DOE Bioenergy Technologies Office (BETO)
2019 Project Peer Review

DE-EE0007967
Advance Biofuels and Bioproducts with AVAP

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Technology Session Area Review

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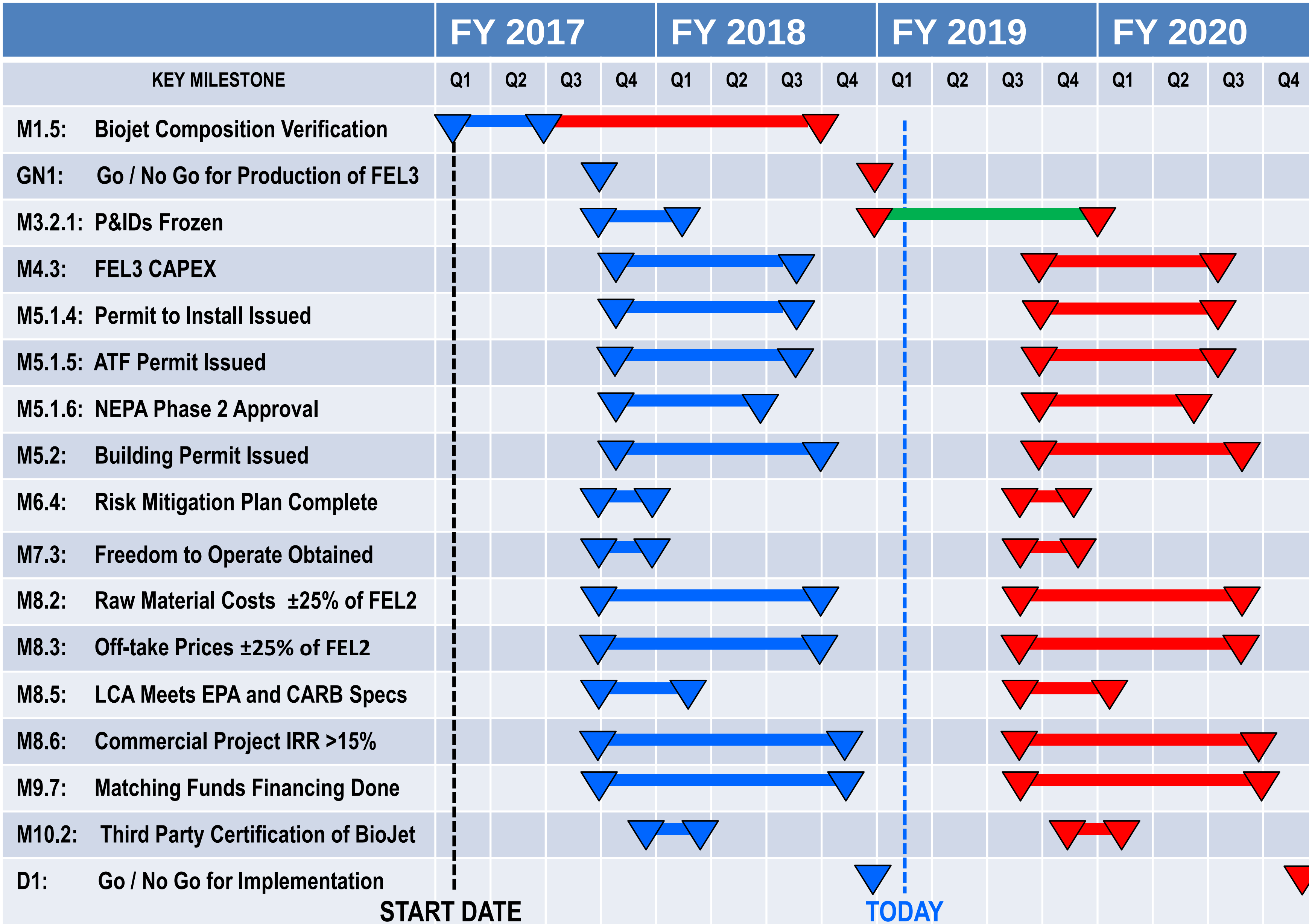
Project ABBA
Goal Statement

The goal of this project is to design, build, and demonstrate the ABBA process at an intermediate pre-commercial scale of 50 BDt/d woody biomass feedstock to produce:

1. Liquid hydrocarbon "drop-in" fuels, principally biojet fuel
2. BioPlus nanocellulose
3. Bio-BDO

The project is aligned with the BETO 2022 goal of producing biofuel at $3/gge, and will demonstrate the technical performance criteria and economic viability of the ABBA process using readily available, underutilized woody biomass feedstocks available in many regions of the United States.

