RENDERING CO-PRODUCTS AS ELECTRON DONORS FOR SUBSURFACE REMEDIATION

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Presentation Overview

- Research background and purpose
- What are rendered animal co-products?
- Experimental Data
  - Raw co-products as electron donors with TCE and Cr(VI) as the primary contaminants
  - Combined co-products as electron donors with TCE as the primary contaminant
- Upcoming experiments
  - Column experiments to investigate amendment and delivery
- Commercialization and intellectual property update
- Conclusions

Broad objective of this technology

- Demonstrate that rendering co-products can serve as electron donors in groundwater bioremediation, and that co-products are better than currently available commercial electron donors

What problem does this solve for the FPRF?

It develops a new market for materials that will otherwise have fewer markets than your primary co-products (i.e. the lower value co-products and DAF)

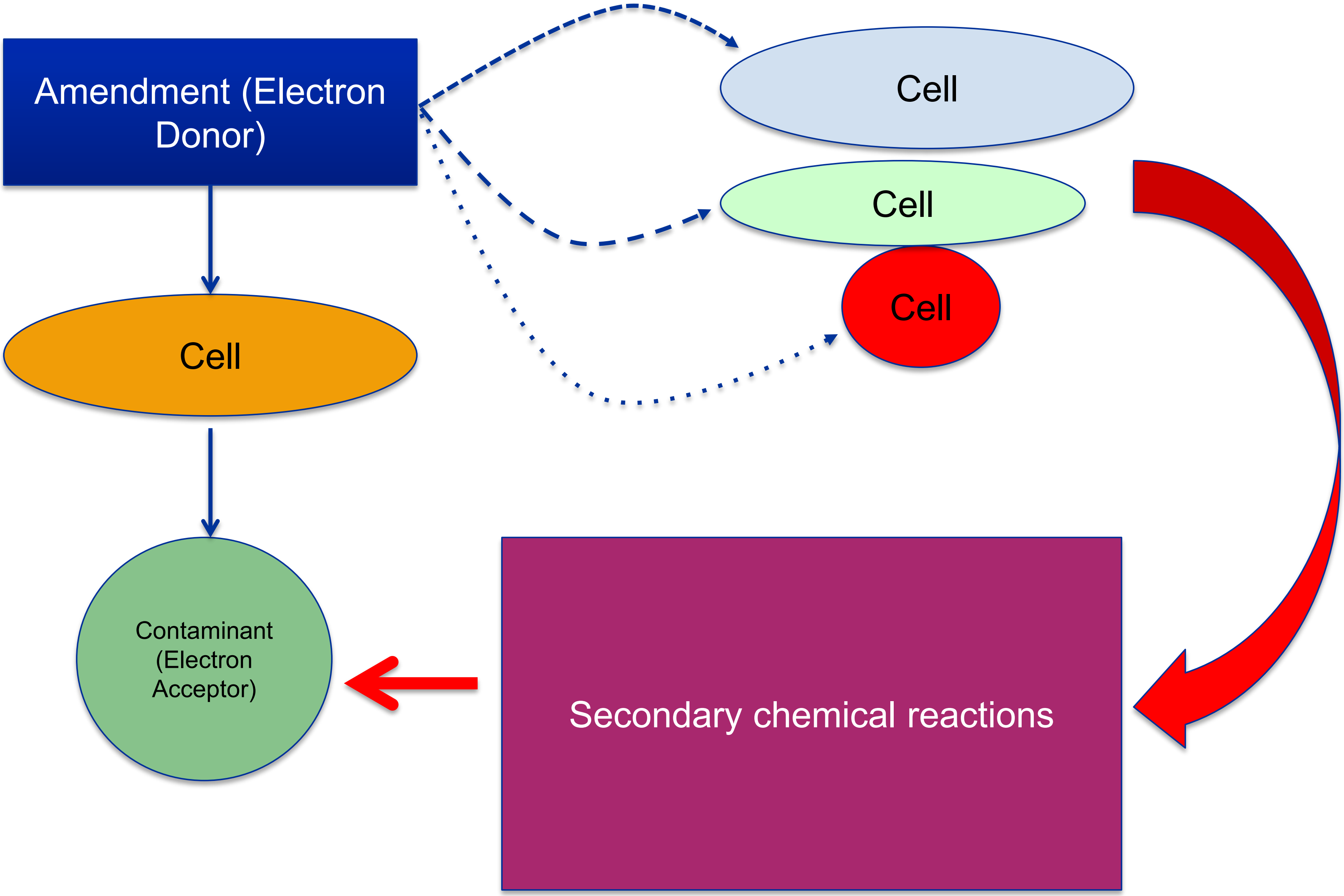
Is there a return on investment for the FPRF?

Yes, the market into which this technology fits has very little competition because it is specialized, and because stakeholders have little understanding of the science

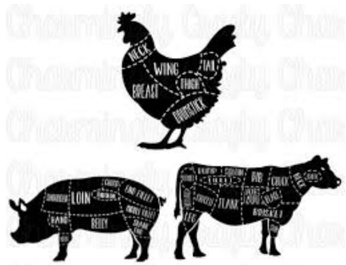
Are there intangible benefits for the renderers?

Clearly focusing on sustainability and environmental restoration will play well for any industry that generates excess materials and wastes as part of a corporate social responsibility platform; several renderers already have a well articulated environment and sustainability initiative

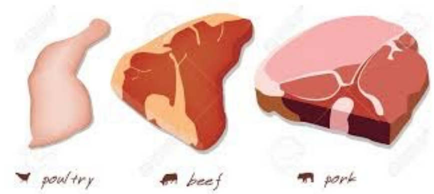
What do I mean by electron donor in bioremediation?



What are rendering co-products?

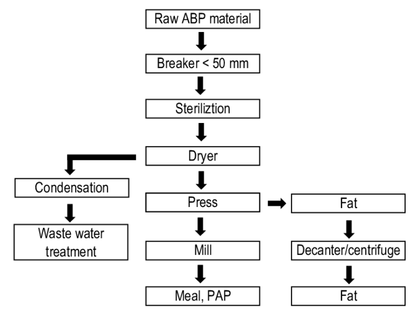


Useable Foodstuffs



Non-Useable Foodstuffs

Rendered Co-Products



- The majority of high energy content materials are returned to animal feed and domestic pet food
- Lower value (but high energy content) materials currently have few markets
- The co-products are combinations of lipid, protein, carbohydrate, and micronutrients (varies depending on sourcing)
- These combinations make better electron donors than singular molecular classes

Purpose of this Research Program

- Demonstrate that rendering co-products can serve as electron donors in groundwater bioremediation (we are focusing on the lower value co-products)

- Use all forms of rendering co-products including
  - DAF
  - Tallow
  - Bone meal
  - Free fatty acids
  - Brown greases
  - Yellow greases
  - Poultry fat
  - Others?

