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High Energy Systems for Transforming CO_2 to Valuable Products

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NETL CO_2 Capture Technology Project Review Meeting, Pittsburgh, PA, August 26-30, 2019

Outline

- **Project Overview**
- **Technology Background**
- **Technical Approach Discussion**
- **Progress and Current Status**
- **Plans for Future**

Introduction to GTI

- Research organization, providing energy and environmental solutions to the government and industry since 1941
- Facilities: 18 acre campus near Chicago

OFFICE

SUBSIDIARY

- Idea
- Market Analysis
- Technology Analysis
- Product Development
- Lab and Field Testing
- Demonstration
- Commercialization

Project Overview

High Energy Systems for Transforming CO_2 to Valuable Products

- **Sponsor**

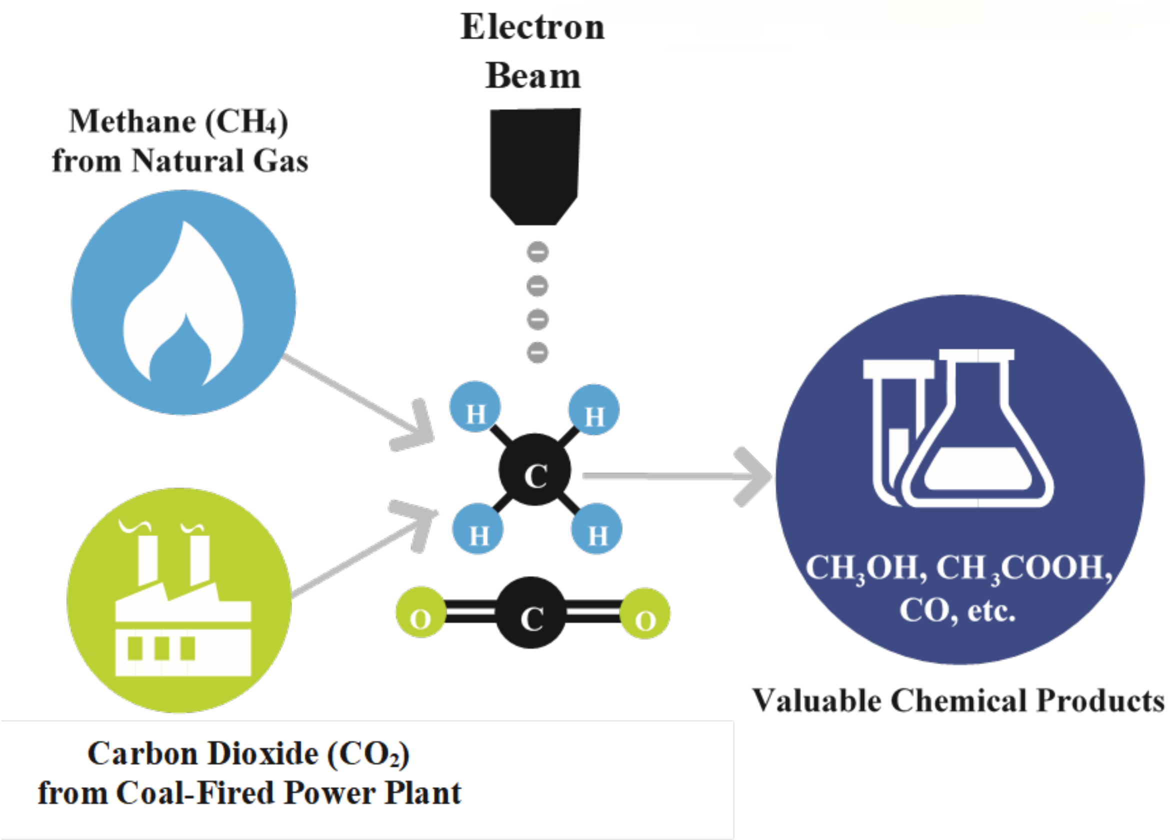
DE-FE0029787

- **Funding**: Federal: $799,997, Cost-share: $206,000, Total: $1,005,997
- **Duration:** 39 months

  BP1: 5/1/2017 – 10/31/2019   BP2: 11/1/2019 – 7/31/2020

- **Objective**: Develop a direct electron beam synthesis (DEBS) process to produce valuable chemicals such as acetic acid, methanol, and carbon monoxide, using carbon dioxide captured from a coal-fired power plant and natural gas.

