SLURRY HYDROCRACKER PROJECT

Appendix K - Email Correspondence with Mr. Frank Nolte

PREPARED FOR

Frank Nolte, PEng
Worley Limited

PREPARED BY

Team 15: TR Solutions

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Jose Te Eng Fo, Student
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Xingming Shan, Student
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DATE: April 9th, 2020

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K.1 SUMMARY

This appendix shows all the correspondence emails between the industrial advisor and the team, as well as, the meeting minutes for the three industrial advisor meetings.

K.2 INITIAL PROJECT DESCRIPTION

Project Design Basis Statement: CH E 435/465 Design II

Project Title: Bitumen Conversion Using Slurry Hydrocracking

Description: Most bitumen conversion in Alberta is achieved by carbon rejection processes such as delayed coking or ebullated bed hydrocracking (EB) (H---Oil or LC---Fining). More Recently Slurry Hydrocracking (SHC) processes are emerging that promise higher conversion of bitumen to synthetic crude oil. This project will develop economic basis for an SHC based bitumen upgrader

Strategic Intent: SHC promises higher conversion of bitumen into saleable products, which improves the overall project economics and may decrease the environmental footprint

Deliverables: The project will develop a concept study the provides the basis, heat and material balance, preliminary equipment sizing and cost for a 100,000 barrel per day bitumen upgrader the uses an SHC unit for bitumen conversion. The objective is to determine anticipated return on capital forthis form of bitumen upgrading. To do this the team will prepare the following deliverables:

1. A Project and team management plan
2. Research options, data acquisition, and evaluation of options to determine project scope
3. BFD & PFD development and process simulation/modeling, with material and energy balances
4. Equipment selection and specification (preliminary) P&ID for a single specific piece of equipment
5. Analysis of regulatory needs: safety, environment, economic and applicable code and standards issues and requirements
6. Safety and Risk Management including process PFD PHA and P&ID Hazard and operability analyses
7. Capital and operating cost estimates
8. Economic and sustainability project evaluations
9. Preliminary project execution strategy
10. Technical written and oral presentations of deliverables

Problem Statement: This project includes both a reaction (hydrocracking) and product separation.

Primary Objective: The primary objective is to determine the return on capital of a standalone merchant upgrader using slurry hydrocracking to convert the bitumen into a pipeline---able synthetic crude

Feedstock Design Basis: The feedstock to the upgrader is assumed to be 100,000 barrel per day of hot bitumen product from a bitumen producer (typical steam---assisted gravity drainage production site in Alberta

Product Design Basis: The synthetic crude from the upgrader will essentially be the liquid product from the SHC unit. Sales price of the final product will on the yield of various synthetic crude components (naptha 50--- 170 C boiling range, light gas oil170---350 C boiling range and heavy gasoil 350---550 C boiling range). The team will determine the value of the end product based on itscomposition.

Additional Information (where team research fails to find adequate into it will be provided).

K.3 EMAIL CORRESPONDANCE

On Tue, Jan 14, 2020 at 5:08 PM, Naira Correia <nairamar@ualberta.ca> wrote:
Dear Frank Nolte,

My name is Naira Correia and I am the leader for the capstone team working on the Slurry Hydrocracker project. CC'ed are my colleagues Jose Te Eng Fo, Jaryl Schmidt, Yichun Zhang, and Xingming Shan.
We are excited and looking forward to working with you for the next upcoming weeks.

Kind regards

Naira Correia (and colleagues)

On Tue, Jan 14, 2020 at 5:10 PM, Nolte, Frank (Edmonton) < frank.nolte@advisian.com> wrote:

Hi Naira

Hello to you and your team. This hopefully will be an interesting project for you and your team and an overall good learning experience.
And as it’s -30C outside you have nothing to distract you from getting started!

Look forward to our first meeting.

Regards

Frank Nolte
Principal Consultant
Global Downstream and Market Services

On Fri, Jan 17, 2020 at 1:23 PM, Naira Correia <nairamar@ualberta.ca> wrote:
Dear Frank Nolte Peng,

It’s Naira from TR Solutions,
We are currently trying to create a more detailed scope for the project, and some questions have arised from our research. From this, we were hoping you could provide some clarity to help us solve some of the uncertainties we are currently facing.