Key Milestones



Project Budget Table

	Original Project Cost (Estimated)			Project Spending and Balance		Final Project Costs
Budget Periods	DOE Funding	Project Team Cost Shared Funding	Contingency	Spending to Date	Remaining Balance	Funding Needed for Completion
BP1	**1,163,320**	**1,163,320**	**0**	**2,244,515**	**82,125**	**82,125**
T1 Validation	1,163,320	1,163,320	0	2,244,515	82,125	82,125
BP2	**2,507,010**	**2,507,680**	**0**	**0**	**5,014,689**	**5,014,689**
T2 Definition Eng.	107,822	107,822	0	0	107,822	107,822
T3 Engineering	1,073,539	1,074,208	0	0	1,073,539	1,073,539
T4 Sched&Cost Est.	162,640	162,640	0	0	162,640	162,640
T5 Permitting	48,968	48,968	0	0	48,968	48,968
T6 Risk Mgt.	375,912	375,912	0	0	375,912	375,912
T7 IP Analysis	44,532	44,532	0	0	44,532	44,532
T8 Commercial	466,759	466,759	0	0	466,759	466,759
T9 Financing	178,596	178,596	0	0	178,596	178,596
T10 Biojet Certification	48,242	48,242	0	0	48,242	48,242

Quad Chart Overview

Timeline

- Project start: January 15, 2017
- Project end: Sept. 30, 2020

  NCE provided for obtaining, installing & troubleshooting ATJ pilot plants, and gathering engineering data.
- Percent complete: 50%

Barriers

- Barriers Addressed

  Pm-A. Strategy & Goals

  Ct-E. Improving Catalyst Lifetime

  Ct-O. Selective Separations of Organic Species

Budget

	Costs (USD)			
	Pre FY17	FY17	FY18	Planned Funding (FY19 to End)
DOE Funded	-	121,924	772,255	2,776,150
Project Cost Share	-	121,924	798,817	2,750,258

Project Partners

Drop-in Fuel:

Petron (12.9%)

Byogy (2.7%)

Nanocellulose Applications:

Georgia Tech (1.3%)

University of Tennessee (0.5%)

Bio-BDO:

Genomatica

1.1

Project Overview

***A**dvance **B**iofuels and **B**ioproducts with **A**VAP (**ABBA**) was submitted by AVAPCO LLC in response to DOE FOA# DE-FOA-0001232.*

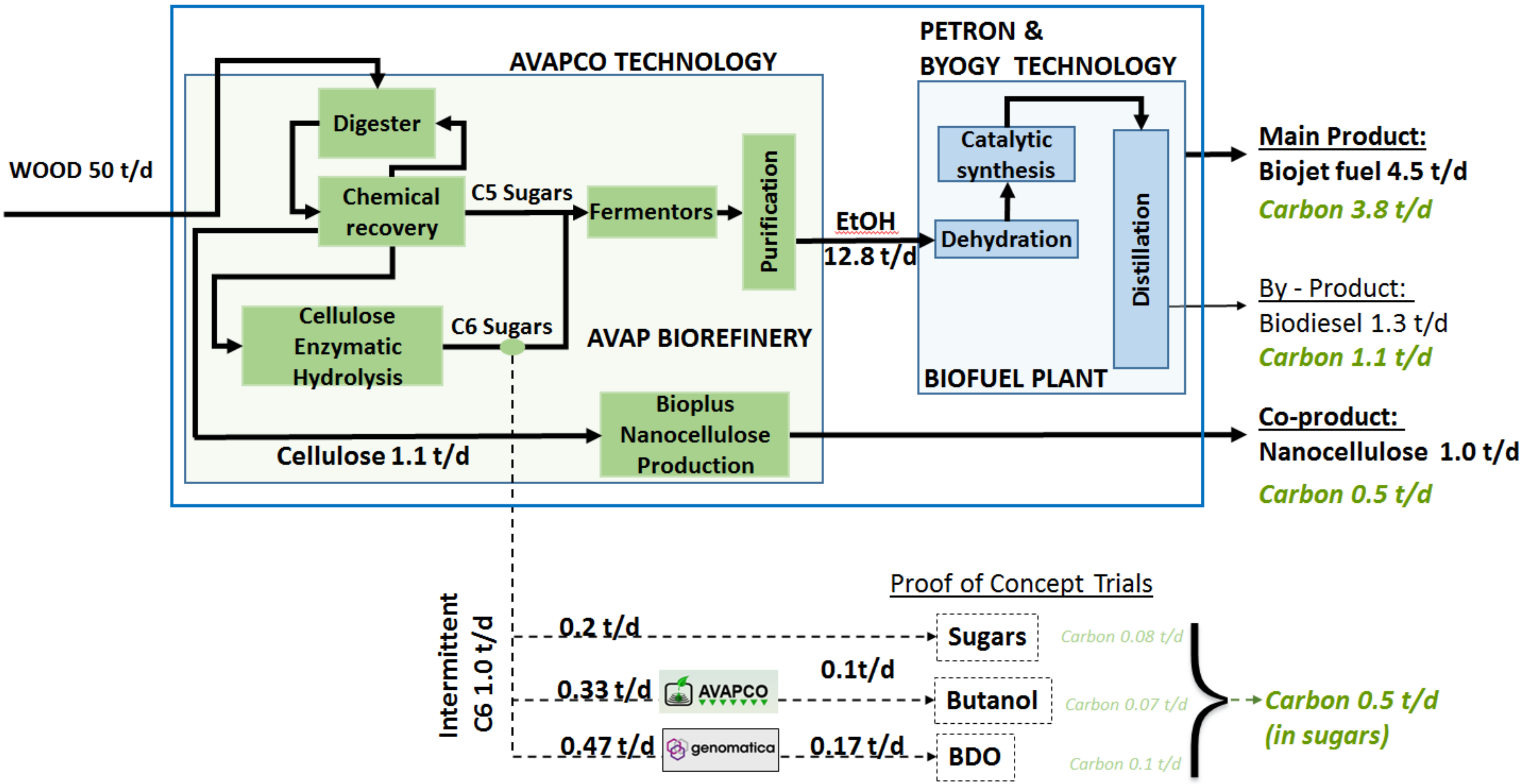
- Phase I - FEL3 for an integrated demonstration plant with a capacity of 50 BDt/d of woody biomass to finished drop-in biofuels, BioPlus® nanocellulose & biochemicals.
- The drop-in biofuels include jet fuel, diesel, and gasoline.
- The co-products include Bio-Plus® nanocellulose (a novel material used for its strength to reinforce and lightweight plastics and paper products), and clean cellulosic sugars for the production of butanediol (a starting material for Spandex).
- The ABBA process LCA is ~95% less than petroleum based transportation fuels and the resulting biofuels are compatible with the RFS2 advanced and cellulosic fuels definitions.
- The renewable biomass feedstock originates from a nearby sawmills and forest harvesting operations.

