Close Proximity Electromagnetic Carbonization (CPEC)

LM122

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June 8, 2017, 9:30am

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Overview

Timeline

- Project Start: 10/1/17
- Project End: 9/30/18
- Progress: ~48%

Budget

- FY16 – FY18: $4.5M
- Funding received in FY16: $1.5M
- Funding for FY17: $1.35M

Barriers

- Barriers addressed
  - Cost: A goal of this project is to reduce energy consumption in the carbon fiber conversion process and therefore total carbon fiber cost.
  - Inadequate supply base: Another goal of this project is to reduce the require processing time for carbonization and therefore increase overall throughput.

Partners

- Project lead: ORNL
- Partner: RMX Technologies

Relevance

- Close Proximity Electromagnetic Carbonization (CPEC) is a new low temperature carbonization process that is faster and more efficient than the conventional process.
- Project Goals
  - Reduce unit energy consumption (kWh/kg) by 50%.
  - Reduce Operational Costs by 25%.
  - Produce the same or better quality carbon fiber.
  - Scale the technology to a nameplate capacity of 1 annual metric ton and demonstrate by project end date.

FY16-17 Milestones

Date	Milestone	Status
December 31, 2015	**M1:** Completion of database of electrical properties of Partially Carbonized Fiber (PCF). Samples of PCF are created and characterized.	**Complete**
May 13, 2016	**M2**: Completion of CPEC-2V model (a virtual computational experimental setup). Simulated performance shows a distribution of heating with a maximum variation of ± 2.5% across the width of the entire simulated tow band sample.	**Complete**
October 15, 2016	**M3:** Completion of CPEC-3 furnace construction. 100% of the CPEC-3 construction is complete. The furnace and required subsystems are in place and ready for initial testing.	**Complete**
December 15, 2016	**Go/No Go M4:** Demonstrate stable processing of material on a continuous basis with the CPEC-3.	**Complete**

FY16-17 Milestones

Date	Milestone	Status
January 31, 2017	**M5:** Successfully carbonize material on a continuous basis in the CPEC-3 with carbonized material achieving a minimum density of 1.5 g/cc.	**Complete**
June 30, 2017	**M6:** Successfully carbonize material on a continuous basis in the CPEC-3 with final carbonized material achieving a minimum density of 1.5 g/cc in under 90 seconds achieving minimum mechanical properties of 150 ksi tensile strength, 15 Msi Modulus.	**On-Track**
September 30, 2017	**Go/No Go M7:** Successfully carbonize material on a continuous basis in the CPEC-3 with final carbonized material achieving a minimum density of 1.5 g/cc in under 90 seconds achieving minimum mechanical properties of 250 ksi tensile strength, 25 Msi Modulus, and 1% strain.	**On-Track**

