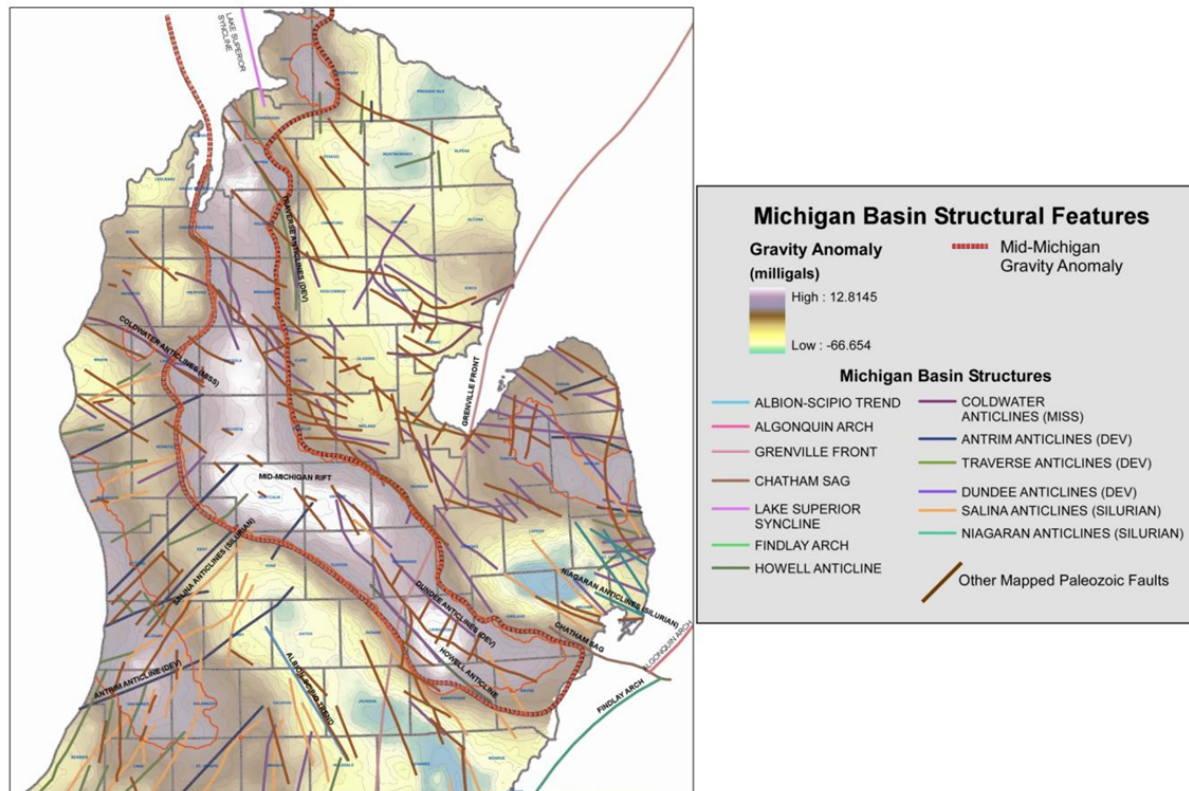


Figure 18: Michigan Basin structural feature



### 4.3 Natural and Induced Seismic Activity

Michigan Basin is structurally stable with few known faults. There are no recorded seismic events in northern Michigan and risk of seismic activity is low with a 0 to 4% chance of a seismic event in northern Michigan and no recorded seismic events (Figure 19A). Nearby 2D and 3D seismic data confirm there are no major structural features around the sites of interest (Figure 19B).

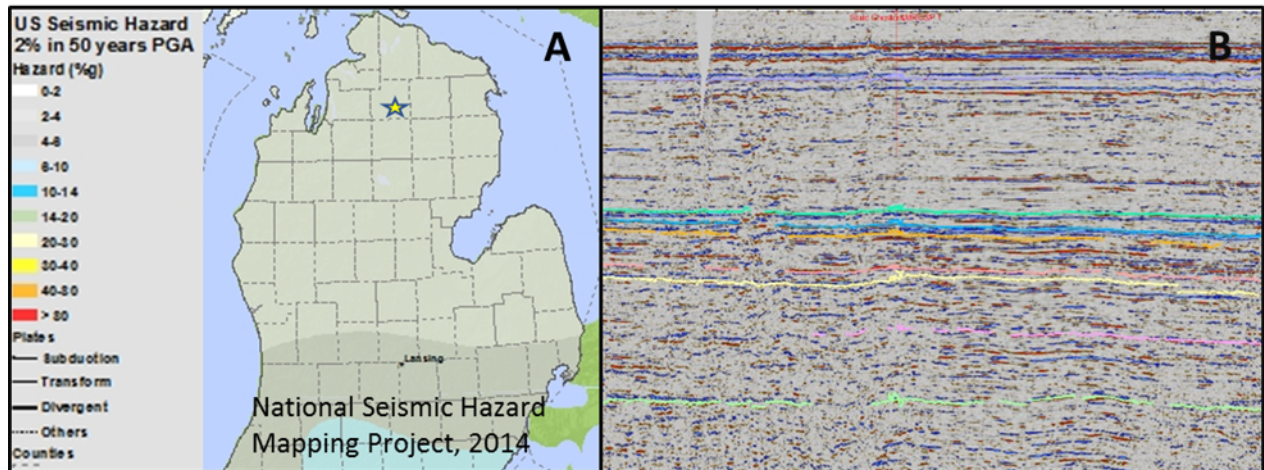


Figure 19: US seismic hazard map (A) with example 2D seismic line (B) showing low risk for seismic activity and no major structural features.

### 4.4 Lateral Migration Outside of a Reef

It is highly unlikely that injected CO<sub>2</sub> will migrate outside of the boundaries of a reef due to the following factors:

- 1) The containment provided by the inherent reef geology consisting of non-porous salts and evaporites along the flanks and overlying the reef structure. This containment is believed to effectively isolate the individual reefs resulting in closed reservoir dynamics observed over the course of MRCSP CO<sub>2</sub> injection (see section 2.1)
- 2) Operational procedures at Core Energy, which monitor injection and production volumes from well-managed wells.
- 3) Periodic material balance associated with the measured reservoir fluid amounts, which has helped correlate and reconfirm that no CO<sub>2</sub> has been lost to the surroundings from the reef thus far.

Containment is also validated by the numerical modeling exercises (both analytical and dynamic numerical models) undertaken for each of the reefs of interest aimed at investigating reef response and CO<sub>2</sub> migration over time.

#### 4.5 Diffuse Leakage through the Seal

Diffuse leakage through the seal, overlying Salina group, is highly unlikely. The seal is composed of several hundred feet of salt, shale, and tight carbonate. Oil and gas production also confirms the successful trapping of fluids in the reefs over geologic time. Additional pressure monitoring and geomechanical modeling of the seals in several reefs confirmed the efficiency and integrity of the confining system.

The fracture gradient is 0.8 psi/ft which is approximately 4130 psi at a depth of 5162 ft (shallowest perforation in Core Energy reefs). The coordinating wellhead (surface) pressure equates to 1761 psi. The maximum pressure tubing can experience is 1400 psi, based on the pressure that can be delivered from the injection compressors. Thus, the fracture pressure is higher than can physically be realized within the well and there is no risk of fracturing the seals. Further, each CO<sub>2</sub> injection well is assigned a maximum surface injection pressure as a part of the US EPA permitting process, whose purpose is to ensure that the reservoir fracture pressure is not exceeded.