1.2 Project Overview

AVAPCO

The ABBA process is a patented biochemical route:

- Biomass is fractionated in ethanol and sulfur dioxide, hydrolyzed and fermented.
- Ethanol is then dehydrated over a catalyst to ethylene, and purified.
- Ethylene is oligomerized , and distilled to drop-in biojet fuel, diesel, and gasoline.



1.3 Project Overview

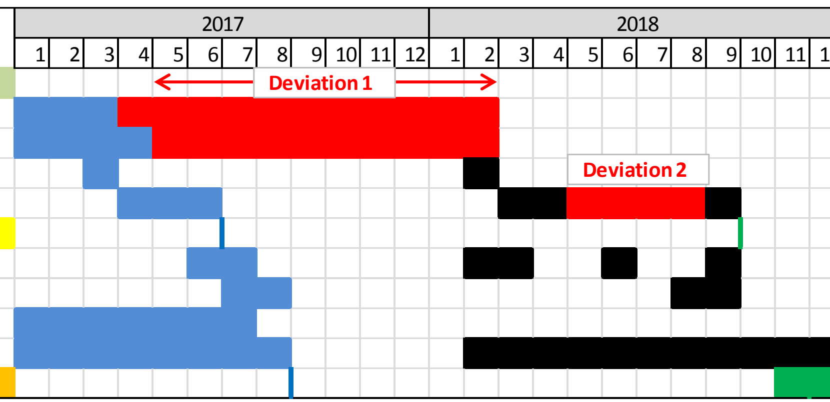
Timeline: Planned v. Achieved

Budget period 1 was planned to be the simple installation and operation of pre-existing pilot ATJ equipment using AVAP produced ethanol.

In actuality, an additional project partner had to be found to supply the first half of the ATJ technology (EtOH -> ETE), and delays were incurred in the delivery and set-up of the ATJ pilot equipment (Deviation 1), and equipment troubleshooting (Deviation 2). As a result, two NCTE were requested and granted.

Budget Period 1 Tasks, Milestones, and Go/NoGo Decision Points

1	Validation	Task	Start	Finish
1.1	Assemble Alcohol To Jet (ATJ) Partner Plant in Thomaston, Shake Down	Subtask	M0	M3
1.2	Ship and Assemble Ethanol to Ethylene (ETE) Module in Thomaston	Subtask	M0	M4
1.3	AVAP Ethanol Production for ETE Module Commissioning and Shake Down	Subtask	M3	M3
1.4	Run ETE and ATJ Modules, Adjust to Achieve Biojet Target from AVAP EtOH	Subtask	M4	M6
1.5	Biojet Compositional Verification Obtained	M1.5	M6	M6
1.6	AVAP Ethanol to Biojet DOE and IE Witness Validation Run	Subtask	M6	M7
1.7	Update Energy and Mass Balance	Subtask	M7	M8
1.8	Commercial Application Development at UTK for Nanocellulose	Subtask	M1	M7
1.9	DOE and IE Preliminary Design Review	Subtask	M0	M8
1.1	Go / No Go Decision to Continue to FEL3	GN1	M9	M9



However, no show-stopping issues were observed in BP1, and the extensive troubleshooting allowed the team to develop a better design optimization plan.

1.4

Project Overview

Dr. Kim Nelson has been appointed to the position of Chief Technology Officer for Nanocellulose.