The questions we currently have are:

- What is the intended location of our site, and what is the location factor?
- How would you like us to price our product?
- What are the hurdle and discount rates?
- What is the currency you would like us to use, and what are the time-bases?

Additionally, we were wondering if you had any recommendations for source material that we can use?

We are looking forward to your reply,

Thank you for your time and patience,
Naira and the rest of the team

On Mon, Jan 20, 2020 at 11:33 AM, Nolte, Frank (Edmonton) <frank.nolte@advisian.com> wrote:

Hi 465 Team

Hope that you have made a good start on your research related to this topic. A few answers to point you in the right direction.

- What is the intended location of our site, and what is the location factor? Plant located in Edmonton area YEG vs USGC factor is 1.35
- How would you like us to price our product? The product is priced a slight discount to the West Texas Intermediate (WTI) benchmark = Use province of Alberta Petroleum Marketing Commission price projections for WTI
- What are the hurdle and discount rates? I would use a hurdle rate of 15% for this project
- What is the currency you would like us to use, and what are the time-bases? Use Cdn$ the project would take 5 years to develop and come on stream in 2026. Base the project life at 35 years from Startup

Additionally, we were wondering if you had any recommendations for source material that we can use? Look up slurry phase hydrocracking see if you can find information from the companies UOP and CLG also look for CanMet pilot test work done at Petro-Canada Edmonton Refinery

Frank Nolte
Principal Consultant
Global Downstream and Market Services

On Wed, Jan 22, 2020 at 09:31 AM, Nolte, Frank (Edmonton) <frank.nolte@advisian.com> wrote:

Team

You may find this useful in your research of slurry hydrocracking technology.

Frank Nolte
Principal Consultant
Global Downstream and Market Services

Honeywell
UOP

REFINING

UOP Uniflex™ MC™ Residue Hydrocracking Process

Robust, cost-effective solution for residue conversion

Introduction

The Uniflex MC process converts vacuum residue and other heavy feedstocks into higher-valued distillable products. This high conversion slurry hydrocracking technology combines elements of several commercial technologies: CANMET™ Hydrocracking process, UOP Unicracking™ process, UOP Unionfining™ process, and employs highactivity molybdenum based MicroCatTM catalyst. The catalyst is produced on site from readily available commodity chemicals. Uniflex MC is easily integrated into existing refinery configurations, providing refiners the ability to increase bottom-of -the -barrel conversion, reduce residual fuel oil production and increase production of light fuels. The product streams are also suitable as high value petrochemical complex feedstock.:

Technology Delivery

Uniflex MC is delivered as two separate technology packages: the Uniflex Process and the MC Catalyst System. Both are delivered through UOP's "Schedule A" Basic Engineering design package. The MC Catalyst System can also be supplied as part of an engineered, modular supply from UOP's Modular Equipment Group to reduce on-site construction and facilitate enhanced process automation and advanced control.

Process Chemistry

The Uniflex Process unit is a thermal cracking / hydrogenation process. Residue molecules are thermally cracked by application of heat at high pressure and with sufficient residence time. The cracked molecules react with hydrogen in the presence of catalyst to produce stable, lighter products predominantly in the transportation fuel range. As a side reaction, free radicals produced as a result of thermal cracking can react to form even larger free radicals which form a "mesophase" of condensed materials. The catalyst inhibits this reaction by terminating the free radicals. A second function of the catalyst is to prevent any mesophase formed from coalescing and forming larger molecules. The relationship between operating temperature, reactor size and catalyst addition rate can be optimized to a refiner's particular processing and economic situation.

Process Description

The configuration of the Uniflex process is very similar to that of a conventional hydrocracking process, consisting of a reaction section, a separation section to recover liquid and gaseous reaction products, and a fractionation section to separate its product into the various boiling- range fractions required by a refiner.

Feedstock, combined with catalyst, and hydrogen-rich recycle gas are heated and then introduced to the bottom of the first upflow reactor at operating temperature.