- Electron donors are "substrates" added to contaminated aquifer material to stimulate microbial degradation of contaminants

- The contaminants that can be addressed include
  - Chlorinated solvents (which is the most critical class of contamination in the US from a risk perspective)
  - Metals (e.g. chromium)
  - Explosives and energetics (e.g. perchlorate)
  - Agricultural chemicals (e.g. nitrate)
  - Metalloids (e.g. arsenic and selenium)
  - And there are others (but chlorinated solvents + chromium is the largest market)

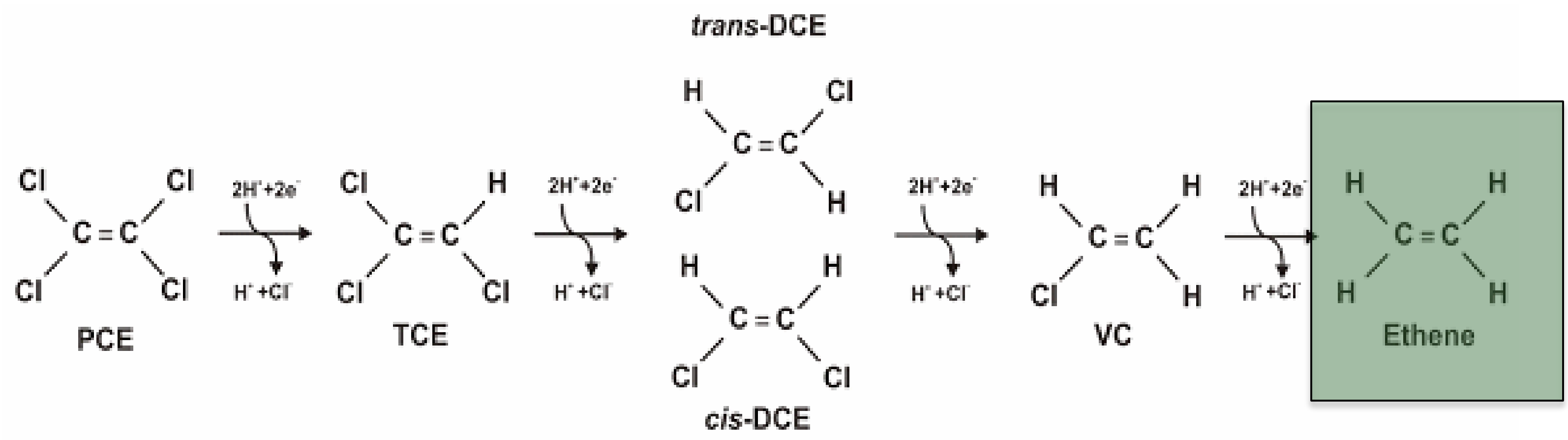
Why consider new electron donors in groundwater remediation?

- Remediation has high capital costs, and remediation amendments are a large percentage of those costs
- Lipid electron donors can market at dollars per pound (substrate cost, not as delivered cost: ESTCP and FRTR reports), with applications up to thousand pounds per site (perhaps more)
- The remediation marketplace has become “vendor driven”, as such, product providers are preferred to knowledge providers
- If co-products can be optimized as electron donors, then they can be marketed to stakeholders of contaminated sites as lower cost alternatives to the designer electron donors
  - This brings back stakeholders that may be priced out with other electron donors
- Co-product raw materials provide a return on investment to the rendering industry in a range from $0 per ton (true waste) to $700 per ton for ”highest value” co-products

Current Data

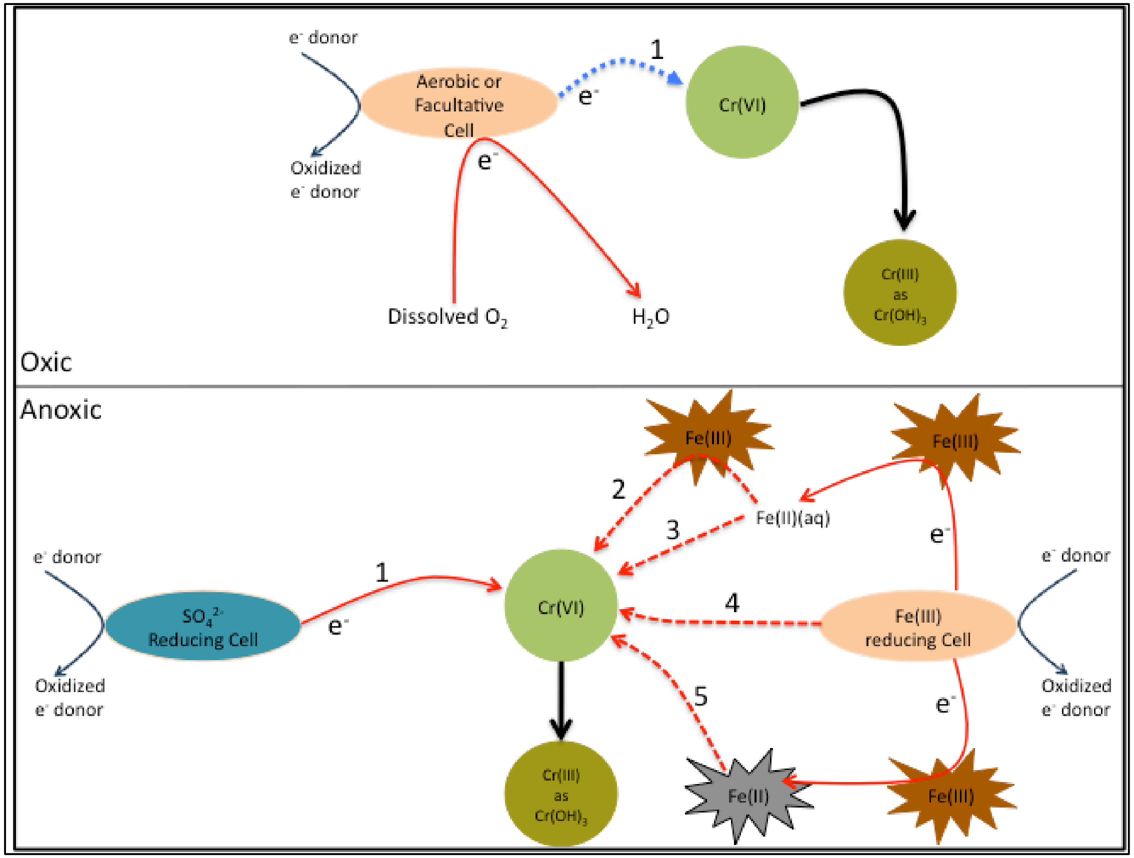
Trichloroethylene (TCE)

- We used the solvent trichloroethylene (TCE) in preliminary experiments
- It is the risk driving compound at the majority of all US contaminated sites
- The biodegradation pathway is below