FY18 Milestones

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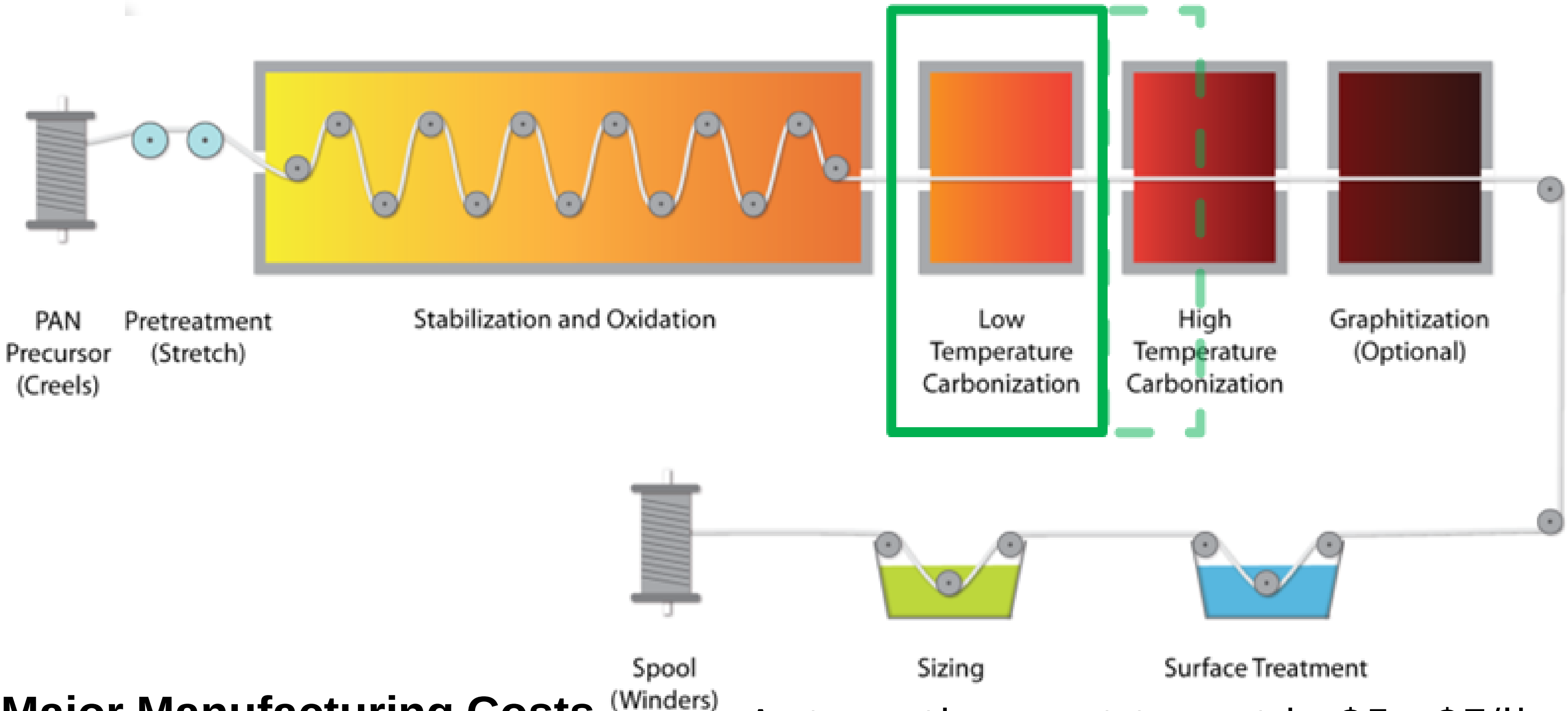
Date	Milestone	Status
November 30, 2017	**M8:** Complete assembly of CPEC-4 and demonstrate stable/proper operation of all subcomponents for 20 minutes.	
March 31, 2018	**M9:** Successfully carbonize 4x24k tows with final mechanical properties of greater or equal to 250 ksi tensile strength and 25 Msi Modulus.	
June 30, 2018	**M10:** Successfully carbonize 4x24k tows with final mechanical properties of greater or equal to 250 ksi tensile strength and 25 Msi Modulus in under 60 seconds.	
September 30, 2018	**Go/No Go M11:** Demonstrate at least 5% cost savings using CPEC versus conventional carbonization.	

Approach Background
Conventional PAN Processing



Major Manufacturing Costs	
Precursor	43%
Oxidative stabilization	18%
Carbonization	13%
Graphitization	15%
Other	11%

Actual percentages vary and are precursor dependent

- Automotive cost target is \$5 - \$7/lb
- Tensile property requirements are 250 ksi, 25 Msi, 1% ultimate strain
- ORNL is developing major technological breakthroughs for major cost elements

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Approach

- Conventional furnaces consume significant energy heating large volumes of inert gas surrounding the fiber.
- If thermal energy could be directly coupled from an energy source to the fiber, tremendous energy savings could be realized.
- This project uses electromagnetic coupling to directly heat the fiber – not the surrounding gas.
- Dielectric heating mechanism is utilized.