FEATURES & BENEFITS

High Reliability Design

- Based on a proven reactor system based on a commercial unit that demonstrated over 15 years operation.
- Supported by 30 years of extensive research, pilot plant operations, and development.
- UOP's expertise in high-pressure hydroprocessing which is reflected in the design, technical services, and project optimization capabilities associated with Uniflex Technology. Ease of Operation

Generates the Highest Product Value

Uniflex has the highest total yield of valued products with 95-98% conversion of a wide range of low-value residue feedstocks. Selectivity to distillate products is the hallmark of Uniflex, with production of LPG, Naphtha, and Diesel as fuels or petrochemical feedstock.

High Product Quality as Products or Feedstocks

The integrated Uniflex/DHT process produces reformer grade Naphtha, Euro V Diesel and sweet, olefin-free LPG. The LPG and Light Naphtha are excellent Steam Cracker feeds with high normal paraffin content. LVGO can be processed in an FCC or Hydrocracking unit, with or without, pretreatment in the Uniflex unit.

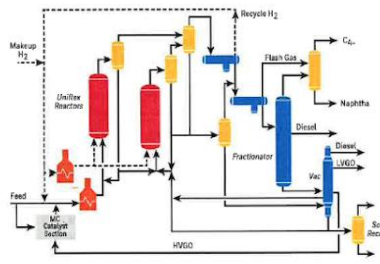
Integration with Other Units

Due to the number of products produced by any slurry hydrocracking technology, integration with the existing or new complex is critical to extract full value from the technology. UOP is uniquely positioned to optimize a total project with a broad understanding of refining and petrochemical configurations.

The reactor's unique design promotes intensive back-mixing of catalyst and reactants without reactor internals. The resulting near-isothermal conditions allow the reactor to operate stably at the higher severity required to achieve maximum residue conversion, while minimizing undesirable secondary cracking reactions that produce lower-valued gaseous byproducts.

The first reactor's liquid effluent is routed to the bottom of the second reactor. The second reactor effluent and vapor from the first reactor flow to the unit's separation section where liquid and vapor fractions are recovered. Vapors are scrubbed, combined with makeup hydrogen and recycled back to the reaction section. Liquid from the separator section flows to the unit's fractionation section for product recovery. A portion of the unconverted residue (pitch) is recycled to the second reactor. The rest of the unconverted residue can be used as a low-cost substitution fuel for conventional heavy liquid residue or coker feed, or used as a solid fuel for end users such as fluidized boilers and gasifiers. Optionally the pitch can be sent to a Solids Recovery section to produce additional liquid products and a solids stream, which can be sent for metals recovery.

Uniflex MC Process Configuration



Additional Processing Options

- Integrated Distillate Hydrotreating: With the addition of six pieces of equipment fuels products can be treated to produce sweet LPG, reformer grade Naphtha and Euro V quality Diesel. This is at a cost of about 50% of a new stand-alone DHT unit.
- Enhanced LPG Recovery: Where LPG has a higher value than fuel gas, recovery of this product can be increased to 99% at an effective capital cost and low utility consumption.
- Side-Car VGO Hydrotreating: VGO quality can be cost effectively improved with the addition of a small HT reactor on the product stream.

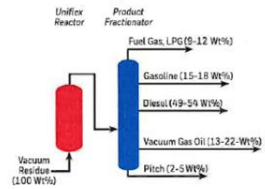
Product Yields

The yield structures produced when processing Vacuum Residue from a typical sour crude in a Uniflex process unit are illustrated in the figure shown below. The advantages of the yields versus other technologies include:

- Ability to be highly selective to Naphtha and Diesel
- Flexibility to shift to heavier products if desired
- Total liquid yields up to 115 vol%

These advantages provide refiners the ability to more-closely tailor their operations to satisfy projected declining residual fuel oil markets and increasing fuel and petrochemical feedstock demands.

Uniflex Process Typical Yields



MicroCat Catalyst

The high-activity catalyst (MicroCat) used in the Uniflex process is generated on-site in the MC Catalyst Section. The refiner will produce the MicroCat from commodity raw materials readily available in bulk quantities on the open market. This section contains simple process operations to produce consistent, high quality catalyst. On site quality assurance testing is part of the technology package.

Additional Opportunities

Refiners can also benefit from the synergies which arise when the Uniflex MC process is used in association with other Refining and Petrochemical processes. The Uniflex MC process unit can be used to upgrade/ convert marginal-quality refinery streams such as FCC slurry oils and heavy coker gas oils. For refiners with existing delayed coking units who are considering increasing refinery throughput, the addition of a Uniflex process can debottleneck the delayed coking unit and provide a significant increase in the refinery's overall liquid product yield.