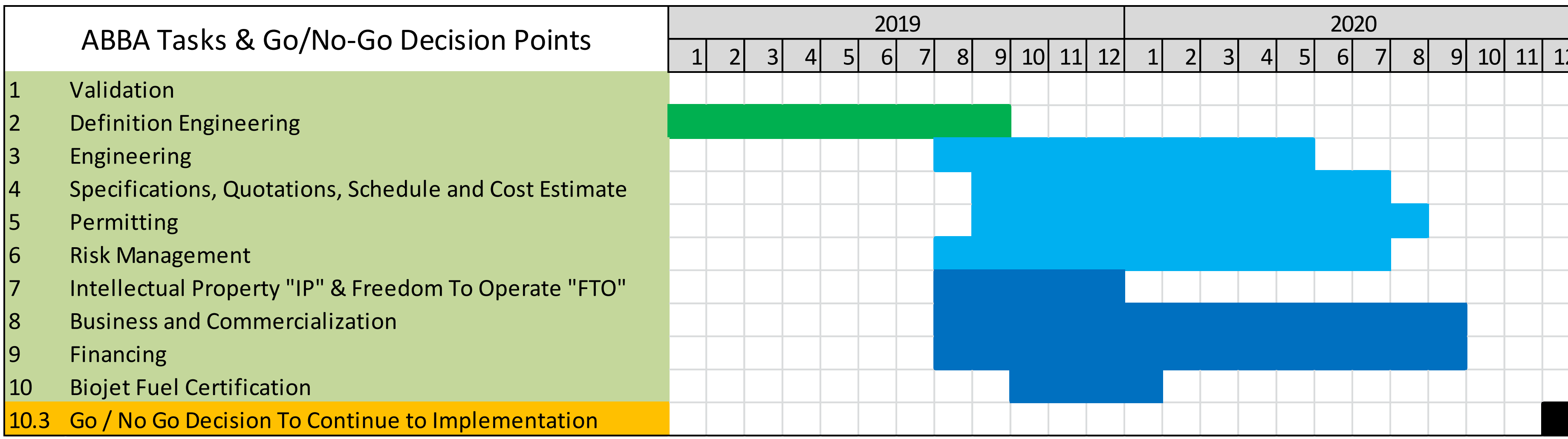
The ABBA project manager, Mr. Steve Rutherford retired in July of 2018. Ryan Zebroski was assigned to the project to fill the vacancy.

AVAPCO has sufficient resources available to it with the necessary skills and experience to complete the project.

2.1 Technical Approach

Task 1 (Validation) & Task 2 (Definition Engineering) Purpose:

- Prove the claimed process metrics.
- Validate assumptions made in the project proposal.
- Clearly define the basis of design for the engineering tasks.



In the Definition Engineering, we will create a unified process data set to be used for in the engineering work.