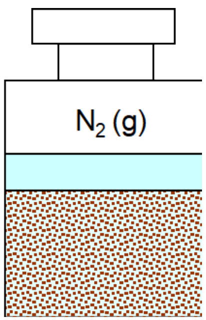


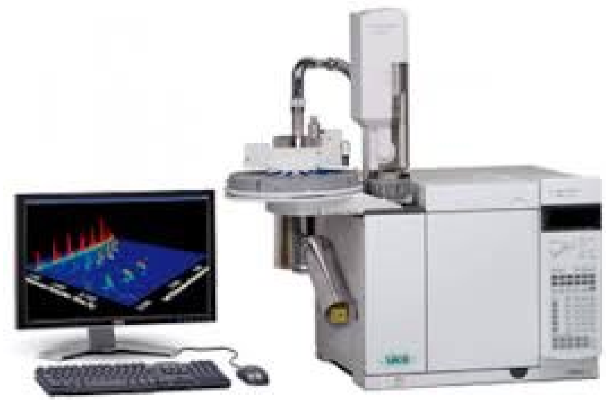
- The critical step is to generate ethene
- If ethene is being generated, then the electron donor is stimulating the correct microbial populations

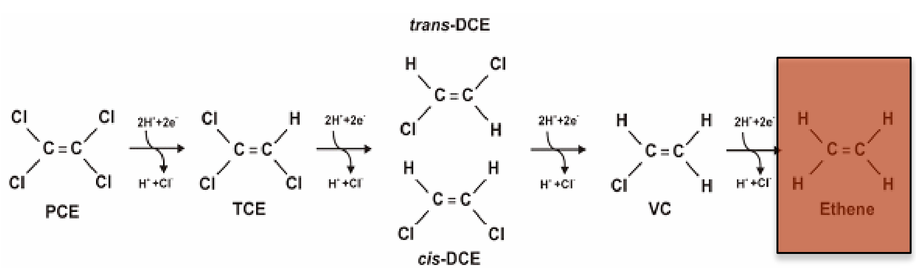
Hexavalent chromium (Cr(VI))