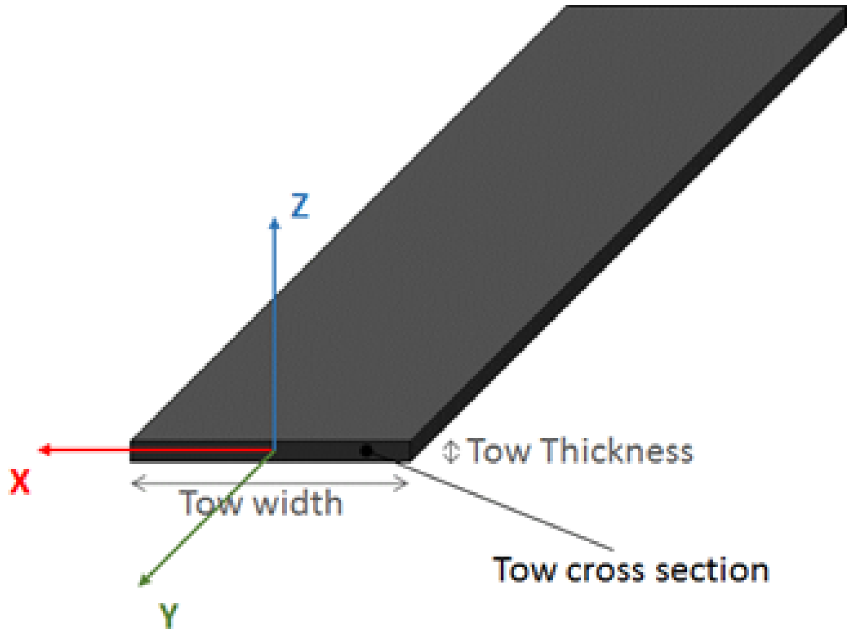
Approach

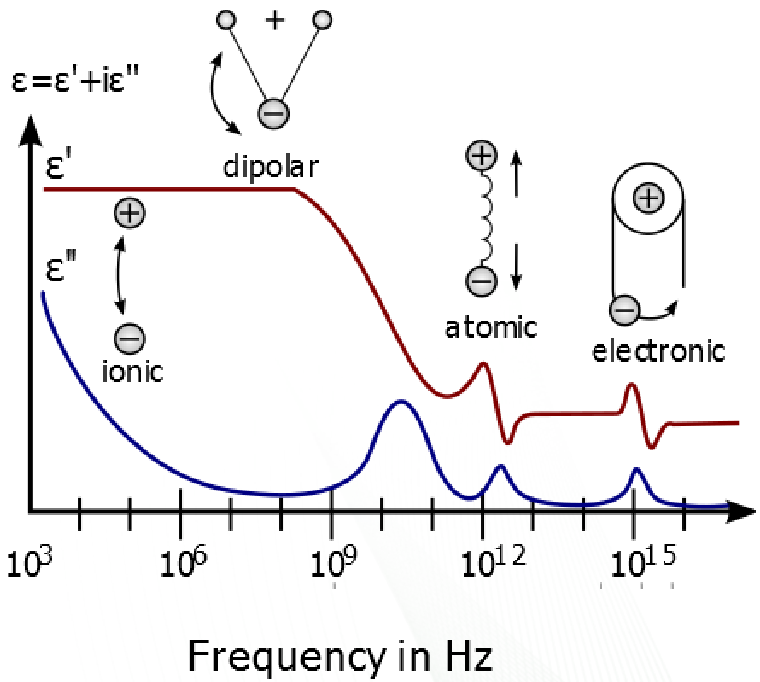
- Based on volumetric power loss due to dipolar electromagnetic heating
  - P_v power absorbed per unit volume, W/m^3
  - ε' is the relative dielectric constant
  - ε_0 is permittivity of free space, 8.85418782 x 10^{-12} F/m
  - $|E|$ is the magnitude of the local electric field intensity
  - $tan\delta$ is the loss tangent of the material
  - f is the operational frequency

$$P_v = 2\pi f|E|^2\varepsilon_0\varepsilon' tan\delta$$

Approach

- Processing 1 x 48k tow in CPEC-3 Furnace





[1] Mauritz, Kenneth A, Dielectric Spectroscopy, The University of Southern Mississippi.