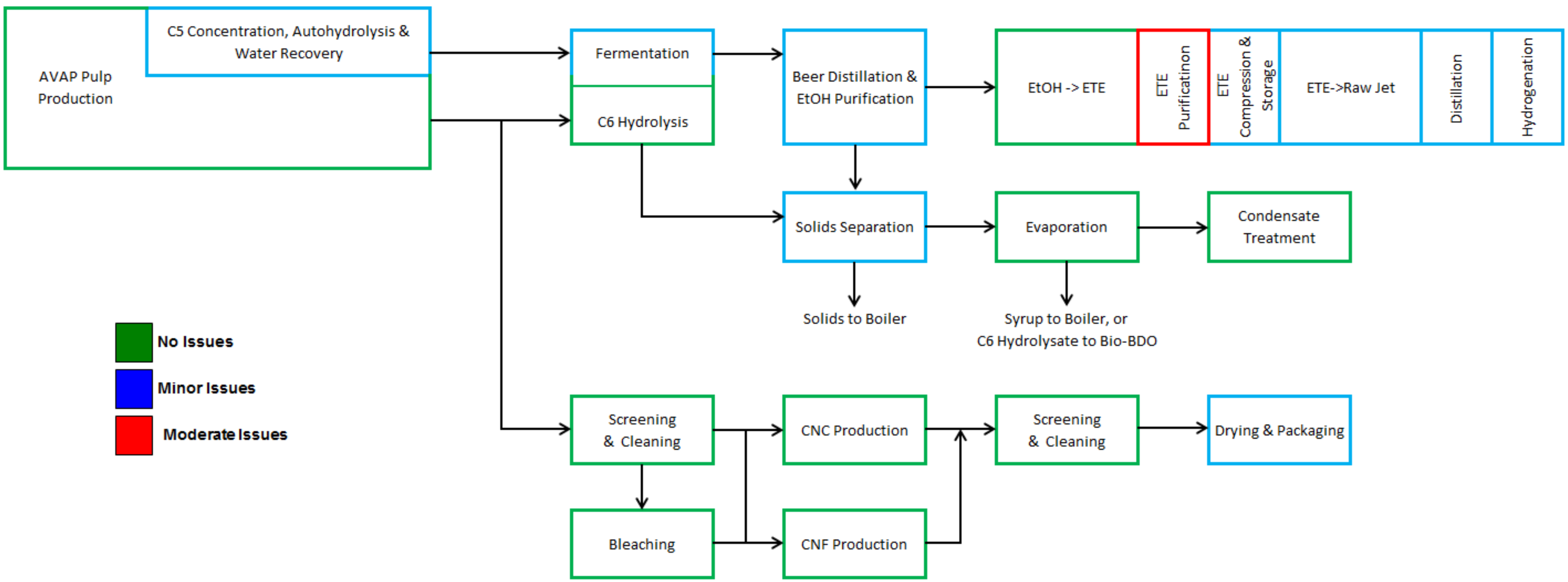
Technical Approach

Critical technical success factors

	Unit Operation	Key Parameter	Unit	Laboratory	Pilot Plant	ABBA Demo	Commercial
AVAP Fractionation	Digester	% Sugars recovered	g sugar \ g wood	0.652	0.65	0.65	0.67
	Saccharification	Time	Hours	72	72	72	72
	Saccharification	% Enzyme dose on Glucan	% wt	2.6%	2.6%	2.5%	2.5%
	Saccharification	% glucan to glucose	% of glucan	98%	85%	92%	92%
	Chemical Recovery	% Ethanol to Hydrolysis	% on original wood	1.3%	0.4%	0.4%	0.4%
BioPlus	Nanocellulose on-spec	% of time			85%	90%	95%
Mixed Alcohol Plant	EtOH Fermentation	Time	Hours	72	48	48	48
	EtOH Fermentation	Yeast Pitch	g/L	2	0.5	0.5	0.5
	EtOH Fermentation	Sugars converted to Ethanol	g EtOH/g Sugar (% theoretical)	0.454 (89%)	0.454 (89%)	0.434 (85%)	0.454 (89%)
Hydrocarbon Plant	Dehydration **(Petron)**	Ethanol to Ethylene	% converted	NA	NA	97%	97%
	Oligomerization **(Byogy)**	Ethylene to liquid hydrocarbons	% yield	NA	96%	97%	97%

2.3

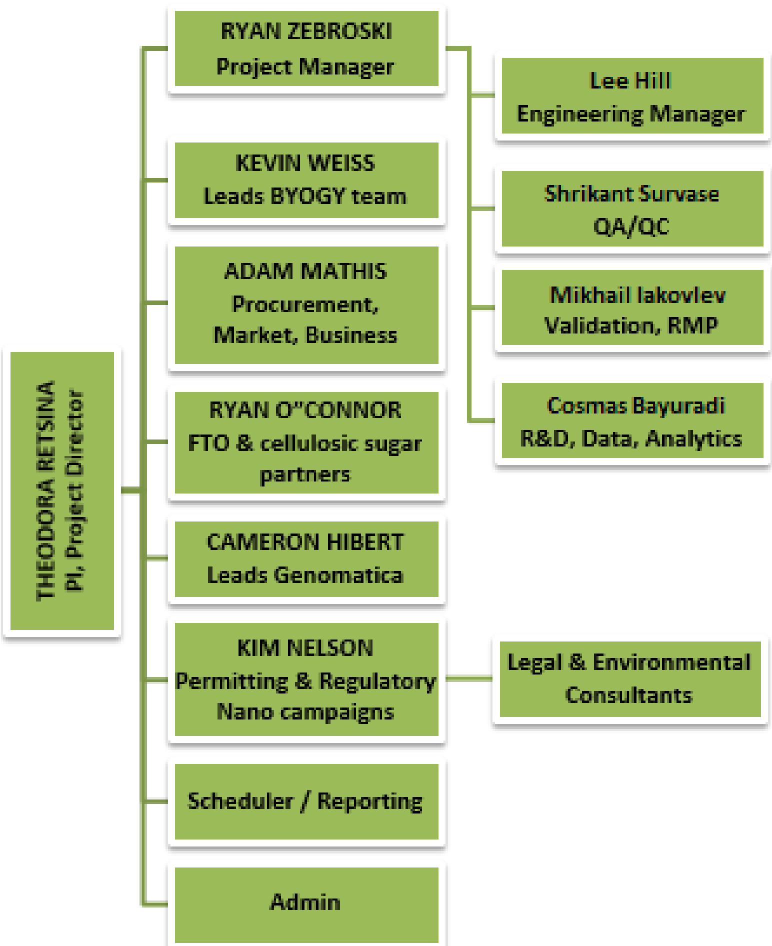
ABBA Process Operations Block Diagram



Potential Challenges

- Nanocellulose drying scale-up.
- Value engineering of ethylene purification.
- Oligomerization catalyst life.