For more information
www.uop.com

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www.uop.com

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Honeywell UOP

On Wed, Jan 22, 2020 at 2:20 PM, Naira Correia <nairamar@ualberta.ca> wrote:

Dear Nolte,

Thank you for addressing our concerns we really appreciate you taking your time to respond to us. We are looking forward to meeting you on Tuesday!

Thank you,

Naira Correia and the Team

On Mon, Jan 27, 2020 at 08:32 AM, Nolte, Frank (Edmonton) <frank.nolte@advisian.com> wrote:

Hi Team

Thanks for a very comprehensive situation report. You are clearly off to a great start on this work.

Prior to the meeting today, I'll give you a few answers to your questions, which we can discuss in more detail in our meeting today. One thing to note, you will run sensitivities on your economics to test your assumptions for variances of say 10 and 20%. This will give you some idea of the risk profile associated with each assumption you've made on feedstock pricing, product pricing and capital cost

See you all later. Looking forward to meeting the team.

Regards

1. Pricing Scheme for Crude Product
    - (BP cuts, Sulfur, Density) You will find pricing of crude oil by density (API gravity) and sulphur content online assume theses
2. What is the reference price for natural gas and Athabasca bitumen on the date Jan 7th, 2020?

Natural gas price : use https://www.statista.com/statistics/252791/natural-gas-prices/

- How do we estimate the price of bitumen over the 35 years? Assume the same discounted price over WTI for the period

3. Is the assumption of the Athabasca bitumen an acceptable assumption? Yes
4. What is the industrial price for an iron-based catalyst (eg. $FeSO4$)? This catalyst is cheap (assume \$5.00/lb inflated at your assumed inflation rate off to the end of the project.
5. Crude product will be assumed to be the same as CANMET product. Is that an acceptable assumption for the business case. What yield for each component (boiling range) did you assume?
6. Do you have any suggestions for what to do with the sulfur product?
    - Sell it? Stockpile it? Look up global sulphur price and assume that value projected out into the future.

Frank Nolte
Principal Consultant
Global Downstream and Market Services

On Tue, Feb 11, 2020 at 11:45 AM, Naira Correia <nairamar@ualberta.ca> wrote:

Good morning Mr. Nolte,

At the moment we are working on simulation and sizing and we discovered that there is no kinetics information available for the iron-based catalyst (FeSO4). Upon talking with professor Semagina and our academic advisor Arno de Klerk we came to two conclusions.
1- We need you to provide the CANMET reactor sizing specification (diameter and height), or can you provide any good reactor sizing estimates to calculate the space velocity for this specific catalyst.
2- The other option would change of catalyst which there is a lot of literature and research available.
The second option is very undesirable because it would require us to design a catalyst regeneration unit.

Best regards,

Naira and Team 15

On Tue, Feb 11, 2020 at 12:43 PM, Nolte, Frank (Edmonton) <frank.nolte@advisian.com> wrote:

Hi TR Team
Sorry for the delayed response. I was out of town this weekend.

LHSV for the reactor is .21/hr. The estimated vapor voidage (volume not occupied by liquid) in the reactor is 40%
Just as a check on the reactor size I have an equipment list for a 41,000 BPSD SHC unit that shows a reactor train consisting of 4 parallel reactors each 13.5 ft OD and 81 ft tangent to tangent length. With a design pressure of 2340 psig and design temp of 900 F. The reactor shell is constructed of 2 ¼ Cr 1Mo V mod stainless steel with a 3 mm TP 321/347 SS liner. The high-pressure portion of the SHC is all constructed of this same material.

I would like for the team to calculate the cross-sectional area and height of reactor required for your reactor based on the LHSV and voidage as a comparison to the datasheet numbers I have for the commercial unit that I have.

Hopefully that helps

Regards

Frank Nolte
Principal Consultant
Global Downstream and Market Services

On Sun, Mar 1, 2020 at 2:01 PM, Naira Correia <nairamar@ualberta.ca> wrote:

Good afternoon Mr. Nolte,

On behalf of TR Solutions (Team 15), I am glad to announce that our second meeting will be held on March 3rd at 2 pm on DICE 8A-246. Please see attached for the meeting agenda, list of questions for discussion and the situational report.