Project Objectives



- Develop the Direct E-Beam Synthesis (DEBS) process
  - Use high-energy electron beams from an accelerator to break chemical bonds
- Produce valuable chemicals, such as acetic acid, methanol, and carbon monoxide, at relatively low severity (pressure near one atmosphere and temperatures <150°C)
  - Utilize near-pure CO_2 captured from a pulverized coal (PC)-fired power plant and methane, imported as natural gas

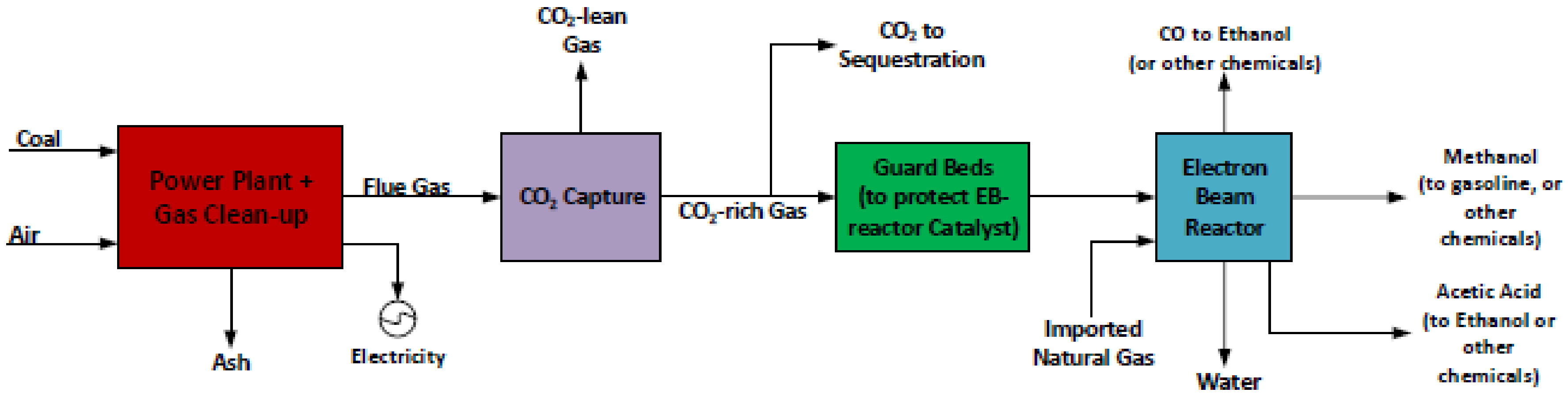
High Energy Systems for Transforming CO2 to Valuable Products