Aquifer Material Incubations

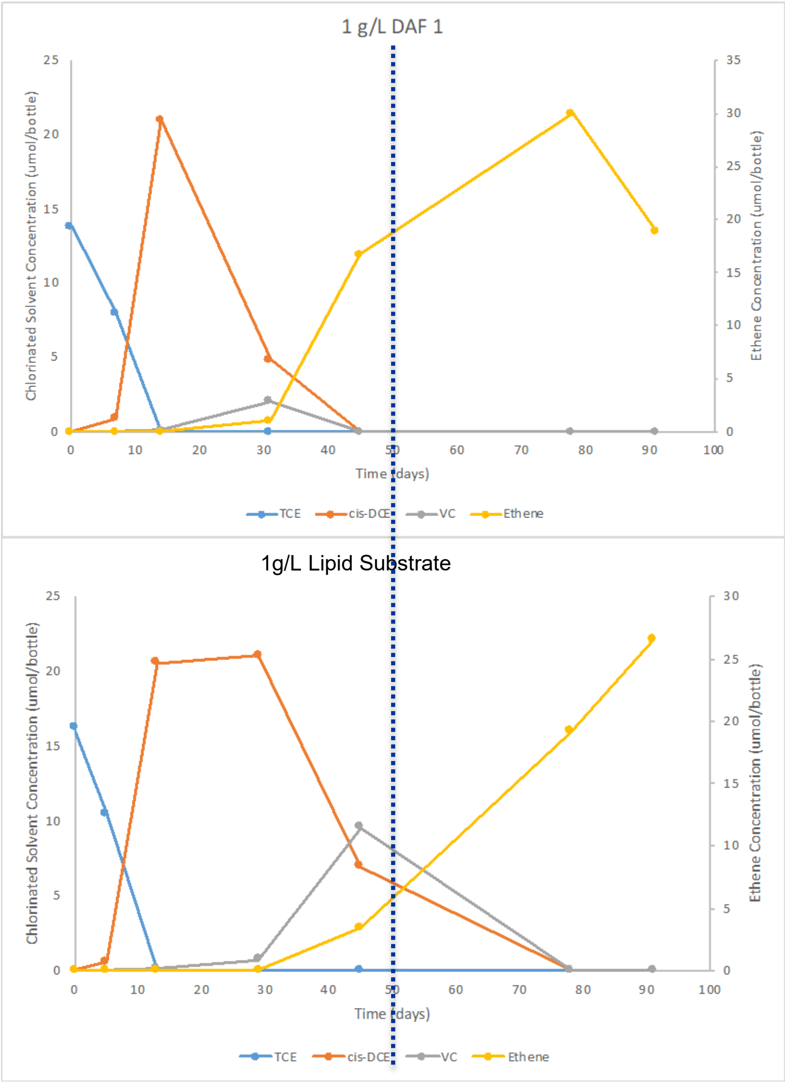


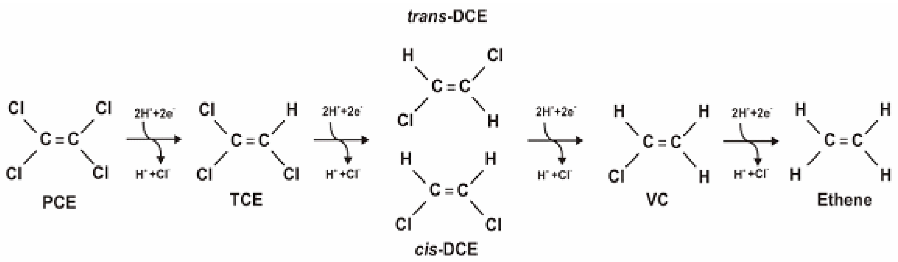




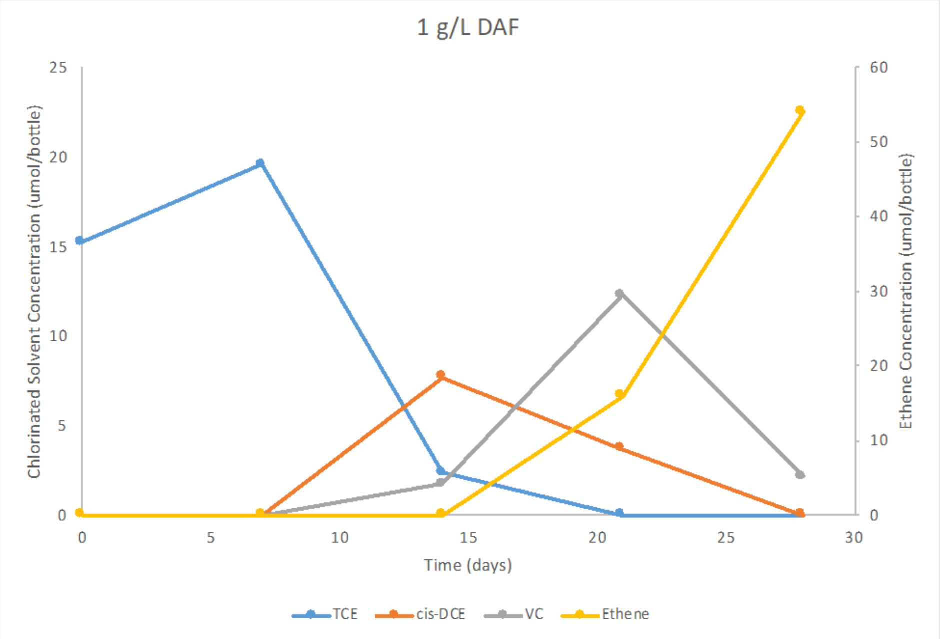
Co-Products Tested: Round 1
DAF
Wapak Bone Meal
TEVB
TEHB
TEFA
TE-80/20
Tallow
Poultry By Products
PNM
PNG
PL
PBME+ E
LoPro 1, 2, 3, and 4
K-MBM
Feather Meal
CWG
Centrysis
Brown Grease
Yellow Grease