Management Approach

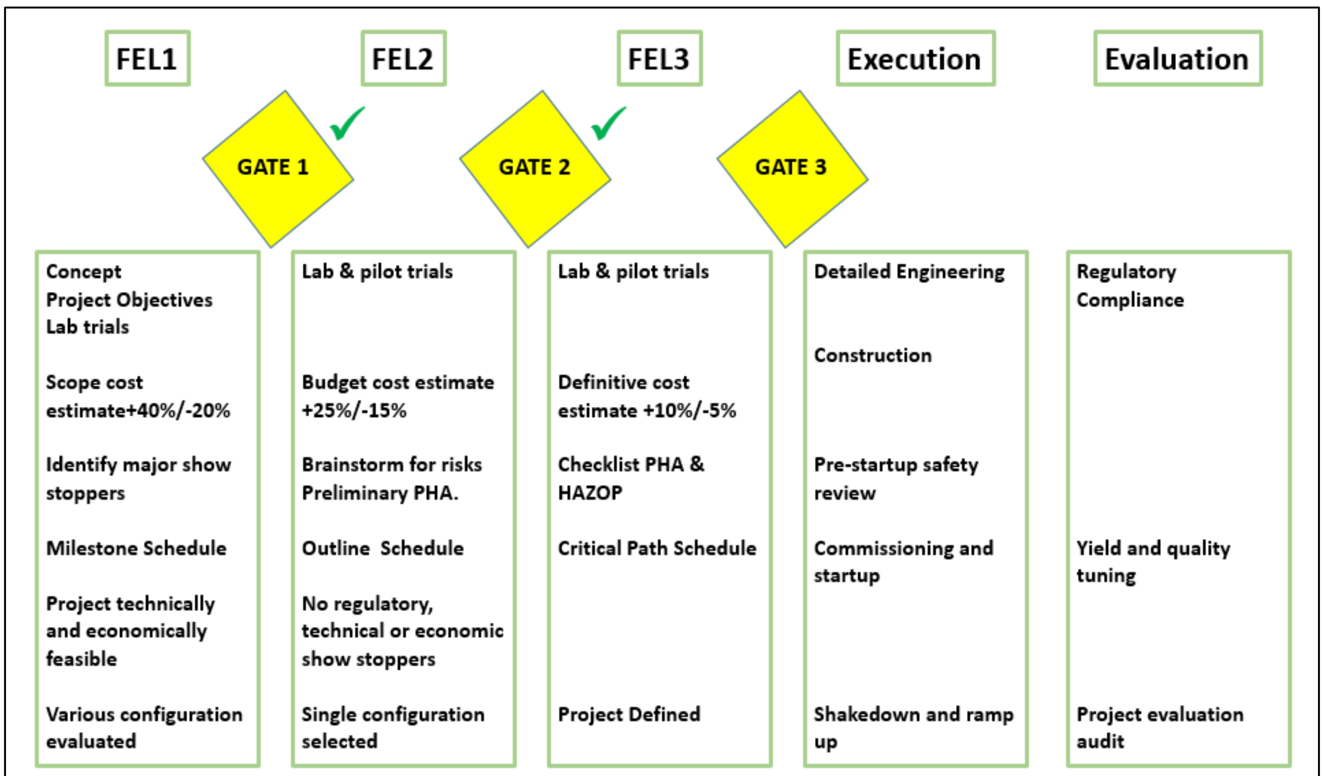


- Dr. Kim Nelson will lead the Nanocellulose development efforts.
- All FEL3 engineering efforts and capital cost estimates will be led by the project manager, Ryan Zebroski & Eng. Manager Lee Hill.
- All validation operations both at AVAPCO and Byogy will be led by Dr. Mikhail Iakovlev and Cosmas Bayuradi.
- Adam Mathis will lead the efforts to secure raw material & offtake contracts, and will lead the TEA and commercialization plan.
- Ryan will be the primary interface with Byogy.

2.5 Management Approach

AVAPCO uses a Stage-Gate Process of 5 phases and three Go/No-Go stage gates to develop and execute projects. The Stage-Gate process restricts investment in the next phase until the project team is satisfied with the estimated project economic and technical viability.

As shown, the ABBA project has successfully passed through Gate 2 and is in the engineering phase.



3.1 Technical Accomplishments Progress & Results

AVAPCO

Major Technical Accomplishments to Date:

The major technical objectives for Budget Period 1 of Phase 1 were to validate the data used in the project proposal and produce small quantities of ABBA biojet for compositional analysis. Specifically:

1. Convert woody biomass to cellulosic ethanol meeting intermediate spec.
2. Convert the ethanol to ethylene meeting the ethylene intermediate spec.
3. Convert the ethylene to raw jet, equivalent to that produced by Byogy in previous DOE work.

Budget Period 1 Tasks, Milestones, and Go/NoGo Decision Points

	1	Validation	Task
✓	1.1	Assemble Alcohol To Jet (ATJ) Partner Plant in Thomaston, Shake Down	Subtask
✓	1.2	Ship and Assemble Ethanol to Ethylene (ETE) Module in Thomaston	Subtask
✓	1.3	AVAP Ethanol Production for ETE Module Commissioning and Shake Down	Subtask
✓	1.4	Run ETE and ATJ Modules, Adjust to Achieve Biojet Target from AVAP EtOH	Subtask
✓	1.5	Biojet Compositional Verification Obtained	M1.5
✓	1.6	AVAP Ethanol to Biojet DOE and IE Witness Validation Run	Subtask
✓	1.7	Update Energy and Mass Balance	Subtask
✓	1.8	Commercial Application Development at UTK for Nanocellulose	Subtask
✓	1.9	DOE and IE Preliminary Design Review	Subtask
✓	1.1	Go / No Go Decision to Continue to FEL3	GN1

3.2 Technical Accomplishments Progress & Results

1. Convert woody biomass to cellulosic ethanol meeting intermediate spec.

	Unit Operation	Key Parameter	Unit	Laboratory	Pilot Plant	BP1 Validation	ABBA Demo	Commercial
AVAP Fractionation	Digester	% Sugars recovered	g sugar / g wood	0.652	0.65	0.623[1]	0.65	0.67
	Saccharification	Time	hours	72	72	72	72	72
	Saccharification	% Enzyme dose on Glucan	% wt	2.6%	2.6%	2.6%	2.5%	2.5%
	Saccharification	% glucan to glucose	% of glucan	98%	85%	89%	92%	92%
	Chemical Recovery	% Ethanol to Hydrolysis	% on original wood	1.3%	0.4%	TBD	0.4%	0.4%
Mixed Alcohol Plant	EtOH Fermentation	Time	hours	72	48	48	48	48
	EtOH Fermentation	Yeast Pitch	g/L	2	0.5	0.5	0.5	0.5
	EtOH Fermentation	Sugars converted to Ethanol	g EtOH/ g Sugar (% theor)	0.454 (89%)	0.454 (89%)	0.434 (85%)	0.434 (85%)	0.454 (89%)

[1] Low sugar content in feedstock wood.