Please let me know if you have any questions and concerns,

See you on Tuesday,

Naira Correia and TR Solutions

On Sun, Mar 1, 2020 at 2:39 PM, Nolte, Frank (Edmonton) <frank.nolte@advisian.com> wrote:

Hopefully this helps for now. Saw you all on Tuesday.

Frank

1. For the sensitivity analysis are there any specific variables that we should consider? For the change in NPV would like 10% or higher?
   - You should vary the followig:
   - CAPEX. -20/+50%
   - OPEX -20/+20%
   - Cost of Capital – we should discuss your assumptions

2. What legislation do you want us to refer to for environmental analysis/ API Codes, ASME Codes? Refer to Alberta Environment Sulphur limited based on sulphur plant throughput, Estimate the GHG (CO2 emissions).
3. Capacity (Flow Rates) is very high, making our sizing estimations grossly large. Are we able to split the process into two different trains? Certainly
4. How do we estimate steam flow rates from the sulfur recovery plant (WHB)? Check out https://www.ogtrt.com/files/publications/256/2018-11%20Sulphur%202018%20-%20Factors%20Affecting%20Claus%20Waste%20Heat%20Boiler%20Design%20and%20Operation.pdf

On Wed, Mar 15, 2020 at 2:51 PM, Naira Correia <nairamar@ualberta.ca> wrote:

Good Afternoon Frank,

We want to confirm a design consideration we implemented for our hydrogen compression train for the hydrogen supply. In traditional compressor design, a knockout drum is installed after intercoolers to knock out condensables to protect the compressor. The compressor train in our design is downstream of a pressure swing adsorber sending hydrogen stream with high purity with negligible to zero amount condensables. Thus, we decided to remove knock out drums but kept the intercoolers to maintain low temperatures.

Also, during the sizing of the three-phase separator D-03 the terminal velocity was found to be 0.47 m/s. With a flow rate of 0.7373 m3/s of mixture fed to the separator. The result:
Separator Minimum Diameter= 1m
Separator Minimum Length= 1.995m
Considering the scale of our separator, we think it might be too small. So alternatively, we want to have something larger, to handle different situations. In the same literature, the suggested L/D ratio was 2 to 4. Can we use a D=3m, and L=12m, with an L/D ratio of 4 instead?

Please let us know if this is a considerable option or if you have any other concerns.

Kindest regards,

Naira Correia

On Wed, Mar 15, 2020 at 6:37 PM, Nolte, Frank (Edmonton) <frank.nolte@advisian.com> wrote:

Hi Naira

Some. Short answers to your questions;

The interstate separator is often needed to remove small amounts of lube oil.

For the separator you also want to consider that you need space for 5 min of residence from the high and low liquid level to both the high high and lowlow liquid level. That also for operator response in the event of alarm

Sent from my Bell Samsung device over Canada's largest network.

On Sun, Mar 29, 2020 at 12:59 PM, Naira Correia <nairamar@ualberta.ca> wrote:

Good afternoon Mr. Nolte,

On behalf of TR Solutions (Team 15), I am glad to announce that our third and final meeting will be held on March 31st at 4 pm online via Zoom Meetings. Please see attached for the meeting agenda, final presentation slides and list of questions for discussion.

Please let me know if you have any questions and concerns,

See you on Tuesday,

Naira Correia and TR Solutions

K.4 MEETING MINUTES

Meeting #1 Minutes summary

Feedbacks from Mr. Frank:

- Consider the components nitrogen and oxygen in bitumen feed
  Potential hydrogen consumers:
  O → H_2O
  N → amine
- Propane and butane are salable products, can improve the economics of the project
- Vacuum gas oil needs to be cracked further to be sold → gasoline and diesel
- What to do with residue?
  - If you concentrate spent catalyst, think about what you can do with that stream...
- Economic: sensitivity analysis on the cost of bitumen
- Contact Marnie: for future pricing (Diluted Bitumen): Sold as WCS (Western Canadian Select) - work backward from that to get bitumen pricing. WCS Indexed on WTI…
- Our product will be a premium compared so SSP made by Suncor/Syncrude/CNRL due to product distribution - very high distillate content in our product
- Sidecar Hydrotreating?
- When heating the bitumen: start stripping bitumen: as the temperature increases, start to allow large bitumen molecules to agglomerate - the precursor to coke formation
- Want heavy end of gas oil for recycle to keep solvency during thermal cracking
- Sequestration of SMR unit (likely outside the scope of this project)? Other Carbon Capture technologies → liquify→ pump? Include a discussion about the CO_2 sequestration (how we can improve on CO_2 emissions)?