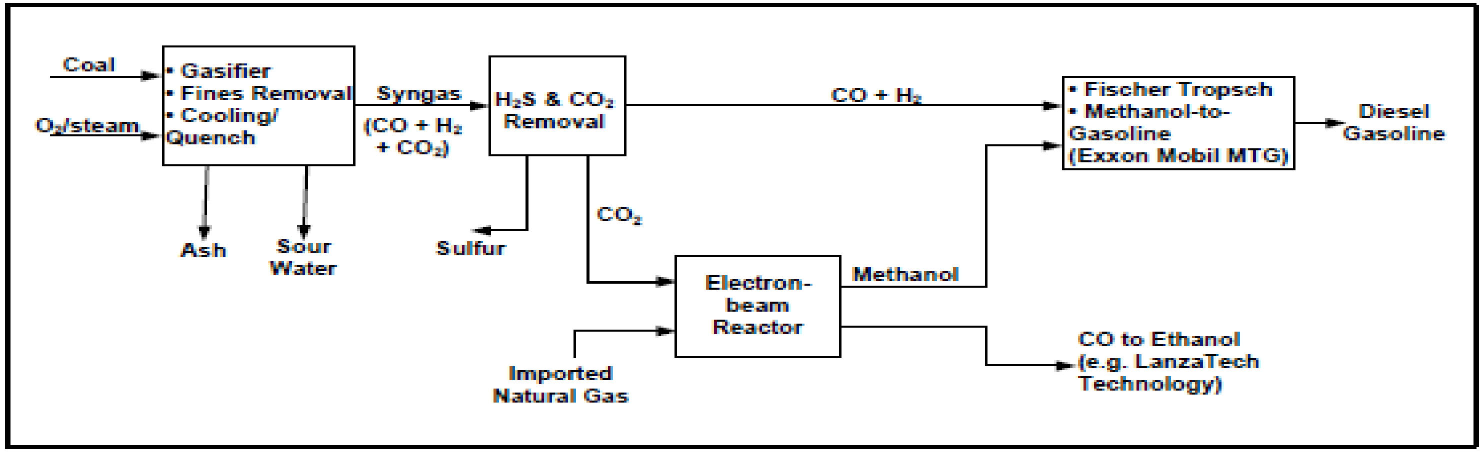
- **Team:**

Member	Role
gti	• Overall project integration and management • Design and construct E-Beam reactor and testing unit • Conceptual design for coal-fired power plants with DEBS
PCT EBEAM AND INTEGRATION	• Provide guidance in E-Beam reactor design and E-Beam accelerator for testing • Provide commercial size electron accelerator design and costing
ESF State University of New York College of Environmental Science and Forestry	• Develop kinetic model for the E-Beam reactor

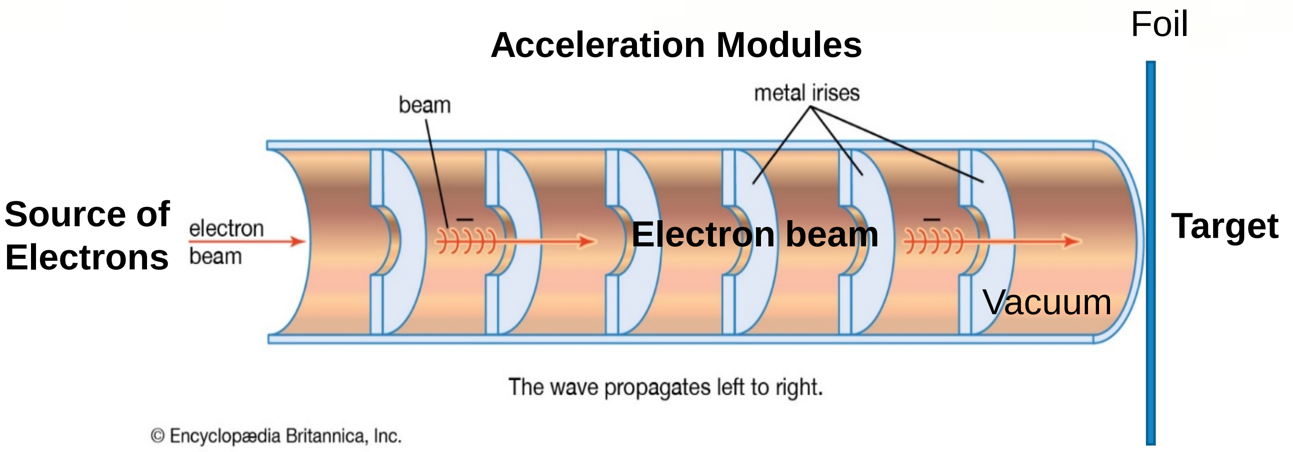
Technology Background

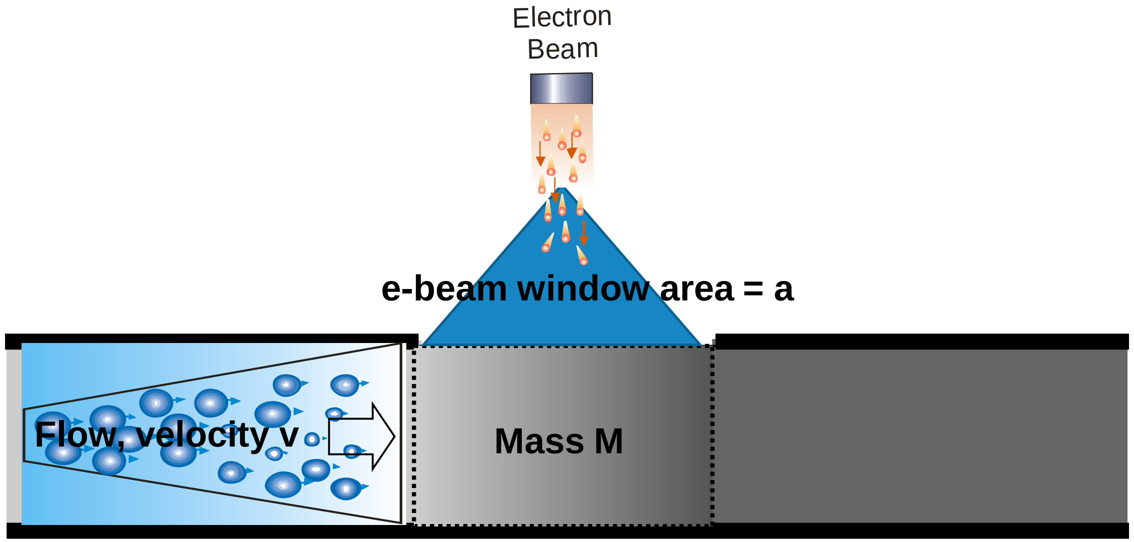
DEBS Process for Post- and Pre-combustion