Additionally, geomechanical analyses were conducted using wireline logs and core tests for select reefs. Analytical techniques were used to estimate changes in minimum horizontal stress,  $\sigma_h$ , caused by changes in pressure and temperature during CO<sub>2</sub> injection and to determine whether the stress state compromises the ability of reservoirs for safe and effective CO<sub>2</sub> storage. It was found that fracturing of the reservoir or caprock is not likely as long as the injection pressure is maintained below the UIC permit pressure limit.

#### 4.6 Pipeline/surface equipment

Leakage through pipelines and surface equipment is a potential risk. Core Energy uses its routine maintenance and daily inspection procedures to minimize this risk. Further, it will deploy three approaches to calculate the amounts of CO<sub>2</sub> lost through pipelines and surface equipment: 1) following GHGRR Subpart W methods for estimating fugitive and vented emissions, 2) using direct metering to measure specific venting events as discussed in Section 2.4.3, and 3) in the event an extreme event were to occur, using engineering best practices to estimate a loss.

### 5. Monitoring

This section describes the general approach to monitoring at the Core Energy facility and indicates how data will be collected for this MRV plan.

#### 5.1 General Monitoring Procedures

As part of its ongoing operations, Core Energy monitors and collects flow, pressure, and gas composition data from each reef in the central HMI computer system.

As indicated in Figure 13 Core Energy uses Coriolis mass flow meters for all measurements included in the mass balance (Section 7) and also uses Vortex flow meters for some operational monitoring. Fluid composition will be determined, at a minimum, quarterly, consistent with EPA



GHGRP's Subpart RR, section 98.447(a). All meter and composition data are documented, and records will be retained for the Specified Period. Quarterly composition analysis will be done at meter #2 at Chester 10 Facility for pure CO<sub>2</sub> gas and at meter #19 at Dover 36 Facility for combined recycle gas. If any other combined recycle gas processing facilities are added, as indicated in Section 2.5, similar Coriolis mass flow meters will be installed and quarterly composition analyses will be conducted. Such new meters would be included in the monitoring report and Section 7 calculations. If not done on a routine basis, Core will use initial baseline data or last available quarter composition analysis as continuation of reporting quarter, with justification as to why analysis was not done/deemed necessary. All composition analysis will be on % wt. basis of CO<sub>2</sub> in gas stream.

Core Energy has invested in Micro Motion Coriolis Mass Flow Meters throughout its operations. These meters are designed to retain calibration. The meters have no moving parts and a non-intrusive measuring sensor. As a result, there are no probes or detectors that come into direct contact with process fluids. The benefit of this design is that there are no bearings or rotors to wear, turbines to be deformed, electrodes to coat, or degradation of orifices to be concerned about. The manufacturer reports that "It has been our experience, and that of our customers, that Coriolis meters do not shift or lose their calibration during the life of the meter.

When calibration issues arise, the focus of the problem is normally traceable to the flow meter installation or a characteristic of the process that was not previously taken into consideration." As a result, there are no prevailing industry standard(s) for meter calibration for these meters.

Core Energy observes trend data from the meters and has on occasion sent meters back to the company for recalibration but this does not occur routinely. This type of meter would have to be severely abused (serious mechanical damage, overheating beyond metal plasticity limits) to change calibration. These types of abuses do not happen during normal operations. Therefore, Core Energy considers this approach to be consistent with EPA GHGRP's Subpart RR, section 98.444(e)(3). These meters will be maintained, operated continually, and will feed data directly to the central HMI computer system. The meters meet the industry standard for meter accuracy and calibration frequency. The level of precision and accuracy for these meters currently satisfies the requirements for reporting in existing UIC permits.

## 5.2 CO<sub>2</sub> Received

Core Energy measures the volume of received CO<sub>2</sub> using Coriolis mass flow meters at the Chester 10 Facility and the Dover 36 Facility. As indicated in Section 2.5, any new recycle gas processing would be measured using Coriolis mass flow meters. No CO<sub>2</sub> is received in containers.

### 5.3 CO<sub>2</sub> Injected into the Subsurface

Injected CO<sub>2</sub> will be metered using the Coriolis mass flow meters dedicated to each injection well at a reef.

### 5.4 CO<sub>2</sub> Produced, Entrained in Products, and Recycled

Mass of CO<sub>2</sub> produced by HP separators is measured by Coriolis mass flow meters at the outlet of each HP separator at the Dover 36 Facility.

Mass of CO<sub>2</sub> produced by LP separators is measured first by Vortex flow meter at the outlet of each LP separator at the Dover 36 Facility and is also aggregated for a single measurement using Coriolis mass flow meter #18.

Produced CO<sub>2</sub> at Dover 36 Facility then flows through the Coriolis mass flow meter at the outlet of the recycle compressor in the Dover 36 Facility.

For any new production facilities added, as indicated in Section 2.5, the mass of CO<sub>2</sub> produced would similarly be measured using Coriolis mass flow meters.

CO<sub>2</sub> is produced as entrained or dissolved CO<sub>2</sub> in produced oil. As the oil passes through low-pressure separation to a gathering tank, a small amount of CO<sub>2</sub> is released. Core Energy has determined the emission factor of 16.84 scf/barrel conservatively estimates this amount (see Section 2.4.3), which is about 150 tonnes per year. As indicated in Section 7.5, Core Energy is using a mass balance approach to determine losses from equipment and CO<sub>2</sub> entrained in oil.

### 5.5 CO<sub>2</sub> Emitted by Surface Leakage

Core Energy uses an event-driven process to assess, address, track, and if applicable quantify potential CO<sub>2</sub> leakage to the surface. Core Energy will reconcile the Subpart W report and results from any event-driven quantification to assure that surface leaks are not double counted.

The monitoring program for event-driven incidents has been designed to meet two objectives, in accordance with the leakage risk assessment in Section 4: 1) to detect problems before CO<sub>2</sub> leaks to the surface; and 2) to detect and quantify any leaks that do occur. This section discusses how this monitoring will be conducted and used to quantify the volumes of CO<sub>2</sub> leaked to the surface.

#### 5.5.1 Monitoring for potential Leakage from the Injection/Production Zone:

Core Energy routinely tracks and reports on a daily basis, the following surface data for all wells: Injection Rate (MCF), Production Rates (BO, BW, MCF), Tubing Pressure (psig), Casing Pressure (psig), Wellhead Temperatures (°F) and Runtime (Hours). Where there is instrumentation, data are collected more frequently but in the oilfield it is normal and customary for data to be reduced to daily volumes and/or averages. With respect to tracking reservoir pressure, episodic surveys are conducted, on a field-by-field or well-by-well basis to gather information about reservoir pressure and other parameters (e.g. kh, skin). Because of the heterogeneity of these carbonate pinnacle reefs, it is not feasible to let injection wells fall-off or producing wells build-up for periods long enough to reach static conditions, thus, the bottom hole pressure measured in an injection

well can be very significantly higher than that measured in a producing well over the typical survey duration (e.g. 3 to 7 days). Therefore, over time, well pressure survey histories are developed for both injection and production wells, that yield general performance behavior and characteristics for each well (field). Then, if a survey is run and its results diverge from this survey history in a statistically significant way, it triggers a deeper evaluation to discern what may be taking place and causing the anomaly. For example if injection wells in a field, over time, yield similar pressure survey results and then suddenly a survey yields an anomalous and lower result, then further evaluation is done to discern what may be causing the change (e.g. net CO<sub>2</sub> in reservoir declined considerably since last survey and/or an injection well was shut-in or its injection rate reduced, then the measured pressure would be expected to be lower than previous surveys).