Overall: Mr. Frank said that we had a comprehensive situation report, he agreed with our proposed solution and made suggestions on what to be improved. The format of the meeting was very interactive, and all the team members had an opportunity to share their questions with Mr. Frank.

Meeting #2 Minutes summary

Meeting 2 was held on March 3rd at 2 pm on DICE 8th floor, Room 8A-246. All team members were present and participated during the meeting. Naira and Jaryl were the main presenters and the entire team participated in the discussion. All the pre-meeting material was submitted on time on Sunday including Mass and Energy balances, PFD and list of questions. The Agenda was sent just a few minutes late but on Sunday as well. All team members completed the ITP Metrics prior to the deadline. Overall the team worked well to achieve the requirements for meeting 2, we receive good feedback from Mr. Nolte, and although we are a week behind we have a strategic plan going forward.

- Frank Nolte will be out of the country for the next meeting (final presentation), therefore the final meeting will be one week before the expected date.
- Possibility of CO2 Sequestration from PSA (CO2 capture)
    - As an opportunity, we could sell it and aid for our economic analysis
    - PSA purge steams seems to be pretty high
- Top-end reaction temperature: 780 F = 465 C
- Reactor pressure can be brought back to 17 Mpa; solution loss H2 at high pressure
- Capacity of hydrogen plant seems too high
    - Can do a hydrogen recovery before putting hydrogen back into PSA
- The sulfur plant
    - The cost might be lower than actual by a factor of 2
    - Most possible of sulfur = 840 tons/day = 5% of bitumen feed
    - May have to apply tail gas unit and sulfur recovery
- Amine plant
    - Only C1, C2, and C3 with partial pressure = around 93 kpa
- Residue conversion
    - 95% conversion is a much more reasonable conversion of a bubble reactor
    - 5% of the unconverted residue from the 665516kg/h still a lot, therefore, look for what opportunities and challenges are available when dealing with it
    - How much of the cement could be used (make better sidewalks)
- Fractionation system should have zero naptha, distillate
- Sensitivity analysis:
    - Capital cost -20/+50%; Operating cost +- 20%; Discount rate: 10 to 20%

Meeting #3 Minutes summary

Meeting 3 was held on March 31st at 4 pm via zoom meetings online. All team members were present for the meeting, as well as, Frank Nolte and Arno De Klerk. The pre-meeting material was submitted on time on Sunday including meeting agenda, final presentation PowerPoint, and list of questions. The presentation participation divided in the following manner Jaryl covered the technology selected, Jose covered the explanation for the PFD, Naira covered the safety and risk analyses, Yichun did the environmental analysis and Shan did the economic analyses. All team members completed the ITP Metrics prior to the deadline. Overall the team worked well to achieve the requirements for meeting 3, we receive good feedback from Mr. Nolte he was pleased with the results presented and he also gave us a few implementations and adjustments to make for the final project.

Mass/Energy balance:

- Heating value of the PSA vent gas in terms of a utility heating stream (how it compares with natural gas
- How much of the SMR load is reactor off-gas
- How much valuable product is lost in the residue stream
- Show a very simple version of “if I have 1kg of bitumen, __g goes to SMR, __ g goes to residue, etc.

Economics:

- Look into hydrogen cost per m3 (production)
    - Possibly buy the hydrogen from another company and save on the capital cost
    - $3/1000 std ft3 (rough number from Frank)
- $6B erected cost doesn’t seem too off (from what he estimates)
- Look at the diluent recovery there is a possibility of selling at a higher price
- Current analysis (we’ve done) is a light/heavy spread - not a bad metric
- CO_2 sequestration credit
- Make sure capital costs make sense