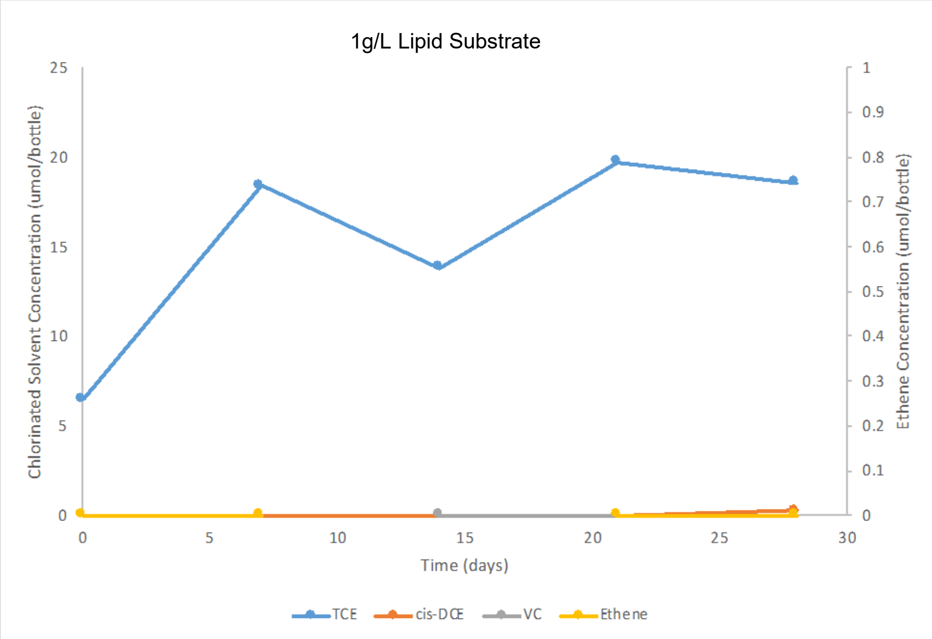
DAF vs. Lipid: Test Site #1



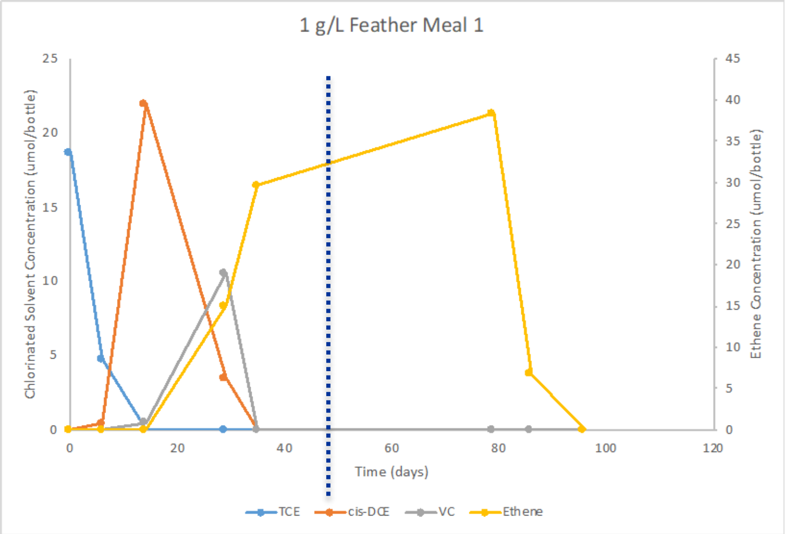


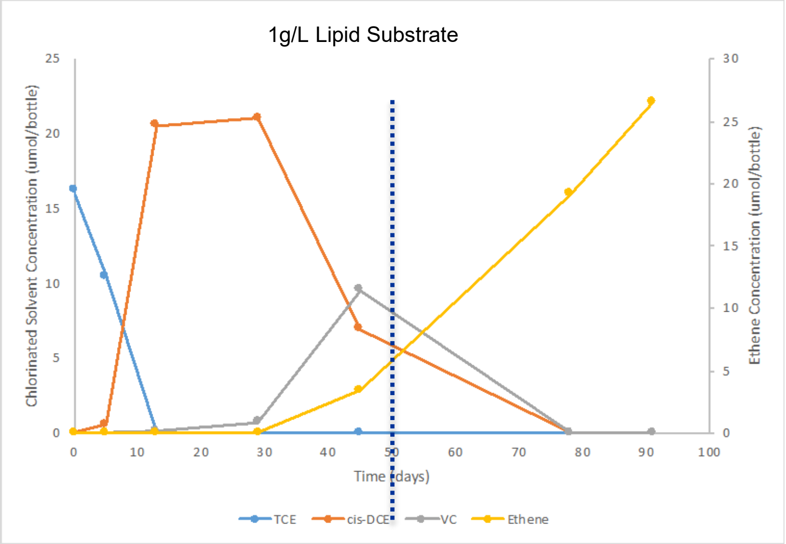
DAF vs. Lipid: Test Site #2



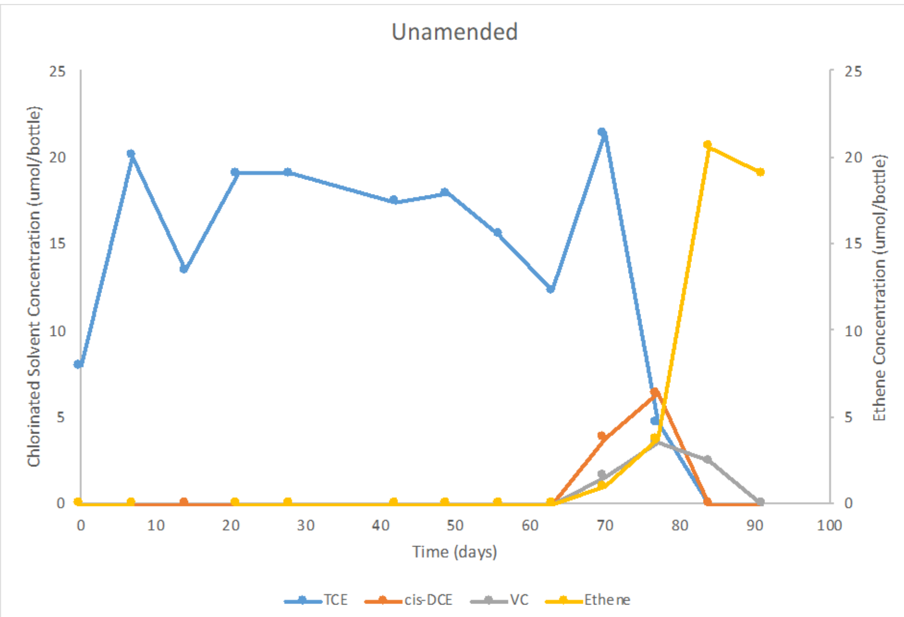