If leakage in the flood zone were detected, Core Energy would use an appropriate method to quantify the involved volume of CO<sub>2</sub>. This might include use of material balance equations based on known injected quantities and monitored pressures in the injection zone to estimate the volume of CO<sub>2</sub> involved.

A subsurface leak might not lead to a surface leak. In the event of a subsurface leak, Core Energy would determine the appropriate approach for tracking subsurface leakage to determine and quantify leakage to the surface. To quantify leakage to the surface, Core Energy would estimate the relevant parameters (e.g., the rate, concentration, and duration of leakage) to quantify the leak volume. Depending on specific circumstances, these determinations may rely on engineering estimates.

#### 5.5.2 Monitoring of Wellbores:

Core Energy monitors wells through continual pressure monitoring in the injection zone (as described in Section 5.1), monitoring of the annular pressure in wellheads, and routine maintenance and inspection. At any time, in the case of an injection well, where there is a loss of MIT, the well must be and is shut-in until such time the wellbore is repaired. Upon completion of the workover, a new MIT is performed under the oversight of the EPA. The results of the MIT along with workover information are supplied to the EPA and if all is in order, they issue a letter authorizing injection to be resumed. Under no circumstances is injection commenced until such time the letter is in hand.

Leaks from wellbores would be detected through the follow-up investigation of pressure anomalies and visual inspection.

Anomalies in injection zone pressure may not indicate a leak, as discussed above. However, if an investigation leads to a work order, field personnel would inspect the equipment in question and determine the nature of the problem. If it is a simple matter, the repair would be made and the volume of leaked CO<sub>2</sub> would be included in the 40 CFR Part 98 Subpart W report for the Core Energy Facility. If more extensive repair were needed, Core Energy would determine the appropriate approach for quantifying leaked CO<sub>2</sub> using the relevant parameters (e.g., the rate, concentration, and duration of leakage).

Anomalies in annular pressure or other issues detected during routine maintenance inspections would be treated in the same way. Field personnel would inspect the equipment in question and

determine the nature of the problem. For simple matters the repair would be made at the time of inspection and the volume of leaked CO<sub>2</sub> would be included in the 40 CFR Part 98 Subpart W report for the Core Energy Facility. If more extensive repairs were needed, the well would be shut in until repairs could be completed and Core Energy would determine the appropriate approach for quantifying leaked CO<sub>2</sub> using the relevant parameters (e.g., the rate, concentration, and duration of leakage).

In the event CO<sub>2</sub> is lost during a repair, the most recent daily volume of CO<sub>2</sub> would be prorated against the number of hours that the failure caused CO<sub>2</sub> to leak from the system. It should be noted that when doing workovers, the wells are always “killed” by using appropriate density fluid and the wells are “dead” (no CO<sub>2</sub> flow), thus, leakage, is very rare during workovers to wells.

#### 5.6 Mass of CO<sub>2</sub> Emissions from Equipment Leaks and Vented Emissions of CO<sub>2</sub> from Surface Equipment Located Between the Injection Flow Meter and the Injection Wellhead

Core Energy evaluates, and estimates leaks from equipment, the CO<sub>2</sub> content of produced oil, and vented CO<sub>2</sub>, using the procedures in 40 CFR Part 98 Subpart W. In the past, the amount of CO<sub>2</sub> leaked has been too small to meet the threshold for reporting. As indicated in Section 7.5, Core Energy is using a mass balance approach to determine losses from equipment and CO<sub>2</sub> entrained in oil.

#### 5.7 Mass of CO<sub>2</sub> Emissions from Equipment Leaks and Vented Emissions of CO<sub>2</sub> from Surface Equipment Located Between the Production Flow Meter and the Production Wellhead

Core Energy evaluates and estimates leaks from equipment, the CO<sub>2</sub> content of produced oil, and vented CO<sub>2</sub>, using the procedures in 40 CFR Part 98 Subpart W. In the past, the amount of CO<sub>2</sub> leaked has been too small to meet the threshold for reporting. As indicated in Section 7.5, Core Energy is using a mass balance approach to determine losses from equipment and CO<sub>2</sub> entrained in oil.

#### 5.8 Demonstration that Injected CO<sub>2</sub> is not expected to Migrate to the Surface

At the end of the Specified Period, Core Energy intends to cease injecting CO<sub>2</sub> for the ancillary purpose of establishing the long-term storage of CO<sub>2</sub> in the Core Energy Facility. After the end of the Specified Period, Core Energy anticipates that it will submit a request to discontinue monitoring and reporting. The request will demonstrate that the amount of CO<sub>2</sub> reported as stored “is not expected to migrate in the future in a manner likely to result in surface leakage” ( §98.441).

At that time, Core Energy will be able to support its request with years of data collected during the Specified Period as well as two to three (or more, if needed) years of data collected after the end of the Specified Period. This demonstration will provide the information necessary for the EPA Administrator to approve the request to discontinue monitoring and reporting including:

- i. An assessment of injection data for each reef indicating the total volume of injected and stored CO<sub>2</sub> as well as the actual surface injection pressures;

- ii. An assessment of the CO<sub>2</sub> leakage detected, if any, including discussion of the estimated amount of CO<sub>2</sub> leaked and the distribution of emissions by leakage pathway; and
- iii. An assessment of reservoir pressure that demonstrates the reservoir pressure in a reef is either too low to enable flow to the surface (i.e., reef has been blown down) or that the reservoir pressure is stable enough to demonstrate that the CO<sub>2</sub> is contained within the reef and not expected to migrate in a manner to create a potential leakage pathway.

## 6. Determination of Expected Baselines

Core Energy will develop the necessary system guidelines to capture the information that is relevant to identify possible CO<sub>2</sub> leakage.

### **Injection / Production Data**

The following surface data for all wells will be tracked on a daily basis:

- Injection Rate (MCF),
- Production Rates (BO, BW, MCF),
- Tubing Pressure (psig),
- Casing Pressure (psig),
- Wellhead Temperatures (°F) and
- Runtime (Hours).

Reservoir pressure will be tracked using episodic surveys on a field-by-field and well-by-well basis. Over time, well pressure survey histories are developed for both injection and production wells that yield general performance behavior and characteristics for each well (field).

### **Wellbore Data**

The following data for all injection wells will be tracked:

- pressure monitoring in the injection zone (as described in Section 5),
- monitoring of the annular pressure in wellheads,
- routine maintenance and inspection, and
- MIT data.

## 7. Site Specific Considerations for the Mass Balance Equation

The Core Energy facility is small relative to many other EOR operations. It operates a current total of 15 injection, 14 production, and 7 monitoring/production wells located in 10 reefs. Core Energy also has 2.11 million metric tonnes of CO<sub>2</sub> inventory that will be reflected, over time, in the mass balance equation. To account for the site conditions and complexity Core Energy proposes to modify the locations for obtaining volume data for the equations in Subpart RR §98.443 as indicated below.