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Technical Accomplishments

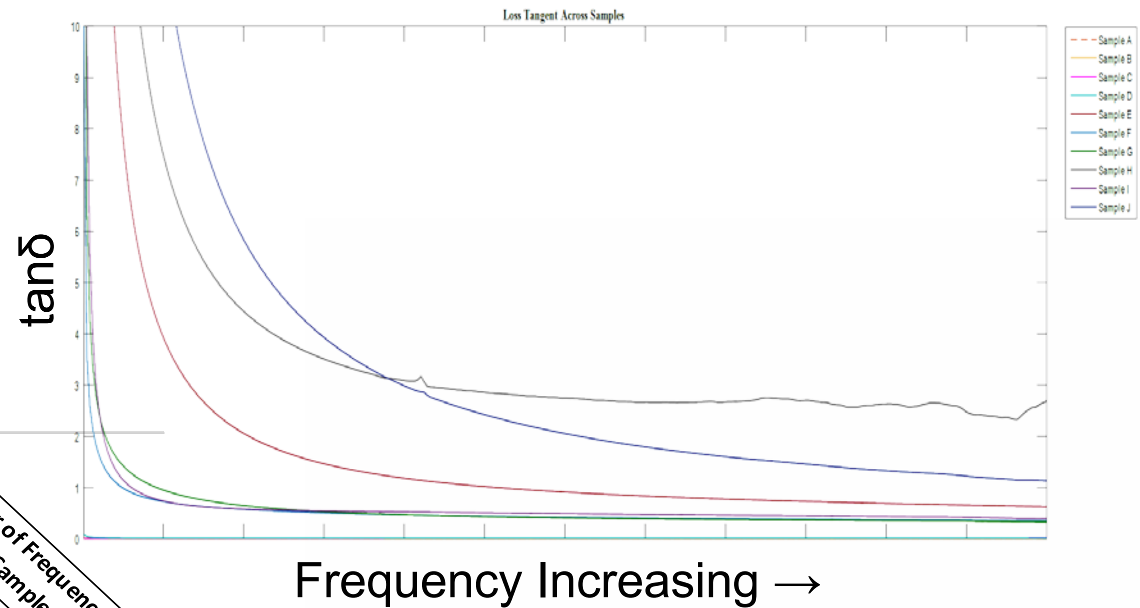
- Implementation Pathway

Material Measurement → Computational Electromagnetic Modeling (CPEC-2V) → Prototype Design and Build (CPEC-3)

- Material Measurement
  - 163 different samples measured consisting of:
    - 10 different carbonization levels or temperatures
    - Multiple temp ramping functions during material characterization
    - Broad frequency range with at least 801 points in each sweep
  - Characterized on 3 different measurement systems
  - Custom Matlab and Visual Basic Data Reduction

Technical Accomplishments

Material Measurement



Samples	Number of Measurements	Number of Unique Samples	Sample Minimum Temperature (°C)	Sample Maximum Temperature (°C)	Number of Samples without PE	Number of Frequency Samples
A	35	11	-100	250	4	1348
B	9	7	21	21	0	801
C	9	7	21	21	0	801
D	9	7	21	21	0	801
E	20	9	-100	250	2	801
F	1	1	21	21	0	801
G	1	1	21	21	0	801
H	1	1	21	21	0	801
I	1	1	21	21	0	801
J	10	2	21	250	1	801
Polyethylene	13	2	21	21	0	801
Polytetrafluoroethylene (Teflon)	4	2	21	21	2	801
Polyacrylonitrile	15	3	20	250	3	972
50 Ohm Calibration Standard	35	3	21	21	35	801
Totals	163	57	-	-	-	11932

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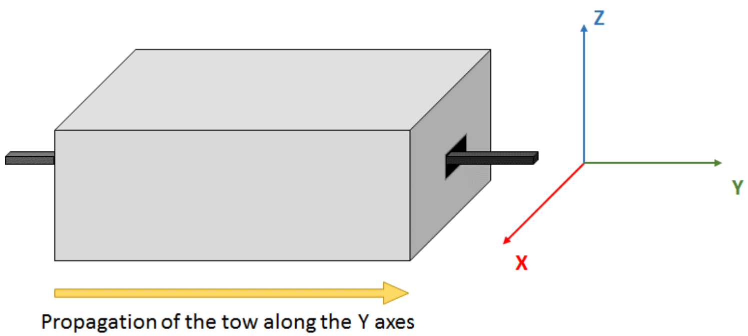
Technical Accomplishments

Computational Electromagnetic Modeling (CPEC-2V)

- Conservative modeling practices produced a design that, when built, carbonizes at lower than expected power levels.
- More than 20 design iterations were evaluated and the optimized embodiment was built.
- Without the need for insulation, wall temperature remains lower than 125°C after 30min of operation on existing furnace. (conventional furnace is 400 -600 C).



The internal furnace geometry and electrode design is not shown.

Technical Accomplishments

- Prototype Design and Build
  - Prior Work: CPEC-1 was the initial proof of concept device
  - CPEC-2V was functionally modeled
  - CPEC-3 Current operational furnace. Constructed based on CPEC-2V
- Images or details cannot be presented due to export control restrictions.
- CPEC-3 is a single-tow (48k) close proximity electromagnetic carbonization furnace. It has been in operation since November 2016.
- CPEC-3 can be operated in batch mode or continuous mode.