Electron Beam Fundamentals





200keV & 20mA E-Beam:
E-Beam power = 4000 watt (4000 J/sec)

Each electron will have:
3.2×10^{-14} J of energy

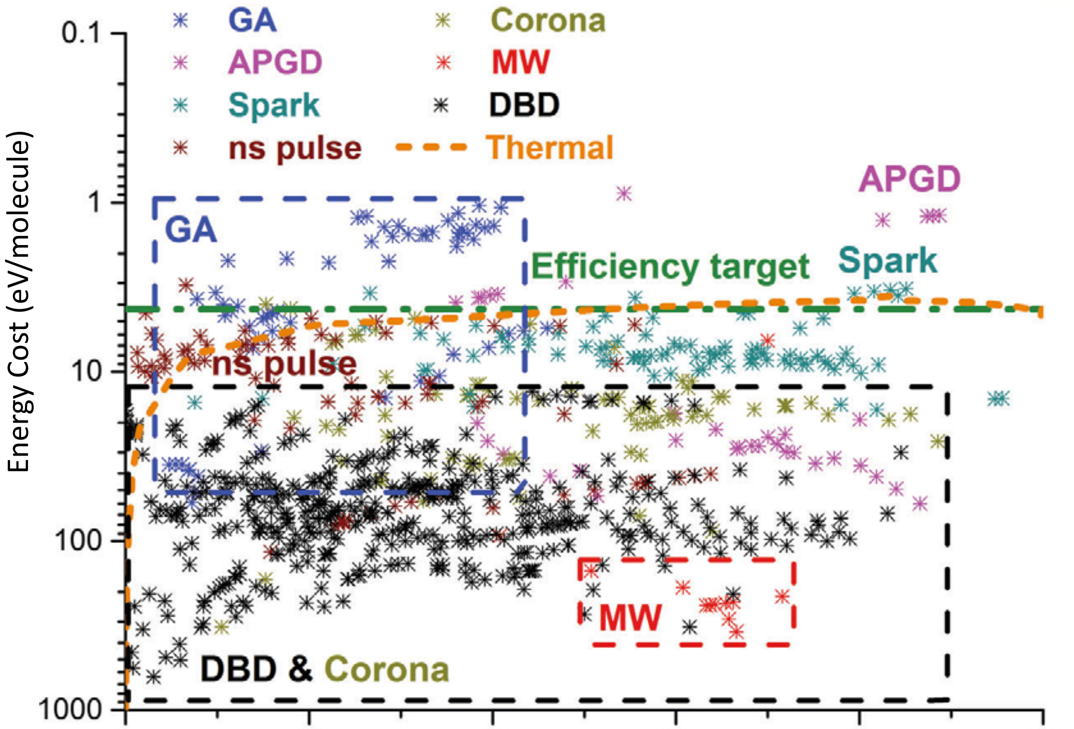
E-Beam will have:
1.25×10^{17} electrons per second

Bond dissociation energy (kJ/mol):

C-H	**337.2**
C-O	**1076.5**

Each electron has the potential to break:
~60,000 C-H
~20,000 C-O

Comparison of Plasma Conversion Technologies



Snoeckx and Bogaerts(*)