## 7.1. Mass of CO<sub>2</sub> Received

Core Energy will use equation RR-1 as indicated in Subpart RR §98.443 to calculate the mass of CO<sub>2</sub> received from the Chester 10 Facility and all recycle gas (currently from Dover 36 Facility but to include other new recycling facilities as indicated in Section 2.5.). In the annual monitoring report, Core Energy will track the current and cumulative volume of Dover 36 Facility CO<sub>2</sub> and indicate when it has reached 2,110,000 metric tonnes of working inventory. Core Energy will continue to calculate mass of CO<sub>2</sub> received in this manner and will compare it to mass of CO<sub>2</sub> injected to determine surface losses as indicated in Section 7.5. In the future, any additional new sources of CO<sub>2</sub> will be added.

$$CO_{2T,r} = \sum_{p=1}^4 (Q_{r,p} - S_{r,p}) * C_{CO_2,p,r} \quad \text{Equation RR-1}$$

where:

CO<sub>2T,r</sub> = Net annual mass of CO<sub>2</sub> received through flow meter r (metric tons).

Q<sub>r,p</sub> = Quarterly mass flow through a receiving flow meter r in quarter p at standard conditions (metric tons).

S<sub>r,p</sub> = Quarterly mass flow (metric tons) through a receiving flow meter r that is redelivered to another facility without being injected into a site well in quarter p

C<sub>CO<sub>2</sub>,p,r</sub> = Quarterly CO<sub>2</sub> concentration measurement in flow for flow meter r in quarter p (wt. percent CO<sub>2</sub>, expressed as a decimal fraction).

p = Quarter of the year.

r = Receiving flow meters.

Core Energy will sum to total Mass of CO<sub>2</sub> Received using equation RR-3 in §98.443

$$CO_2 = \sum_{r=1}^R CO_{2T,r} \quad \text{Equation RR-3}$$

where:

CO<sub>2</sub> = Total net annual mass of CO<sub>2</sub> received (metric tons).

CO<sub>2T,r</sub> = Net annual mass of CO<sub>2</sub> received (metric tons) as calculated in Equation RR-1 for flow meter r.

r = Receiving flow meter.

## 7.2 Mass of CO<sub>2</sub> Injected into the Subsurface

Core Energy will use equation RR-4 as indicated in Subpart RR §98.443 to calculate the mass of CO<sub>2</sub> injected into the subsurface at each of the ten reefs. Core proposes to use a method to calculate "C<sub>CO<sub>2</sub>,p,u</sub>" that uses a weighted average concentration that reflects

Equation RR-4

the different CO<sub>2</sub> concentrations in the different sources of CO<sub>2</sub> as explained below.

$$CO_{2,u} = \sum_{p=1}^4 Q_{p,u} * C_{CO_2,p,u}$$

where:

CO<sub>2,u</sub> = Annual CO<sub>2</sub> mass injected (metric tons) as measured by flow meter u.

Q<sub>p,u</sub> = Quarterly mass flow rate measurement for flow meter u in quarter p (metric tons per quarter).

C<sub>CO<sub>2</sub>,p,u</sub> = Quarterly CO<sub>2</sub> concentration average measurement in flow for all injection flow meters (wt. percent CO<sub>2</sub>, expressed as a decimal fraction) as determined from Equation A below.

p = Quarter of the year.

u = Injection Flow meter.

For the weighted average concentration, C<sub>CO<sub>2</sub></sub>, Equation A indicates the current calculation using CO<sub>2</sub> from Chester 10 Facility and Dover 36 Facility. If new facilities are added, the weighted concentration average would be modified to include them in the same manner.

Equation A

$$Concentration\ Average = \frac{Q_{p,CH10} * C_{CO_2,p,CH10} + Q_{p,D36} * C_{CO_2,p,D36}}{Q_{p,CH10} + Q_{p,D36}}$$

Where:

Q<sub>p,CH10</sub> = Quarterly mass flow rate measurement of pure CO<sub>2</sub> (from Chester 10 Facility at flow meter #2) in quarter p (metric tons per quarter).

Q<sub>p,D36</sub> = Quarterly mass flow rate measurement of recycle gas (from Dover 36 Facility at flow meter #19) in quarter p (metric tons per quarter).

C<sub>CO<sub>2</sub>,p,CH10</sub> = Quarterly CO<sub>2</sub> concentration of pure CO<sub>2</sub> (from Chester 10 Facility at flow meter #2) in quarter p (wt. percent CO<sub>2</sub>, expressed as a decimal fraction).

C<sub>CO<sub>2</sub>,p,D36</sub> = Quarterly CO<sub>2</sub> concentration of recycle gas (from Dover 36 Facility at flow meter #19) in quarter p (wt. percent CO<sub>2</sub>, expressed as a decimal fraction).

Core Energy will aggregate injection data using equation RR-6:

$$CO_{2i} = \sum_{u=1}^U CO_{2,u}$$

Equation RR-6

where:

CO<sub>2i</sub> = Total annual CO<sub>2</sub> mass injected (metric tons) through all injection wells.



$CO_{2,u}$  = Annual  $CO_2$  mass injected (metric tons) as measured by flow meter u.

### 7.3 Mass of $CO_2$ Produced

Core Energy uses Coriolis mass flow meters to measure  $CO_2$  in produced fluids in the high-pressure separators and will use equation RR-7 to calculate mass of  $CO_2$  produced from these facilities. It will use the aggregate Coriolis meter #18 to determine the total  $CO_2$  produced from low-pressure separators. It will use equation RR-9 to aggregate these calculations.

In addition, Core Energy uses Vortex volumetric flow meters to measure  $CO_2$  produced through the low-pressure separators and will use equation RR-8 to calculate mass of  $CO_2$  produced from these facilities. These mass amounts will not be reported but will be used internally for operations and as a check on the meter #18 calculation.

Core will determine a single quarterly  $CO_2$  concentration for the recycle gas at Dover 36 Facility flow meter #19 for use in calculating  $CO_2$  produced using equations RR-7 and RR-8 below for Dover 36 separators. If new production facilities are added, as indicated in Section 2.5, the concentration for each separating facility will be determined in the same manner.

$$CO_{2,w} = \sum_{p=1}^4 Q_{p,w} * C_{CO_2,p,w} \quad \text{Equation RR-7 as modified}$$

Where:

$CO_{2,w}$  = Annual  $CO_2$  mass produced (metric tons) through separator w.

$Q_{p,w}$  = Quarterly gas mass flow rate measurement for separator w in quarter p (metric tons).

$C_{CO_2,p,w}$  = Quarterly  $CO_2$  concentration of recycle gas (currently at Dover 36 Facility flow meter #19) for separator w in quarter p (wt. percent  $CO_2$ , expressed as a decimal fraction).

p = Quarter of the year.

w = Separator.

For the vortex type flow meters on the low-pressure separators, Core will use equation similar to RR-7 :

$$CO_{2,w} = \sum_{p=1}^4 Q_{p,w} * D * C_{CO_2,p,w} \quad \text{Equation RR-8}$$

Where:

$CO_{2,w}$  = Annual  $CO_2$  mass produced (metric tons) through separator w.

$Q_{p,w}$  = Volumetric gas flow rate measurement for separator w in quarter p at standard conditions (standard cubic meters).