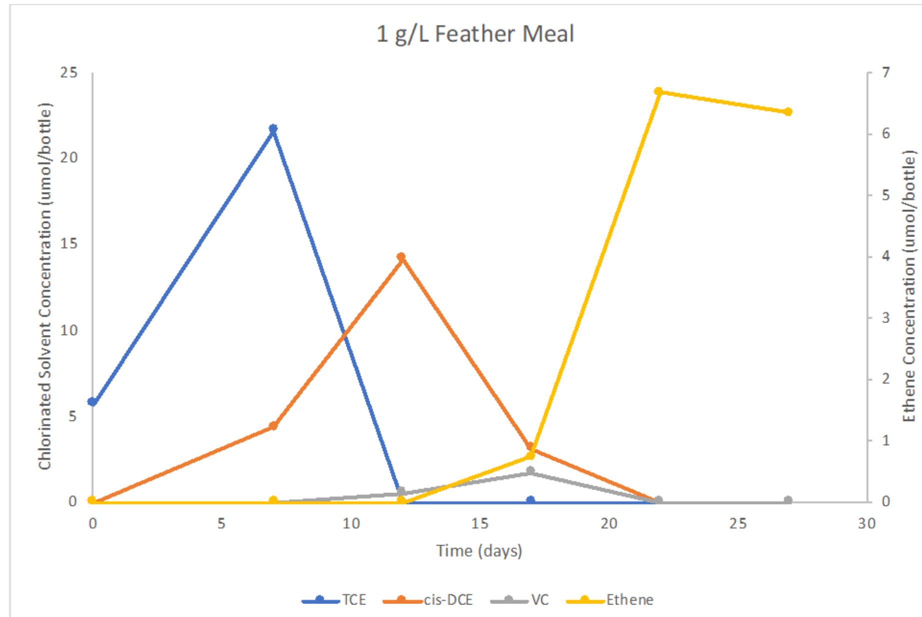
Feather Meal vs. Lipid: Test Site #1



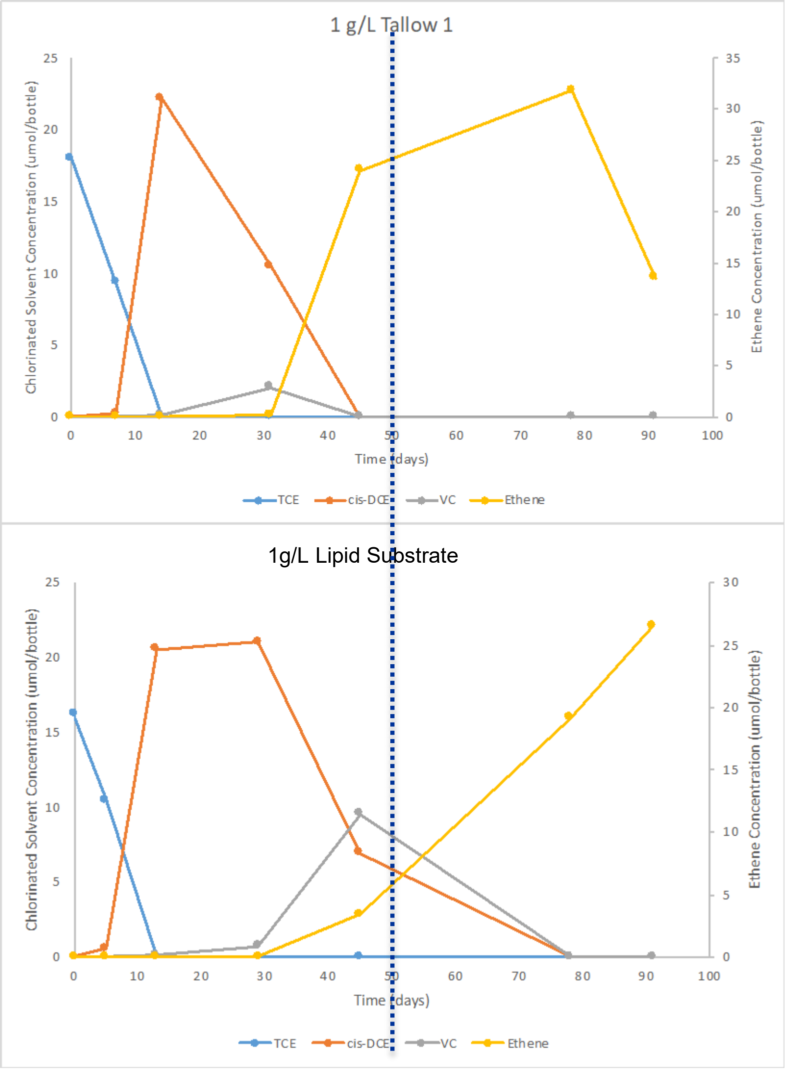


Feather Meal vs. Unamended: Test Site #2

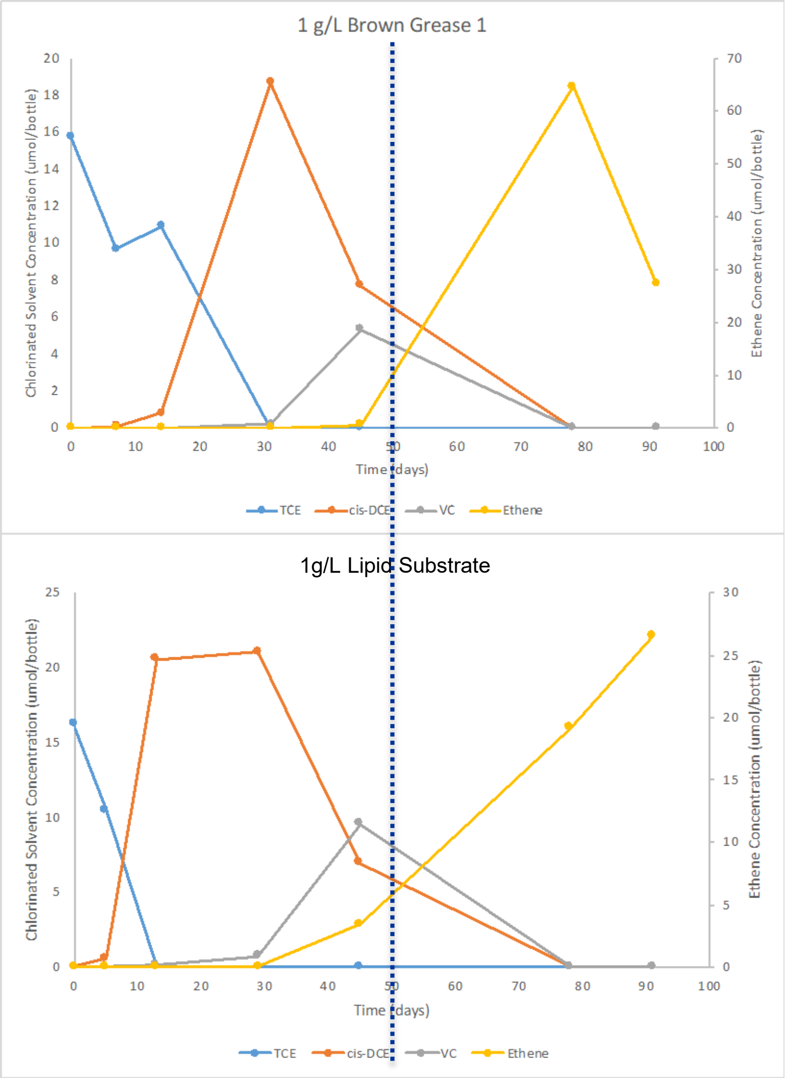




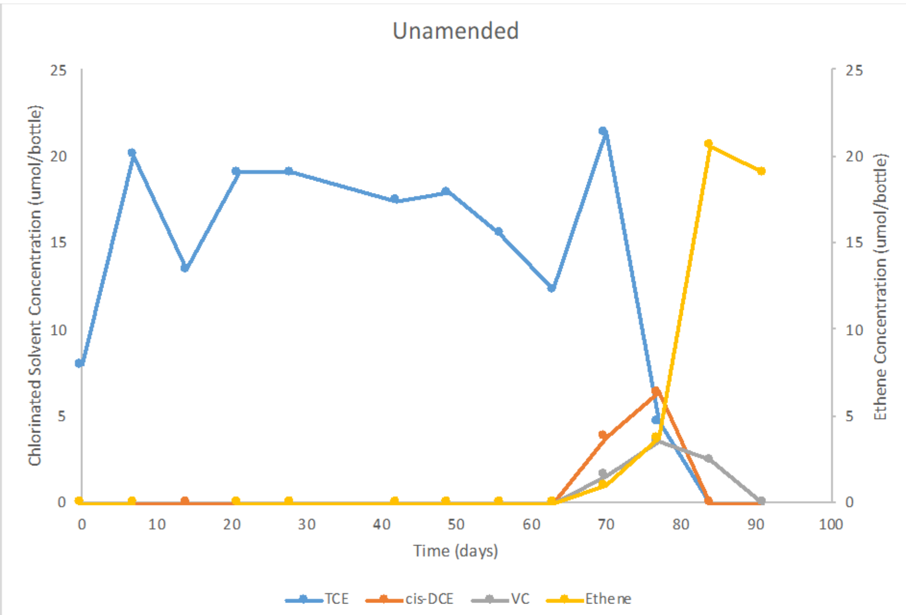
Tallow vs. Lipid