3.3 Technical Accomplishments Progress & Results

1. Convert woody biomass to cellulosic ethanol meeting intermediate spec.
   - The AVAP validation run exceeded the target enzymatic hydrolysis yield (89% vs. target of 85%).
   - The carbohydrate content of the wood used in run 120 was low (57% vs. target of 66%).
   - The wood was stored outside for 5 months, which resulted in some carbohydrate degradation. This resulted in less carbohydrate being available in the biomass for conversion to ethanol; therefore, for an equivalent comparison, the ethanol yield on the basis of the original wood sugars was provided along with the gallon per tonne biomass basis.

Metric	Units	Demo Target	Commercial Target	Run 120	Run 120 Normalized
AVAP Ethanol yield	gallons / BDt Wood	91.0	95.0	91.4	90.8
AVAP Ethanol yield	kg/kg Anhydrous Carbohydrate in Wood	0.411	0.429	0.479	0.444

3.4 Technical Accomplishments Progress & Results

2. Convert the ethanol to ethylene meeting the ethylene intermediate spec.
   - The ethanol to ethylene conversion listed in the project application was 97%.
   - The measured ethanol to ethylene conversion in the validation was **98.4%**.
   - Only 0.2% of the ethanol was unconverted, and only 1.5% of the ethanol was converted to products other than ethylene.

	Unit Operation	Key Parameter	Unit	Laboratory	Pilot Plant	BP1 Validation	ABBA Demo	Commercial
Hydrocarbon Plant	Dehydration **(Petron)**	Ethanol to Ethylene	% converted	NA	NA	98.4%	97%	97%
	Oligomerization **(Byogy)**	Ethylene to liquid hydrocarbons	% yield	NA	96%	65.4%[2]	97%	97%

[2] Single pass conversion. The gas phase HC was not recycled to the reactor in the BP1 validation.

3.5 Technical Accomplishments Progress & Results

3. Convert the ethylene to raw jet, equivalent to that produced by Byogy in previous DOE work.

- The validation resulted in raw jet yields approaching the best yields Byogy obtained in its prior work.
- The raw jet quality that was determined to be consistent with the core jet fuel characteristics seen in the multiple Byogy fuel samples tested in past.
- The U.S. Air Force Research Laboratory provided an analysis of the hardwood based raw jet sample produced in the budget period 1 validation work.

	Unit Operation	Key Parameter	Unit	Laboratory	Pilot Plant	BP1 Validation	ABBA Demo	Commercial
Hydrocarbon Plant	Dehydration **(Petron)**	Ethanol to Ethylene	% converted	NA	NA	98.4%	97%	97%
	Oligomerization **(Byogy)**	Ethylene to liquid hydrocarbons	% yield	NA	96%	65.4%[2]	97%	97%

[2] Single pass conversion. The gas phase HC was not recycled to the reactor in the BP1 validation.

4.1

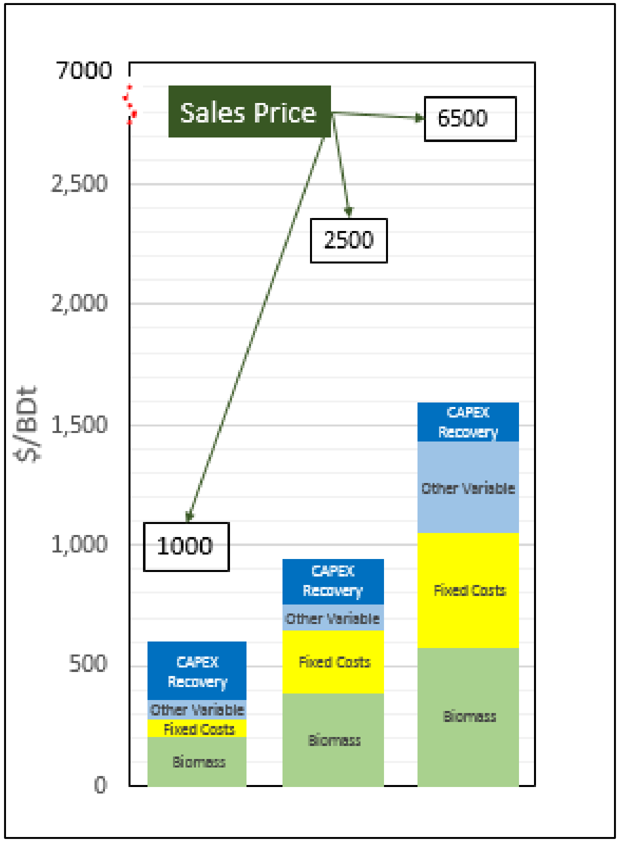
Relevance

The ABBA project responds to several of this FOA, the DOE, EERE and BETO policy and technical goals .