D = Density of CO<sub>2</sub> at standard conditions (metric tons per standard cubic meter): 0.0018682.  
 C<sub>CO<sub>2</sub>,p,w</sub> = Quarterly CO<sub>2</sub> concentration of recycle gas (currently at Dover 36 Facility flow meter #19) for separator w in quarter p (wt. percent CO<sub>2</sub>, expressed as a decimal fraction)  
 p = Quarter of the year.  
 w = Separator.

Core will aggregate production data using equation RR-9

$$CO_{2P} = \sum_{w=1}^W CO_{2,w} \quad \text{Equation RR-9}$$

Where:

CO<sub>2p</sub> = Total annual CO<sub>2</sub> mass produced (metric tons) through all separators in the reporting year.

CO<sub>2,w</sub> = Annual CO<sub>2</sub> mass produced (metric tons) through separator w in the reporting year.

w = Separator flow meter.

#### 7.4 Mass of CO<sub>2</sub> emitted by Surface Leakage

Core Energy will calculate and report the total annual Mass of CO<sub>2</sub> emitted by Surface Leakage using an approach that is tailored to specific leakage events. As described in Sections 4 and 5.1.5-5.1.7, Core Energy is prepared to address the potential for leakage in a variety of settings. Estimates of the amount of CO<sub>2</sub> leaked to the surface will likely depend on a number of site-specific factors including measurements, engineering estimates, and emission factors, depending on the source and nature of the leakage.

Core Energy's process for quantifying leakage will entail using best engineering principles or emission factors. While it is not possible to predict in advance the types of leaks that will occur, Core Energy describes some approaches for quantification in Section 5.1.5-5.1.7. In the event leakage to the surface occurs, Core Energy would quantify and report leakage amounts, and retain records that describe the methods used to estimate or measure the volume leaked as reported in the Annual Subpart RR Report. Further, Core Energy will reconcile the Subpart W report and results from any event-driven quantification to assure that surface leaks are not double counted.

Equation RR-10 in 48.433 will be used to calculate and report the Mass of CO<sub>2</sub> emitted by Surface Leakage:

$$CO_{2E} = \sum_{x=1}^X CO_{2,x} \quad \text{Equation RR-10}$$

where:

CO<sub>2E</sub> = Total annual CO<sub>2</sub> mass emitted by surface leakage (metric tons) in the reporting year.

CO<sub>2,x</sub> = Annual CO<sub>2</sub> mass emitted (metric tons) at leakage pathway x in the reporting year.

x = Leakage pathway.

## 7.5 Mass of CO<sub>2</sub> sequestered in subsurface geologic formations.

Core Energy proposes an approach to calculating equipment leaks and venting that relies on mass balance as well as direct measurements. Rather than modifying the equation, Core Energy proposes to determine  $CO_{2FI}$  for use in equation RR-11 in 98.443 as being equal to the difference between the amount of CO<sub>2</sub> received (in section 7.1, equation RR3) and the amount of CO<sub>2</sub> injected (in section 7.2, equation RR6). This calculation is more accurate than measuring the amount of CO<sub>2</sub> entrained in oil and using Subpart W results. Currently there is a difference of roughly 13,000 tonnes per year between these two values. Of this, roughly 7,000 tonnes is explained by the calculations conducted in accordance with GHG Reporting Rule Subpart W and an additional 150 tonnes is explained by the entrained oil factor. Rather than attempting to directly measure the balance, Core Energy will use the entire difference as losses from equipment and entrained in oil.

$$CO_2 = CO_{2I} - CO_{2P} - CO_{2E} - CO_{2FI} - CO_{2FP} \quad \text{Equation RR-11}$$

where:

$CO_2$  = Total annual CO<sub>2</sub> mass sequestered in subsurface geologic formations (metric tons) at the facility in the reporting year.

$CO_{2I}$  = Total annual CO<sub>2</sub> mass injected (metric tons) in the well or group of wells covered by this source category in the reporting year.

$CO_{2P}$  = Total annual CO<sub>2</sub> mass produced (metric tons).

$CO_{2E}$  = Total annual CO<sub>2</sub> mass emitted (metric tons) by surface leakage in the reporting year.

$CO_{2FI}$  = Total annual CO<sub>2</sub> mass emitted (metric tons) from equipment leaks and vented emissions of CO<sub>2</sub> from equipment located on the surface, which will be calculated as RR-3 – RR-6.

$CO_{2FP}$  = Total annual CO<sub>2</sub> mass emitted (metric tons) from equipment leaks and vented emissions of CO<sub>2</sub> from equipment located on the surface between the production wellhead and the flow meter used to measure production quantity as in Subpart W. Note: This calculation is subsumed in the calculation of  $CO_{2FI}$  and will be reported as zero.

## 7.6 Cumulative mass of CO<sub>2</sub> reported as sequestered in subsurface geologic formations

Core Energy will sum up the total annual volumes obtained using equation RR-11 in 98.443 to calculate the Cumulative Mass of CO<sub>2</sub> Sequestered in Subsurface Geologic Formations.

## 8. Estimated Schedule for Implementation of MRV Plan

This plan will be effective as of January 1, 2018.

## 9. Quality Assurance Program

### 9.1 Monitoring

Core Energy will follow the requirements in 40 CFR part 98.444 as indicated in Sections 2, 5 and 7. As indicated in Section 5.1, Core Energy has invested in Micro Motion Coriolis Mass Flow Meters throughout its operations. These meters are designed to retain calibration. The meters have no moving parts and a non-intrusive measuring sensor. As a result, there are no probes or detectors that come into direct contact with process fluids. The benefit of this design is that there are no bearings or rotors to wear, turbines to be deformed, electrodes to coat, or degradation of orifices to be concerned about. The manufacturer reports that “It has been our experience, and that of our customers, that Coriolis meters do not shift or lose their calibration during the life of the meter. When calibration issues arise, the focus of the problem is normally traceable to the flow meter installation or a characteristic of the process that was not previously taken into consideration.” As a result, there are no prevailing industry standard(s) for meter calibration for these meters. Core Energy observes trend data from the meters and has on occasion sent meters back to the company for recalibration but this does not occur routinely. Core Energy considers this approach to be consistent with EPA GHGRP’s Subpart RR, section 98.444(e)(3). These meters will be maintained, operated continually, and will feed data directly to the central HMI computer system. The meters meet the industry standard for meter accuracy and calibration frequency. The level of precision and accuracy for these meters currently satisfies the requirements for reporting in existing UIC permits.

### 9.2 Procedures for estimating missing data.

In the event Core Energy is not able to collect data for the mass balance equations, it will follow the requirements in 40 CFR part 98.445 to provide missing data.

When estimating the volume of missing CO<sub>2</sub> data due to an interruption in data collection or mechanical failure of a meter (equipment) is to use the most recent daily volume of CO<sub>2</sub> associated with the meter and calculate the proportionate volume of “lost” CO<sub>2</sub> based on the number of hours involved in the data gap or until meter repaired.

### 9.3 MRV Plan Revisions

In the event there is a material change to the monitoring and/or operational parameters of the Core Energy CO<sub>2</sub> EOR operations that is not anticipated in this MRV plan, the MRV plan will be revised and submitted to the EPA Administrator within 180 days as required in §98.448(d).

## 10. Records Retention

Core Energy will maintain and submit records required under 40 CFR Part 98.3(g) and 40 CFR Part 98.447. Records will be maintained by Core Energy in electronic format at the Core Energy headquarters. In addition, Core Energy has well and facility data in three forms; A.) Paper copies (scanned to server), B.) Keyed in data from paper copies into database, and C.) Automated capture of limited set of data that was recently instrumented (Fall of 2016).