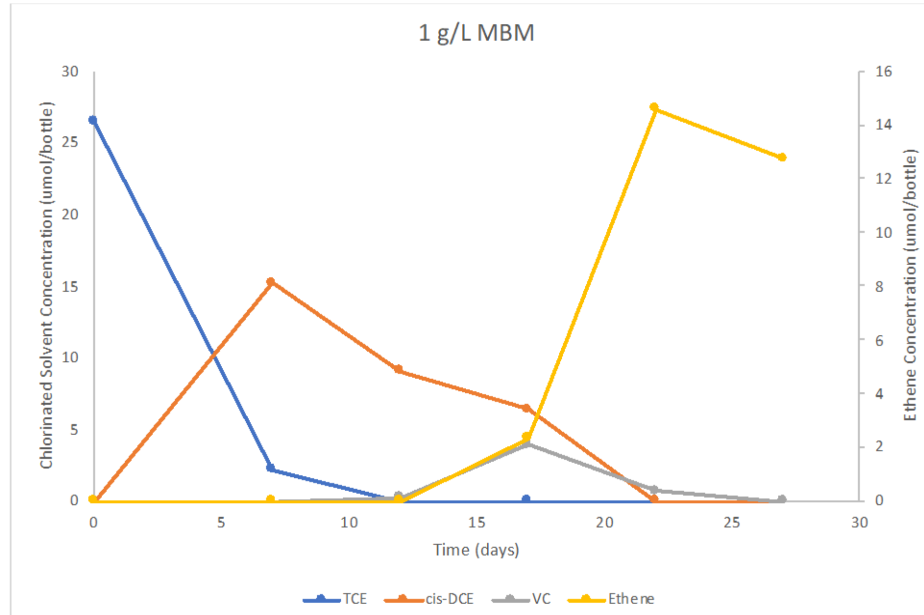


Brown Grease vs. Lipid

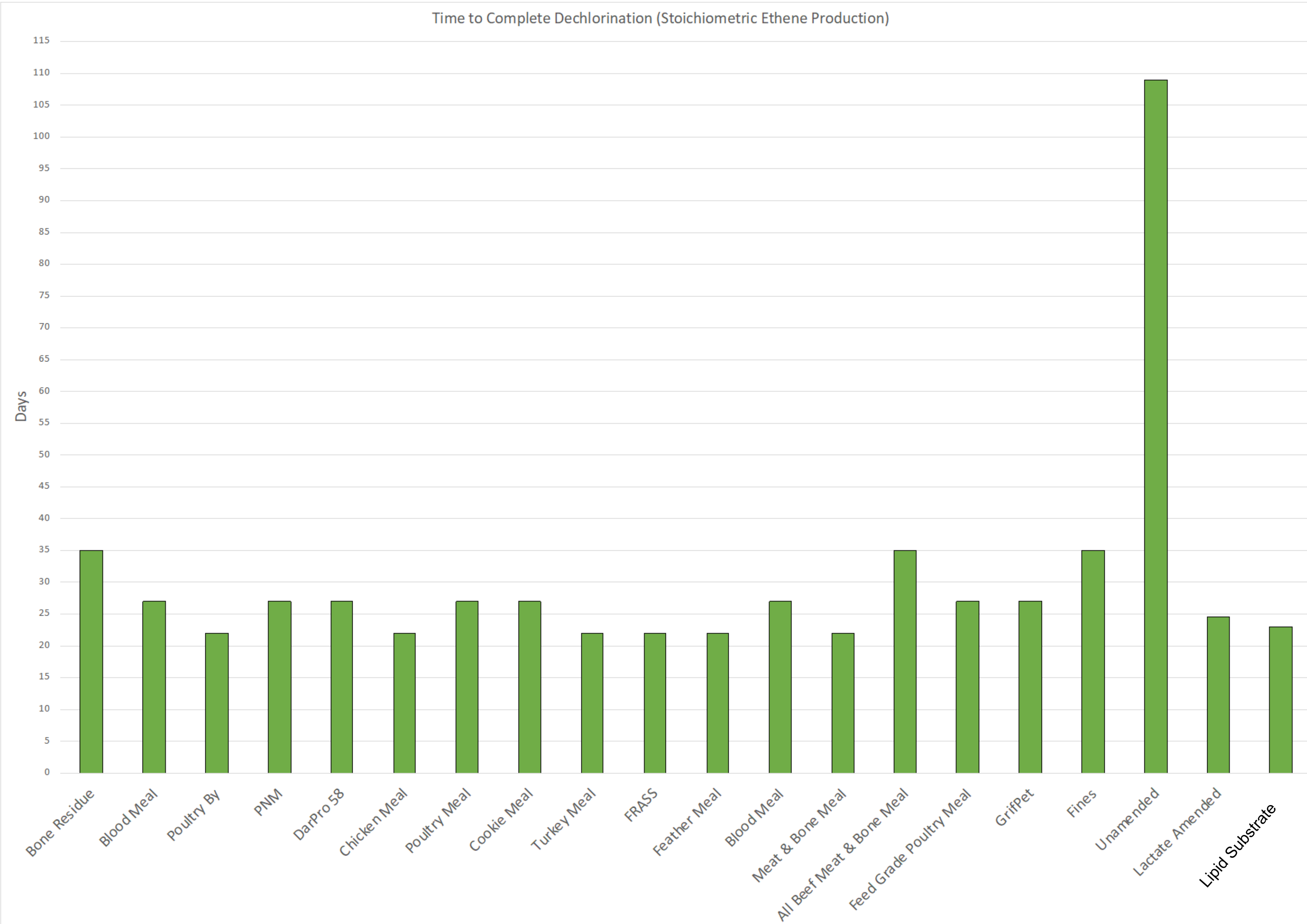


MBM vs. Unamended: Test Site #2

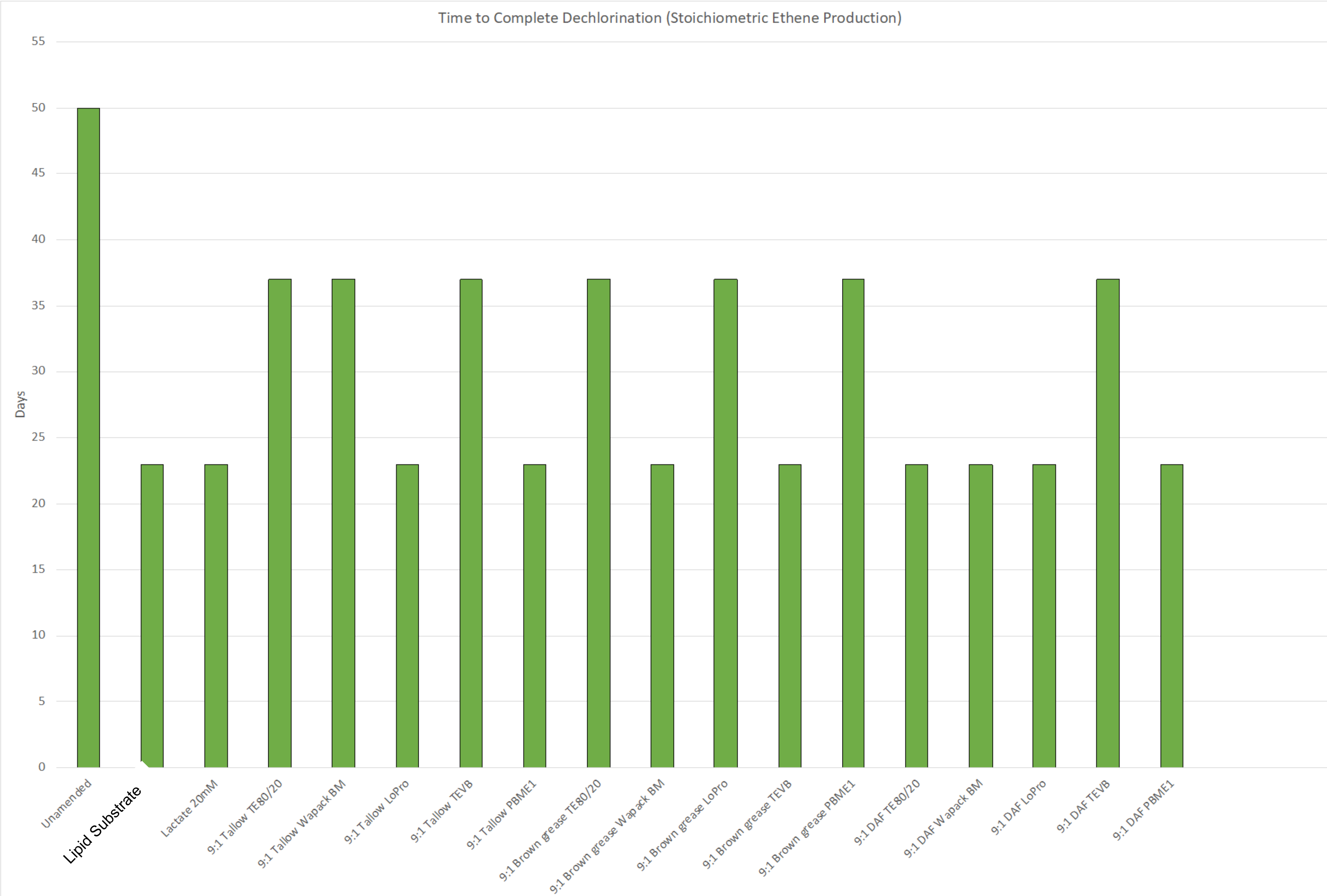




Time to complete dechlorination: raw co-products (Site #1)