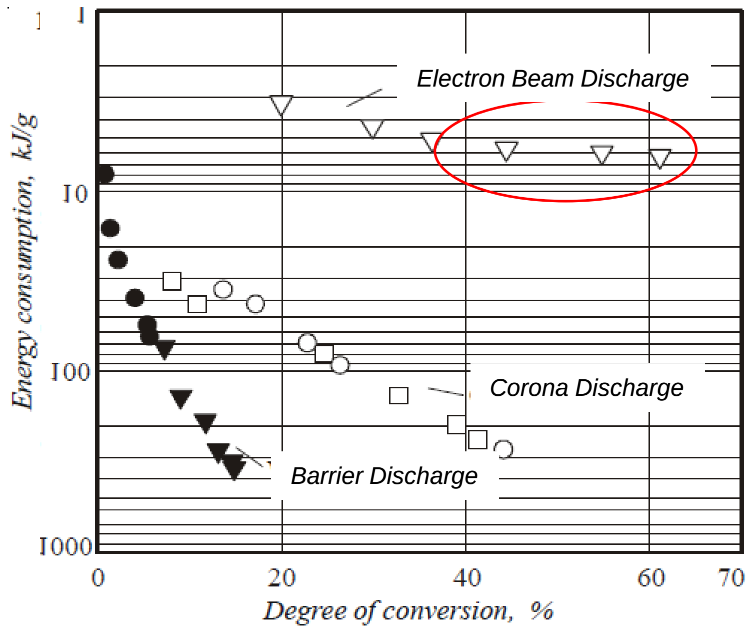


Fig. 1. Energy consumption vs. degree of conversion of methane using different methods of activation: ●, □, △ : 100% CH_4; ○,▲: mixture (1:1) of CH_4 and CO_2.

Vinokurov(**)

*Plasma technology – a novel solution for CO_2 conversion?, Chem. Soc. Rev., 2017,46, 5805-5863, Ramses Snoeckx and Annemie Bogaerts

**Vinokurov et al., Chemistry & Technology of Fuels and Oils, V-41, #2, 2005

Advantages Over Traditional Processes

- The DEBS process uses **high-energy electron beams** to break chemical bonds, allowing production of the desired chemicals at **near-ambient pressure and temperatures**

- Valuable chemical production by DEBS technology applied to CO_2 captured from coal-fired power plant will provide:
    1. **Low pressure / low temperature single reactor operation**
    2. **More energy-efficient CO_2 utilization**
    3. **Lower capital and operating costs**