## 11. References

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# Appendix

## Appendix I: List of Wells

Table A-1. Core Energy Wells used for Monitoring and Accounting

Unit	Facility	API Permit	DEQ Permit	Well Name	Well Type	Well Status
<b>Dover 33 EOR Unit</b>	Dover 36 CPF	21-137-29565-00-00	29565	Lawnichak & Myszkiec 1-33	Injection	INJ
<b>Dover 33 EOR Unit</b>	Dover 36 CPF	21-137-00652-00-00	61209	Lawnichak 9-33	Oil	PR
<b>Dover 33 EOR Unit</b>	Dover 36 CPF	21-137-51603-00-00	51603	Lawnichak & Myszkiec 5-33 HD1	Oil	PR
<b>Dover 33 EOR Unit</b>	Dover 36 CPF	21-137-50985-04-00	55942	Lawnichak & Myszkiec 2-33 HD4	Oil	PR
<b>Bagley 11-14-23 EOR</b>	Dover 36 CPF	21-137-39758-01-00	39866	Wrubel 4-14A	Injection	INJ
<b>Bagley 11-14-23 EOR</b>	Dover 36 CPF	21-137-30536-00-00	30536	MBM 1-22	Injection	INJ
<b>Bagley 11-14-23 EOR</b>	Dover 36 CPF	21-137-38240-00-00	38240	Daughters of Friel 2-11	Injection	INJ
<b>Bagley 11-14-23 EOR</b>	Dover 36 CPF	21-137-37794-00-00	37794	Janik Mackowiac 1-11	Oil	OBS
<b>Bagley 11-14-23 EOR</b>	Dover 36 CPF	21-137-38286-00-00	38286	Janik Stevens 3-11	Oil	OBS
<b>Bagley 11-14-23 EOR</b>	Dover 36 CPF	21-137-39748-00-00	39748	Janik Strappazon 3-14	Oil	OBS
<b>Bagley 11-14-23 EOR</b>	Dover 36 CPF	21-137-38859-02-00	39897	Glasser 1-14B	Oil	OBS
<b>Charlton 19 Unit (EOR)</b>	Dover 36 CPF	21-137-42766-00-00	42766	El Mac Hills 2-18	Injection	INJ
<b>Charlton 19 Unit (EOR)</b>	Dover 36 CPF	21-137-40911-04-00	57261	El Mac Hills 1-19D	Oil	SI-P
<b>Charlton 19 Unit (EOR)</b>	Dover 36 CPF	21-137-41801-01-00	61197	El Mac Hills 1-18A	Oil	PR
<b>Charlton 30/31 EOR Unit</b>	Dover 36 CPF	21-137-30203-00-00	30203	State Charlton C2-30	Injection	INJ
<b>Charlton 30/31 EOR Unit</b>	Dover 36 CPF	21-137-59048-00-00	59048	State Charlton & Larsen 3-31	Injection	INJ
<b>Charlton 30/31 EOR Unit</b>	Dover 36 CPF	21-137-29989-00-00	29989	State Charlton 1-30A	Injection	INJ
<b>Charlton 30/31 EOR Unit</b>	Dover 36 CPF	21-137-57916-00-00	57916	State Charlton 4-30	Oil	PR
<b>Charlton 30/31 EOR Unit</b>	Dover 36 CPF	21-137-31287-00-00	31287	State Charlton 2-30	Oil	PR
<b>Charlton 6 EOR Unit</b>	Dover 36 CPF	21-137-35209-00-00	35209	Zeimet-Higgins & St Charlton 1-6	Injection	INJ
<b>Charlton 6 EOR Unit</b>	Dover 36 CPF	21-137-59086-00-00	59086	State Charlton & Boeve 2-6	Oil	PR
<b>Chester 2 EOR Unit</b>	Dover 36 CPF	21-137-29430-00-00	29430	Wolf, Carl 1A	Injection	INJ
<b>Chester 2 EOR Unit</b>	Dover 36 CPF	21-137-29958-01-00	29958	Wolf, Carl et al C1-HD1	Oil	PR



<b>Chester 2 EOR Unit</b>	Dover 36 CPF	21-137- 60596-01-00	60596	Cargas 3-2 HD2	Oil	PR
<b>Chester 5 EOR Unit</b>	Dover 36 CPF	21-137- 59237-00-00	59237	Borowiak 2-6	Injection	INJ
<b>Chester 5 EOR Unit</b>	Dover 36 CPF	21-137- 58926-00-00	58926	Butler 3-5	Injection	SI-I
<b>Chester 5 EOR Unit</b>	Dover 36 CPF	21-137- 29265-01-00	60833	Piasecki 1-7A	Oil	PR
<b>Dover 35 EOR Unit</b>	Dover 36 CPF	21-137- 29236-00-00	29236	Salling Hanson Trust 1-35	Injection	INJ
<b>Dover 35 EOR Unit</b>	Dover 36 CPF	21-137- 37324-01-00	59238	Pomarzynski et al 5-35A	Oil	SI-P
<b>Dover 35 EOR Unit</b>	Dover 36 CPF	21-137- 29947-01-00	29995	Salling Hanson Trust 4-35A	Oil	PR
<b>Dover 35 EOR Unit</b>	Dover 36 CPF	21-137- 57787-00-00	57787	Pomarzynski et al 6-35	Oil	PR
<b>Dover 36 EOR Unit</b>	Dover 36 CPF	21-137- 29348-00-00	29348	Kubacki State 3-35	Injection	INJ
<b>Dover 36 EOR Unit</b>	Dover 36 CPF	21-137- 29235-00-00	29235	Kubacki State 1-36	Injection	INJ
<b>Dover 36 EOR Unit</b>	Dover 36 CPF	21-137- 52719-00-00	52719	Dover State 36 Unit 3-36	Oil	PR
<b>Chester 16 EOR Unit</b>	Dover 36 CPF	21-137- 61189-00-00	61189	Chester 16 Unit 6-16 Pilot	Injection	INJ
<b>Chester 16 EOR Unit</b>	Dover 36 CPF	21-137- 61186-00-00	61186	Chester 16 Unit 8-16	Oil	OBS

Table A-2. Summary of Niagaran Wells by Reef With Listing of Depth, Completion Date, and Wireline Log Inventory used for Geologic Characterization

Source: Michigan DEQ Oil and Gas Well Database ([http://michigan.gov/deq/0,1607,7-135-3311\\_4111\\_4231-97870--,00.html](http://michigan.gov/deq/0,1607,7-135-3311_4111_4231-97870--,00.html))

Note: CAL=CALIPER; GR=GAMMA RAY; NPFI=NEUTRON POROSITY; RHOB=DENSITY; PE=PHOTOELECTRIC; SON=SONIC; RES=RESISTIVITY; CBL=CEMENT BOND LOG; CBIL= circumferential borehole image log (acoustic image log); NEUTRON= neutron log reported in neutron units; PNC=Pulsed Neutron Capture log.

(a) Indicates currently active (not plugged/abandoned) producing well.

(b) Indicates currently active (not plugged/abandoned) injection well.

(c) Deviated well; total depth amsl will be determined after acquiring deviation survey.