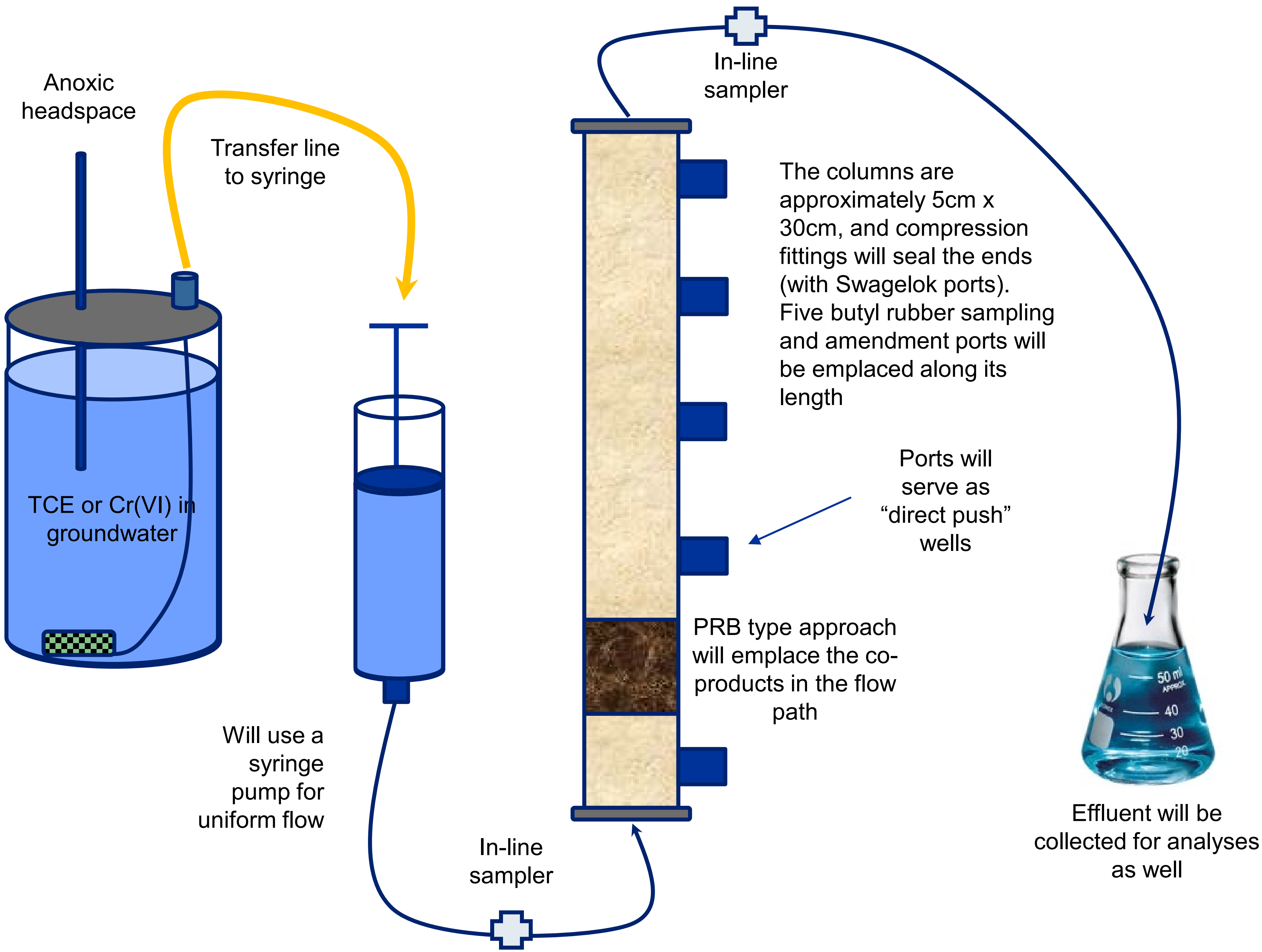
Time to complete dechlorination: combined co-products (Site #1)



Upcoming Research

What are the big questions now?

- We have demonstrated that this technology works in batch incubations, and works as well as or better than commercially available electron donors or low molecular mass organic acids
- We are ready to move towards implementation
- To that end, one big question is how to most effectively deliver the raw co-products or the co product mixtures to contaminated aquifer material (i.e delivery of amendments)
- This is always a critical question in remediation
- We will use two approaches: permeable reactive barrier (PRB) and direct push technology
  - Column studies/experiments will be used to asses this



Anoxic headspace
Transfer line to syringe
TCE or Cr(VI) in groundwater
In-line sampler
The columns are approximately 5cm x 30cm, and compression fittings will seal the ends (with Swagelok ports). Five butyl rubber sampling and amendment ports will be emplaced along its length
Ports will serve as “direct push” wells
PRB type approach will emplace the co-products in the flow path
Will use a syringe pump for uniform flow
In-line sampler
50 ml
APPROX
40
30
20
Effluent will be collected for analyses as well

Example Application of the Technology (back to the *why do this*)

- *Even though in some cases the rates and extent of degradation were better with our technology*
- *Cost is the clear benefit, see the example below:*

- **<u>Using Numbers taken directly from an ESTCP report on lipid electron donor:</u>**
- To treat an approximately 200,000 gallon volume (10,000 ft^2 aerial view)

- All other assumptions equal: this is only cost of electron donor considered for TCE to ethene
- Report indicated 30,000 pounds (or 15 US tons) of lipid was added
- Lipid substrate cost in this application was $40,000 (to completely reduce TCE to ethene)

- In this application the lipid was $1.33 per **pound**

- *Animal co-products are value added products to the rendering industry at $0.00 to $700.00 per **ton***

- *Let's assume the maximum: $700 per ton, that brings the cost of this application to $10,500 (this would be the cost of the most consistent co-product we have tested)*

- *The co-product mixtures developed are more in the range of $200-$300 per ton: $3,000 to $4,500 per comparable application*

Commercialization

- Provisionally patented as of August 2018
- Full patent application (Clemson University) in progress
  - Patent # 62/690,573
  - http://curf.technologypublisher.com/technology/28452
- NDA in place with a primary vendor:
  - Tersus Environmental (NDA in place since 2016)
    - Leveraged funding discussed: SBIR and STTR grants (small business grants with limited scope research agreement in place)
- In discussion with two FPRF member companies (NDA in place)
- NSF STTR submitted and under review with Tersus Environmental

Conclusions

- Rendering co-products (both high and low value materials) are effective electron donors for reducible contaminant transformation
- The process can be optimized by adding the right combination and/or concentration of electron donor(s)
- The two critical contaminants, TCE and Cr(VI), are both reduced by microbial oxidation of rendered co-products
- It is likely that this now patented technology will enter into the bioremediation market space as a competitor with commercially available electron donors

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