Technical Accomplishments

Continuous Processing of Fiber with CPEC-3 Furnace

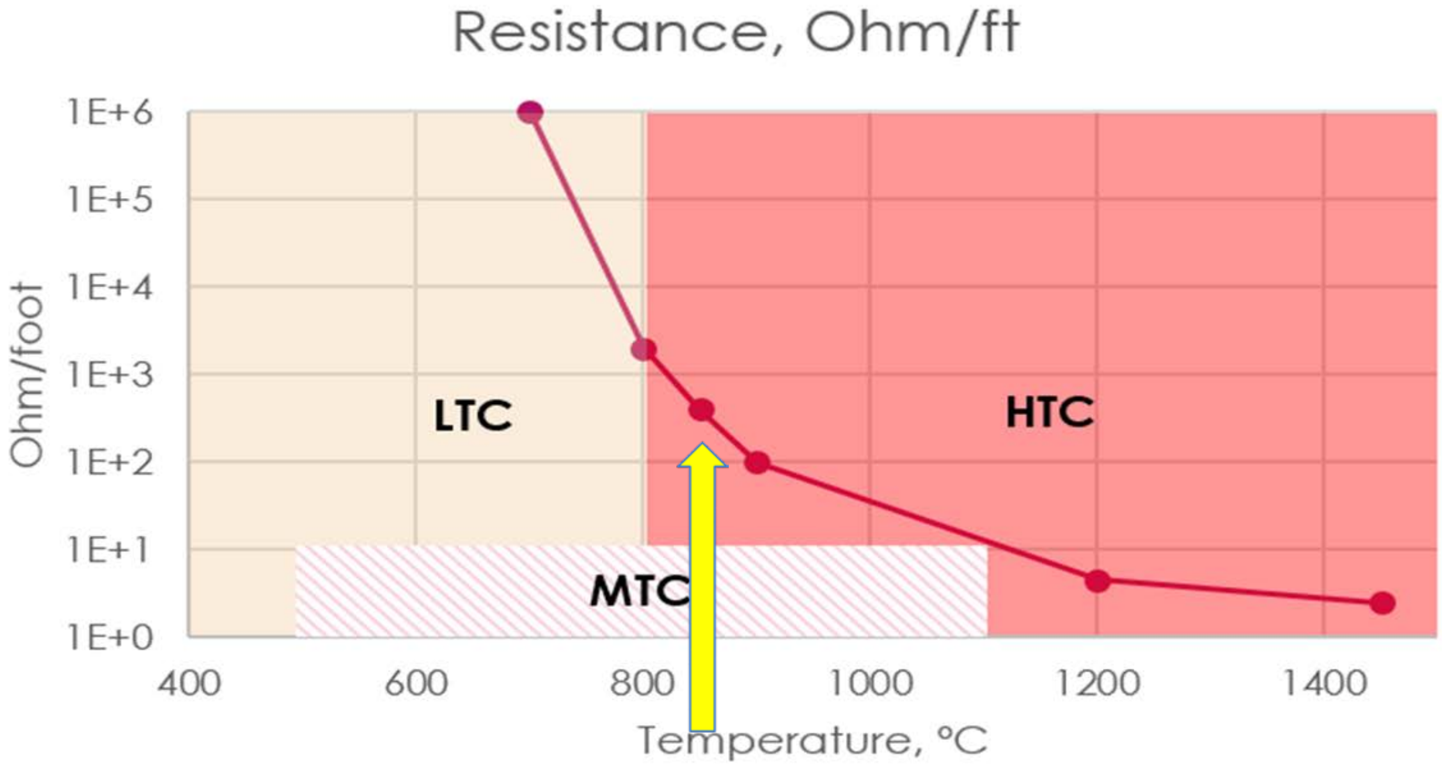
Conventional 90+ seconds

Mechanical Properties of Partially Carbonized Fiber

Sample	Diameter [µm]	Peak stress [ksi]	Modulus [Mpsi]	Strain at peak stress [%]
CPEC-3_0035	8.95	162.4	11.54	1.29
Sample A	13.52	29.2	1.05	21.62
Sample B	12.01	21	0.98	4.22
Sample C	11.45	40.1	1.35	7.45
Sample D	11	72.8	2.58	3.95
Sample E	10.69	117.3	5.52	2.03
Sample F	9.76	176.7	9.53	1.76
Sample G	9.87	108.3	12.32	1.37
Sample H	8.8	208.4	16.25	1.18
Sample I	9.07	308.6	21.05	1.33
Sample J	8.77	329.2	21.99	1.36

Electrical Characterization

Conventionally Carbonized Chart Data



CPEC Sample 35 Electrical characterization:

Position (in)	1.6	3.1	4.7	6.3	7.9	9.4	11.0	12.6	14.2	15.7	17.3	18.9	20.5	22.0
Resistance per ft (Ω/ft)	76	232	171	1143	1295	229	152	183	259	457	381	655	1219	381

Average Resistance Per Ft	490 Ω/ft

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Response to Previous Year Reviewer's Comments

- This project was not reviewed last year in FY16.