Reef	Well Permit No.	Well Name	Well No.	Total Depth, ft		Date Completed	Wireline Logs
				bgs	amsl		
Bagley	29074	Yule King Tree	1-15	6135	- 4815	1/14/1973	CAL,GR,NPFI,RHOB,RES
	29085	Alan Gornick	1-23	6177	- 4867	1/18/1973	CAL,GR,NPFI,RHOB
	29249	Alan Gornick	1-14	6165	- 4869	11/23/1973	CAL,GR,NPFI,RHOB
	30536 <sup>(a)</sup>	MBM	1-22	6013	- 4689	10/24/1975	CAL,GR,NPFI,RHOB,RES
	37794 <sup>(a)</sup>	Janik & Mackowiac	1-11	6326	- 5021	9/11/1984	CAL,GR,NPFI,RHOB,RES,PNC
	38240 <sup>(b)</sup>	Daughters of Friel	2-11	6250	- 4739	10/30/1984	CAL,GR,NPFI,RHOB,RES
	38286 <sup>(a)</sup>	Janik & Stevens	3-11	6045	- 4676	11/2/1984	CAL,GR,NPFI,RHOB,RES
	38859	Glasser	1-14A	6115	- 4811	3/2/1986	CAL,GR,NPFI,RES
	38923	Yule King Tree	1-14	6024	- 4725	10/17/1985	CAL,GR,NPFI,RES,PNC

Reef	Well Permit No.	Well Name	Well No.	Total Depth, ft		Date Completed	Wireline Logs
				bgs	amsl		
	39554	Stevens and State Bagley	1-22	6295	- 4975	1/13/1986	CAL,GR,NPHI,RHOB,RES
	39748 <sup>(a)</sup>	Janik & Strappazon	3-14	6000	- 4706	2/24/1986	CAL,GR,NPHI,RHOB,RES
	39758	Wrubel	4-14	6140	(c)	3/9/1986	CAL,GR,NPHI,RHOB,RES
	39850	Glasser	1-14A	6367	- 4839	3/12/1986	CAL,GR,NPHI,RHOB,RES
	39866 <sup>(a)</sup>	Wrubel	4-14A	6191	- 4822	4/21/1986	CAL,GR,NPHI,RHOB,RES
	39897 <sup>(a)</sup>	Glasser	1-14B	6130	- 4752	5/7/1986	CAL,GR,NPHI,RES,PNC
	55307	Stevens and State Bagley	1-22A	6270	- 4910	1/9/2003	CAL,GR,NPHI,RHOB,RES
Charlton 6	28895	Zeimet & Higgins	1-6	6008	- 4724	6/21/1972	CAL,GR,NPHI,RHOB,RES
	35209 <sup>(b)</sup>	Zeimet, Higgins & State Charlton	1-6	5975	- 4745	12/10/1981	CAL,GR,NPHI,RHOB,PE,RES
	59086 <sup>(a)</sup>	State Charlton & Boeve	2-6	6202	- 4796	6/19/2008	CAL,GR,NPHI,RHOB,RES,PE
Charlton 19	40911	El Mac Hills	1-19	5675	- 4552	3/9/1988	CAL,GR,NPHI,RHOB,RES,SON
	41801	El Mac Hills	1-18A	5466	- 4341	2/24/1989	CAL,GR,NPHI,RHOB,RES,PNC
	42766 <sup>(b)</sup>	El Mac Hills	2-18	5555	(c)	2/5/1990	CAL,GR,NPHI,RHOB,RES,PNC
	54416	El Mac Hills	1-19A	5433	- 4297	6/22/2001	Not Logged
	54582	El Mac Hills	1-19B	5421	(c)	6/27/2001	Not Logged
	54583	El Mac Hills	1-19C	5321	- 4246	7/1/2001	Not Logged
	57261 <sup>(a)</sup>	El Mac Hills	1-19D	5495	- 4335	12/21/2005	CAL,GR,NPHI,RHOB,RES,SON,PNC
Charlton 30-31	29073	Salling Hanson et al	1-31	5770	- 4645	1/9/1973	CAL,GR,NPHI,RHOB,SON,RES
	30195	State Charlton "C"	1-30	5679	- 4497	3/21/1975	CAL,GR,NPHI,RHOB,RES

Reef	Well Permit No.	Well Name	Well No.	Total Depth, ft		Date Completed	Wireline Logs
				bgs	amsl		
	32605	State Charlton "C"	3-30	5746	- 4563	12/16/1978	CAL,GR,NPHI,RHOB,RES
	29989 <sup>(b)</sup>	State Charlton	1-30A	5650	- 4582	12/24/1974	CAL,GR,NPHI,SON,RES
	30203 <sup>(b)</sup>	State Charlton "C"	2-30	6255	- 4588	4/22/1975	CAL,GR,NPHI,RHOB,RES
	31287 <sup>(a)</sup>	State Charlton	2-30	5660	- 4517	12/7/1976	CAL,GR,NPHI,SON,RES
	57916 <sup>(a)</sup>	State Charlton	4-30	5800	- 4599	11/30/2006	CAL,GR,NPHI,RHOB,PE,RES
	59048 <sup>(b)</sup>	State Charlton & Larsen	3-31	5800	- 4689	7/7/2008	CAL,GR,NPHI,RHOB,PE,RES
Chester 2	28459	Cargas, Perry J	1	6005	- 4762	10/4/1971	CAL,GR,NPHI,RHOB,SON,RES
	28706	Finnegan, Bernard et al	1	6051	- 4818	1/6/1972	CAL,GR,NPHI,RES
	29677	Wolf, Carl	1-B	5847	- 4568	6/27/1974	CAL,GR,NPHI,RHOB,RES
	31646	Cargas, Perry J	1-2A	5990	- 4745	9/9/1977	CAL,GR,NPHI,RHOB,RES
	29430 <sup>(b)</sup>	Wolf, Carl	1-A	5973	- 4710	12/2/1973	CAL,GR,NPHI,RHOB,RES
	29958 <sup>(a)</sup>	Wolf, Carl et al "C"	1	5806	- 4536	12/9/1974	CAL,GR,NPHI,RHOB,RES
	29958-01 <sup>(a)</sup>	Wolf, Carl et al "C"	1 HD1	6570	- 4509	10/9/2001	CAL,GR,CBL
	60596 <sup>(a)</sup>	Cargas, Perry J	3-2 HD-1	6962	- 4556	10/9/2012	CAL,GR,NPHI,RHOB,RES,SON,PNC
Chester 5-6	29067	Borowiak	1-6	6022	- 4673	1/11/1973	CAL,GR,NPHI,SON,RES
	29234	Borowiak	1-5	5725	- 4409	4/13/1973	CAL,GR,NPHI,SON,RES
	29254	Kosiara	2-7	5750	- 4398	5/24/1973	CAL,GR,SON,RES
	29265	Piasecki	1-7	5770	- 4416	5/4/1973	CAL,GR,NPHI,SON,RES,PNC