DEBS - Direct Electron Beam Synthesis

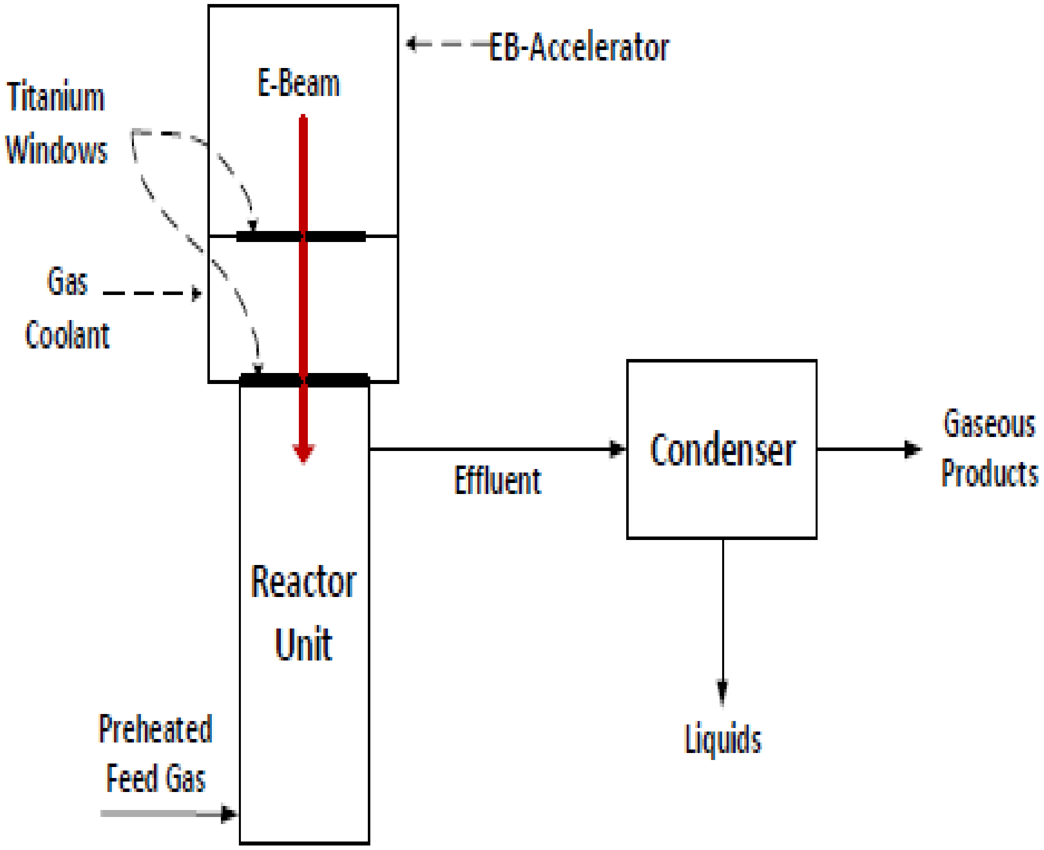
Challenges

- Technology Challenge:
  - Delivering maximum e-beam dose
  - Determining which products are more probable
  - Minimizing power use by E-Beam Accelerator

gti

Technical Approach

Experimental Design & Key Experimental Parameters



- **E-Beam dose, (kJ/gm)**
- **Gas residence time (ms)**
- **E-Beam energy : 80-200 (keV), 20 (ma)**
- **Use of a promoter**
- **Use of catalyst(s) to promote desired reactions**

Milestone Schedule

Budget Period	Milestone Number	Title or Brief Task Description	Task Completion Date		
			Original Planned	Revised Planned	Actual
1A	1.1	Update Project Management Plan	4/30/17	6/1/17	6/27/17
1A	1.2	Kickoff Meeting	4/30/17	6/13/17	7/13/17
1B	2.1	Complete Final Design	5/1/17	8/1/19	8/1/19
1B	1.3	Submit Continuation Application	1/1/18	8/1/19	8/21/19
1B	7.1	Develop Preliminary Kinetic Model	12/31/17	10/31/19	
2	5.1	Start Parametric Testing	2/1/18	11/15/19	
2	5.2	Determine key operating parameters that would Maximize per pass CO_2 Conversion	3/31/18	12/31/19	
2	6.1	Identify Operating Conditions and Catalyst Combinations for Chemical Production	7/31/18	12/31/19	
2	7.2	Develop Kinetic Model	2/28/19	7/31/20	
2	8.1	Report Analysis of Experimental Data	2/28/19	7/31/20	
2	8.2	Complete Economic Analysis	2/28/19	7/31/20	
2	1.4	Submit Final Technical Report	4/1/19	8/31/20	

Success Criteria

Decision Point	Date	Success Criteria
Go / No-Go	10/31/2019	• Complete design and manufacture of testing skid with E-Beam reactor. • Successful commissioning of a viable reactor system and testing unit: Verify gas flow meter control by measuring the vent using a dry test meter Operate chiller for condenser to achieve less than -20°C in the condenser Verify detection limit of acetic acid and methane using RGA at 100ppmv • Identify at least two catalysts to control the recombination and increase the yields for more valuable products • Complete design and cost estimate for the modification to a commercial electron accelerator shield housing
Completion of the project	7/31/2020	• 85% acetic acid, 15% methanol and CO selectivity • Higher than 25% CO_2 conversion per pass • Development of kinetic model • Reduce the COE by at least 50% compared to DOE Case 12-B • Achieve no net GHG emissions in production of products

Risk Status

Initial Risks:

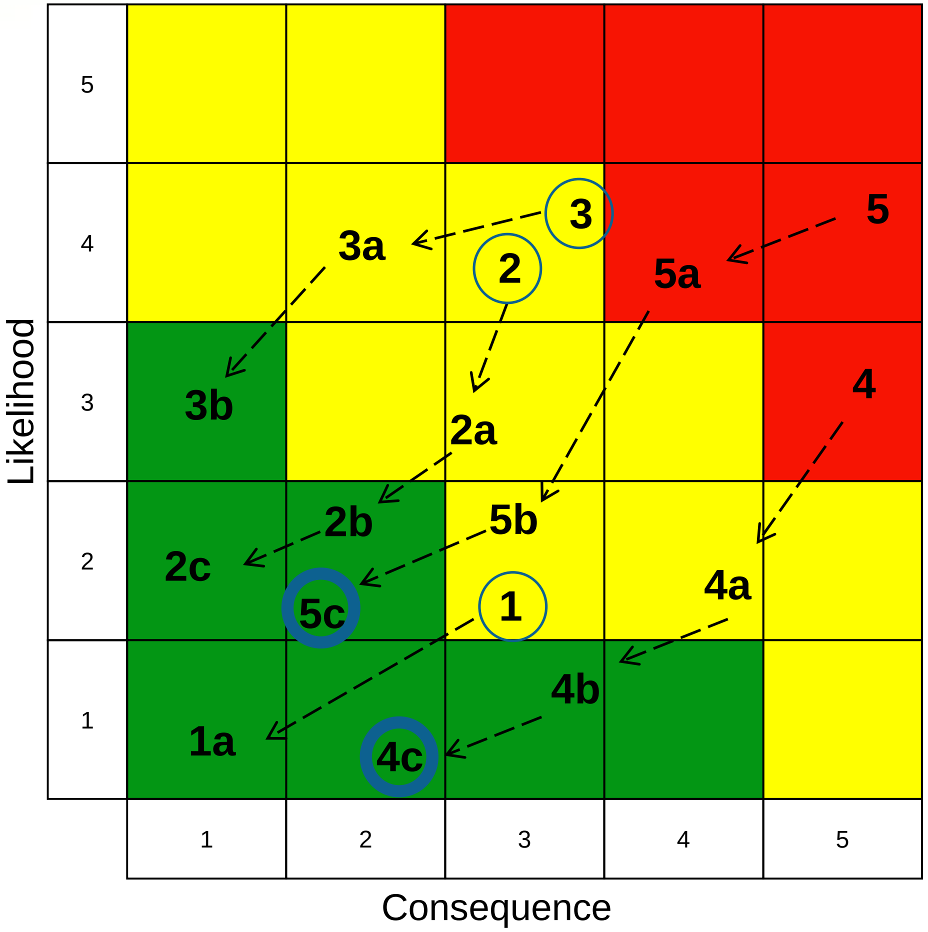
1. **Reactor size too small for practical use in testing unit**
   - 1a. Reduce E-Beam power and increase reactor size
2. **Recombination reactions occur too quickly**
   - 2a. Decrease residence time in reactor
   - 2b. Include a "recombination chamber"
   - 2c. Change location of catalyst
3. **Reactions produce unidentified products**
   - 3a. Increase analytical diagnostic capability
   - 3b. Change catalyst

Resource Risk:

4. **Accelerator provider not able to perform project**
   - 4a. Reserved "beam time" for GTI's experiments
   - 4b. Collaborate with other accelerator facilities
   - 4c. Operate accelerator at GTI

Resource Issue:

5. **Accelerator provider not able to perform experiments**
   - 5a. Identify other facilities with similar capability
   - 5b. Collaborate with other accelerator facilities
   - 5c. Working with PCT-Ebeam Integration



Progress and Current Status of Project

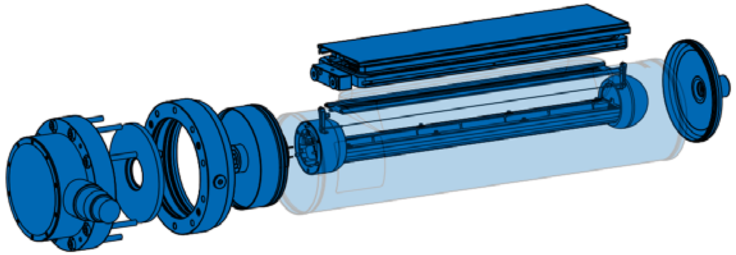
Electron Accelerator

- Electron accelerator provided by PCT E-Beam Integration
- Uses a seal lamp unit from COMET
- Custom made accelerator