- ***This FOA requires liquid infrastructure compatible cellulosic biofuel*** complying with RFS2 Advanced Biofuel definition as the Primary Product(s). The Primary Product stream must contain at least 50% of the biogenic carbon leaving the facility as salable product. The feedstock for a demonstration plant must be 50 BDt/d or above.
- ***Develop and transform our renewable biomass resources into commercially viable, high-performance biofuels, bioproducts,*** and biopower through targeted research, development, demonstration, and deployment.
  - ABBA Hydrocarbon biofuels are “drop-in” fuels that can act as true petroleum substitutes to replace diesel, jet fuel, heavy distillates.
  - The project includes the production of high margin BioPlus Nanocellulose, and hydrolysate for a range of other fuel and chemical products.
  - The feedstock for the ABBA demonstration plant and subsequent commercial plants is renewable, sustainably harvested woody biomass.

Relevance

- ***Reduce GHG emissions*** ABBA will improve the environmental impact of transportation fuel use. Life Cycle Analysis shows the ABBA process to give ~ 95% reduction of greenhouse gas (GHG) emissions for the biomass-derived jet fuel, compared to conventional jet fuel.
- ***The DOE cost targets aims to achieve a modeled pump price of $3.00 per gallon (2007 dollars) for renewable gasoline, diesel, and jet fuel.*** The current FEL2 level techno-economic performance of the ABBA project shows that the ABBA commercial project meets the BETO 2022 goal of ***a mature modeled sale price of $3/gallon*** gasoline equivalent of Advanced Biofuel in 2007 dollars.



Production costs and sales price for commercial ABBA plant

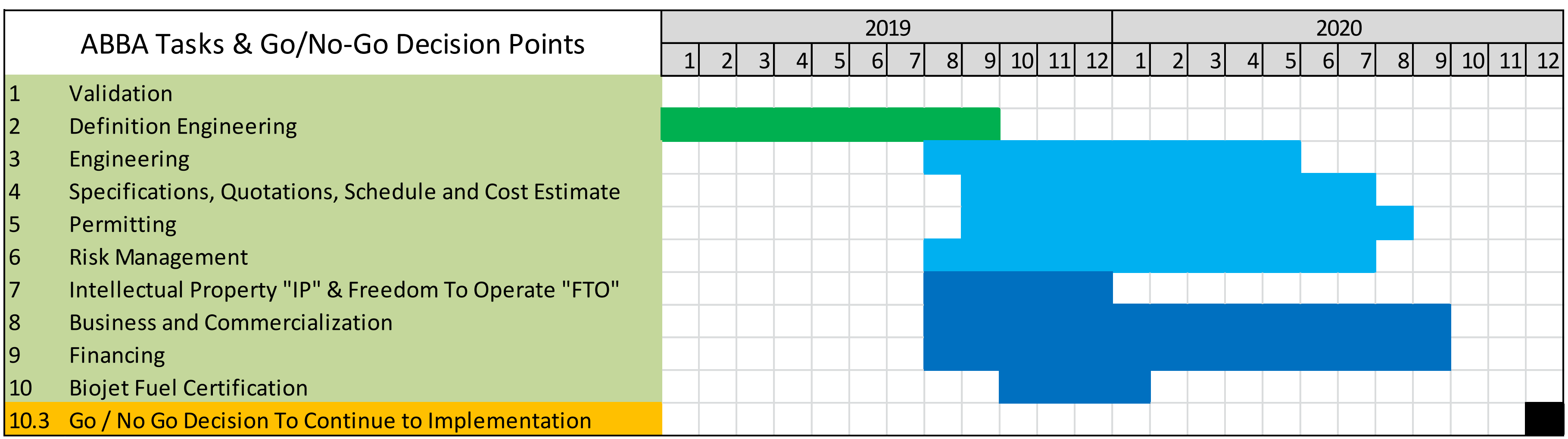
5.1

Future Work

The project work for the next 18 months consists three major efforts, which will be headed by three groups within the project management structure, with a lead for each:

1) Definition Engineering (T2, T10), including production of additional engineering data.
2) Engineering (T3,T4, T5, T6), including costing of site and utility costs of target sites.
3) Commercial development and negotiations (T7, T8, T9), including negotiation of site contracts

AVAPCO has selected well qualified candidates to lead each of these three groups.



Summary
Advance Biofuels & Bioproducts with AVAP

1. The ABBA project will produce quality drop-in biofuels, but importantly will also produce high margin BioPlus nanocellulose, as well other chemicals. The production of the high margin BioPlus nanocellulose is an important part of the project, given the current low oil prices.
2. Additional emphasis is being placed on the methodical and detailed technical approach to producing a single, definitive and comprehensive process data set, prior beginning the engineering and subsequent costing work.
3. The technical targets of the budget period 1 validation have been met.
4. The ABBA project is very well aligned with the goals and objectives of the DOE.
5. With project is well positioned to be completed per the schedule (slide 3) and budget (slide 4) described above.