Reef	Well Permit No.	Well Name	Well No.	Total Depth, ft		Date Completed	Wireline Logs
				bgs	amsl		
	31515	Piasecki, John State Chester	1-7	5800	- 4462	6/1/1977	CAL,GR,NPHI,RHOB,RES
	32207	Kosiara, Josephine	2-7A	5881	(c)	3/20/1978	CAL,GR,NPHI,RHOB,RES
	38424	Gottloeb	1-8	6080	(c)	11/21/1984	CAL,GR,NPHI,RHOB,PE,RES
	40169	Nienaber	2-5	5985	- 4633	12/16/1986	CAL,GR,NPHI,RHOB,PE,RES
	58926 <sup>(b)</sup>	Butler	3-5	5897	- 4585	5/1/2008	CAL,GR,NPHI,RHOB,RES,CBIL,CRA
	59237 <sup>(b)</sup>	Borowiak	2-6	6100	- 4751	7/25/2008	CAL,GR,NPHI,RHOB,PE,RES,CBIL,CBL
Chester 16	28159	Gaylord Mortgage	1-16	6210	- 4873	1/4/1971	CAL,GR,NPHI,RHOB,RES,SNP
	28433	Veraghen, Martin G	4-21	6303	- 4972	8/13/1971	CAL,GR,NPHI,RHOB,RES,SNP,SON
	28511	Gaylord Mortgage	2-16	6250	- 4907	9/4/1971	CAL,GR,NPHI,RES,SNP,SON
	28743	Veraghen & Rypkowski	5-21	6350	- 5037	3/29/1972	CAL,GR,NPHI,RES,SNP,SON
	28796	Gaylord Mortgage	3-16	6222	- 4896	8/22/1972	CAL,GR,NPHI,RES,SNP
	28798	Dreffs	4-16	6265	- 4913	3/13/1972	RES,SNP, SON
	28918	Veraghen & Dreffs	6-21	6318	- 4995	7/20/1972	CAL,GR,RES,SNP,SON
	61186	Chester	8-16	6455	- 5020	2/26/2017	CAL,GR,NPHI,RES,RHOB,SON
	61189***	Chester	6-16	6697	- 5061	12/23/2016	CAL,GR,NPHI,RES,RHOB,SON,PNC
Dover 33	29565 <sup>(b)</sup>	Lawnichak & Myszkier	1-33	5675	- 4528	5/20/1974	CAL,GR,NPHI,RES,RHOB,SON,PNC
	29781	Lawnichak & Myszkier	3-33	5625	- 4404	8/16/1974	CAL,GR,NPHI,RES
	29809	Koblinski & Fisher	1-28	5514	- 4397	8/22/1974	CAL,GR,NPHI,RES,SNP

Reef	Well Permit No.	Well Name	Well No.	Total Depth, ft		Date Completed	Wireline Logs
				bgs	amsl		
	29840	Kirt House	2-28	5475	- 4290	8/7/1974	CAL,GR,NPHI,RES,SON
	30392	Winter	2-33	5840	- 4560	8/9/1975	CAL,GR,NPHI,RES,SON
	31108	Amejka	2-34	5886	- 4657	9/5/1976	CAL,GR,NPHI,SON
	31228	Boughner State Dover	3-28	5520	- 4401	7/23/1977	CAL,GR,NPHI,SON
	31303	Thompson	1-33	5690	- 4540	11/22/1976	CAL,GR,NPHI,RES,RHOB
	32298	Boughner State Dover	4-28	5505	(c)	7/7/1978	CAL,GR,NPHI
	33830	Lawnichak & Myszkier	5-33	5775	- 4565	7/28/1980	CAL,GR,NPHI,RES,SON
	33937	Lawnichak & Myszkier	5-33A	5746	- 4536	8/4/1980	CAL,GR,NPHI,RES,SON
	35195	Winter	1-33	5740	- 4457	12/31/1982	CAL,GR,NPHI,RES,RHOB
	35584	Lawnichak & Morey	1-33	5703	- 4539	8/24/1982	CAL,GR,NPHI,RHOB
	50985	Lawnichak & Myszkier	2-33	5763	- 4597	11/22/1996	CAL,GR,NPHI,RHOB,PNC
	51601	Lawnichak & Myszkier	2-33 HD1	6990	- 4315	12/30/1996	CAL,GR,TDT
	51603	Lawnichak & Myszkier	5-33 HD1	6456	- 4354	2/2/1997	CAL,GR,PNC
	55479	Lawnichak & Myszkier	2-33 HD2	6138	(c)	8/21/2003	Not Logged
	55845	Lawnichak & Myszkier	2-33 HD3	7335	- 4368	9/23/2003	Not Logged
	55942	Lawnichak & Myszkier	2-33 HD4	7134	- 4348	12/29/2003	Not Logged
	61209	Lawnichak	9-33	6085	- 4677	12/3/2016	CAL,GR,NPHI,RES,RHOB,SON
□ ○ ☹	29374	Pomerzynski	2-35	5760	- 4619	9/27/1973	CAL,GR,NPHI,SON,RES

Reef	Well Permit No.	Well Name	Well No.	Total Depth, ft		Date Completed	Wireline Logs
				bgs	amsl		
	29947	Salling Hanson Trust	4-35	5564	- 4450	10/18/1974	CAL,GR,SON
	35941	Tinsey	1-35	5792	(c)	8/23/1982	CAL,GR,NPHI,RHOB,PE,RES
	37324	Pomerzynski et al	5-35	5715	- 4575	12/22/1983	CAL,GR,NPHI,RHOB,PE,RES
	37381	Taskey & Saddler Estate	1-35	5768	- 4615	2/14/1984	CAL,GR,NPHI,RHOB,RES
	29236 <sup>(b)</sup>	Salling & Hanson	1-35	5780	- 4656	5/25/1973	CAL,GR,NPHI,SON,RES
	29995 <sup>(b)</sup>	Salling Hanson Trust	4-35A	5715	- 4504	11/4/1974	CAL,GR,NPHI,SON,RES
	57787 <sup>(a)</sup>	"Pomarzynski"	6-35	5950	- 4688	11/30/2006	CAL,GR,NPHI,RHOB,PE,RES
	(59238) <sup>(a)</sup>	"Pomarzynski"	5-35A	5864	- 4437	8/24/2008	CAL,GR,NPHI
Dover 36	29303	Kubacki Cole	2-36	5765	- 4592	6/14/1973	CAL,GR,NPHI,SON,RES
	29664	Freese, Charles E III et al	1-2	5830	- 4614	4/8/1974	CAL,GR,NPHI,SON,RES
	29235 <sup>(b)</sup>	Kubacki & State Dover	1-36	5835	- 4683	4/29/1973	CAL,GR,NPHI,SON,RES
	29348 <sup>(b)</sup>	Kubacki State	3-35	6431	(c)	7/6/1973	CAL,GR,NPHI,SON,RES
	52719 <sup>(a)</sup>	Dover 36 Unit	3-36	5700	- 4533	7/31/1998	CAL,GR,NPHI,RHOB,PE,RES

Source: [Michigan DEQ Oil and Gas Well Database](#)

Note: CAL=CALIPER; GR=GAMMA RAY; NPHI=NEUTRON POROSITY; RHOB=DENSITY; PE=PHOTOELECTRIC; SON=SONIC; RES=RESISTIVITY; CBL=CEMENT BOND LOG; CBIL= circumferential borehole image log (acoustic image log); NEUTRON= neutron log reported in neutron units; PNC=Pulsed Neutron Capture log.

(a) Indicates currently active (not plugged/abandoned) producing well.

(b) Indicates currently active (not plugged/abandoned) injection well.

(c) Deviated well; total depth amsl will be determined after acquiring deviation survey.



## Appendix II: Map of Core Energy pipelines