  and reactor housing

COMET Sealed Lamp Accelerator

- 200 keV, 20 ma electron beam
- Beam window is 40mm x 400mm

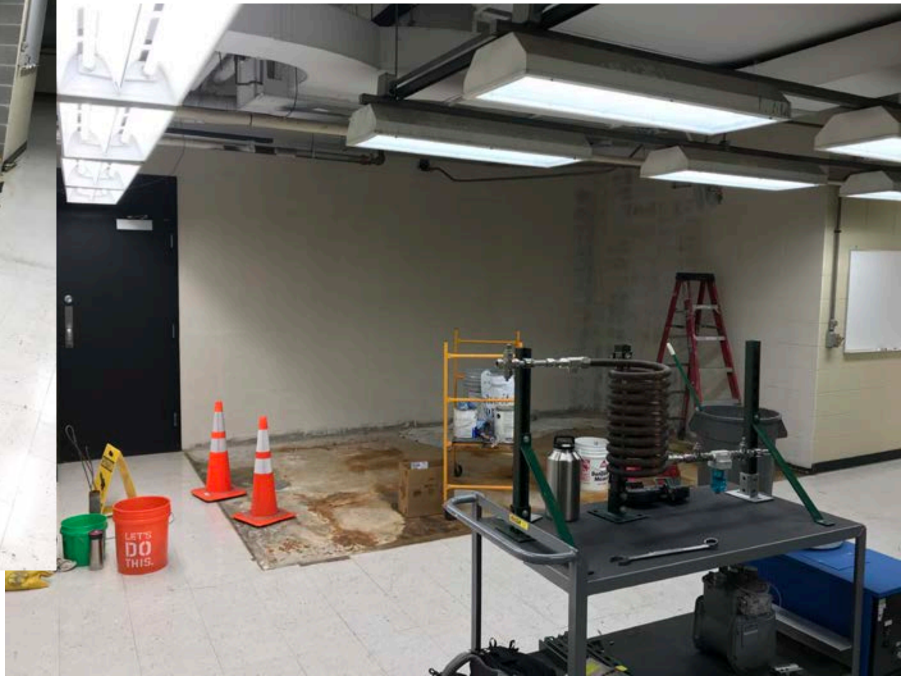


Completed Accelerator Housing

- Construction and completed accelerator housing during Factory Acceptance Test at PCT E-Beam Integration.

GTI Facility Modification

- Remodeled a section of existing laboratory to accept electron accelerator.
- Upgraded ventilation to allow for high volume of combustible gas use.



Electron Accelerator Delivered to GTI

Plans for Future Testing

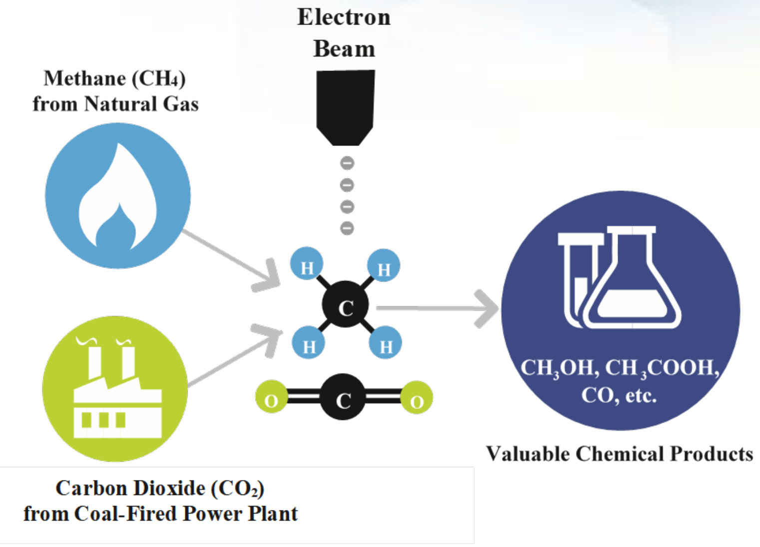
Plans for future testing/development

- Finish reactor and testing skid fabrication
- Begin testing at GTI with new reactor and accelerator
- Kinetic model verification
- Techno-economic analysis

- Scaling up accelerator and reactor is not expected to be an issue:
  1. Available beam coverage from existing equipment is large
  2. Multiple accelerators can be connected to increase beam coverage if necessary

Summary

- Objective is to develop a commercially viable non-equilibrium process that breaks bonds directly unlike conventional chemistry that requires heating the entire molecule
- Irradiation of CH_4 and CO_2 mixture has been modeled for over 200 compounds with over 1600 reactions
- E-Beam reactor designed and constructed
- Electron accelerator is delivered to GTI and being commissioned for parametric testing



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