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Collaboration and Coordination with Other Institutions

RMX TECHNOLOGIES

- RMX Technologies is a sub to ORNL.
  - Provides electrical engineering expertise.
  - RMX Technologies has previously partnered with ORNL to successfully develop plasma oxidation technology that is now being commercialized.
  - This same ORNL/RMX partnership is involved with the current project.

Potential Future Commercialization Partners
(Same team that commercialized plasma oxidation)

4M™ CARBON FIBER TECHNOLOGIES

LITZLER DRIVEN BY RIGHT

- 4M Carbon Fiber Technologies is a company created by RMX to manufacture plasma systems. Will be involved in commercialization at conclusion of project.
- C.A. Litzler & Co., Inc. is RMX's oven manufacturing partner. Will be involved in commercialization at conclusion of project.

Remaining Challenges and Barriers

- Eliminate the damage experienced by the material due to arcing by implementing appropriate isolation.
- Control the consistency of the process.
- Select a design that would make the next furnace (CPEC-4):
  - Demonstrate scalability of the CPEC concept
  - Highly robust to large scale industrial processing

Proposed Future Research

Any proposed future work is subject to change based on funding levels.

- FY17
  - Demonstrate final carbon fiber properties using the CPEC-3 furnace.
- FY18
  - Design and build the CPEC-4 furnace, a 1 ton low temperature carbonization furnace.
  - Operate CPEC-4 furnace and produce carbon fiber meeting or exceeding required mechanical properties.

Summary

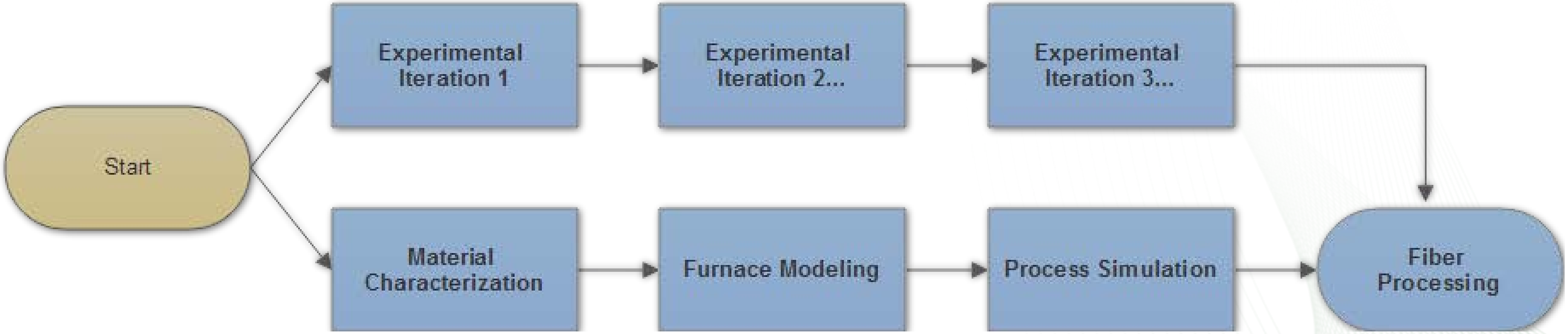
- A CPEC furnace was successfully modeled and built based upon material characterization.
- CPEC-3 can produce fiber with properties exceeding those obtained from conventional Low Temperature Carbonization (LTC)
- CPEC-3 typical residence time is 50 seconds. This replaces conventional ramping sections, Low Temperature Carbonization (LTC), and partial High Temperature Carbonization (HTC).
- Projected full scale cost savings of CPEC based upon current capabilities is 48-51% of conventional carbonization.

Thank You

- Questions?

Technical Backup

- Initially this project was proposed as an iterative, completely experimental effort, based on prior feasibility work conducted.
- After project start, with initial discussion and analysis of early work, it was decided to change focus and look at a focused modeling effort.



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