2018 | THE ALMOND CONFERENCE

APPLICATION AND PRODUCTION OF BLACK CARBON FROM ALMOND SHELLS

ROOM 306-307 | DECEMBER 6, 2018

california almonds
Almond Board of California

growing ADVANTAGE
The Almond Conference

AGENDA

- **Guangwei Huang**, Almond Board of California, moderator
- **Bill Orts**, USDA-ARS, Albany
- **Sullivan Grosz**, ABC Leadership Participant
- **Ning Sun**, Lawrence Berkeley National Laboratory

Application and Production of Black Carbon from Almond Shells

William Orts – Research Leader, Bioproducts

USDA

December 6, 2018

Industry Partners & USDA Researchers

Karen Lapsley

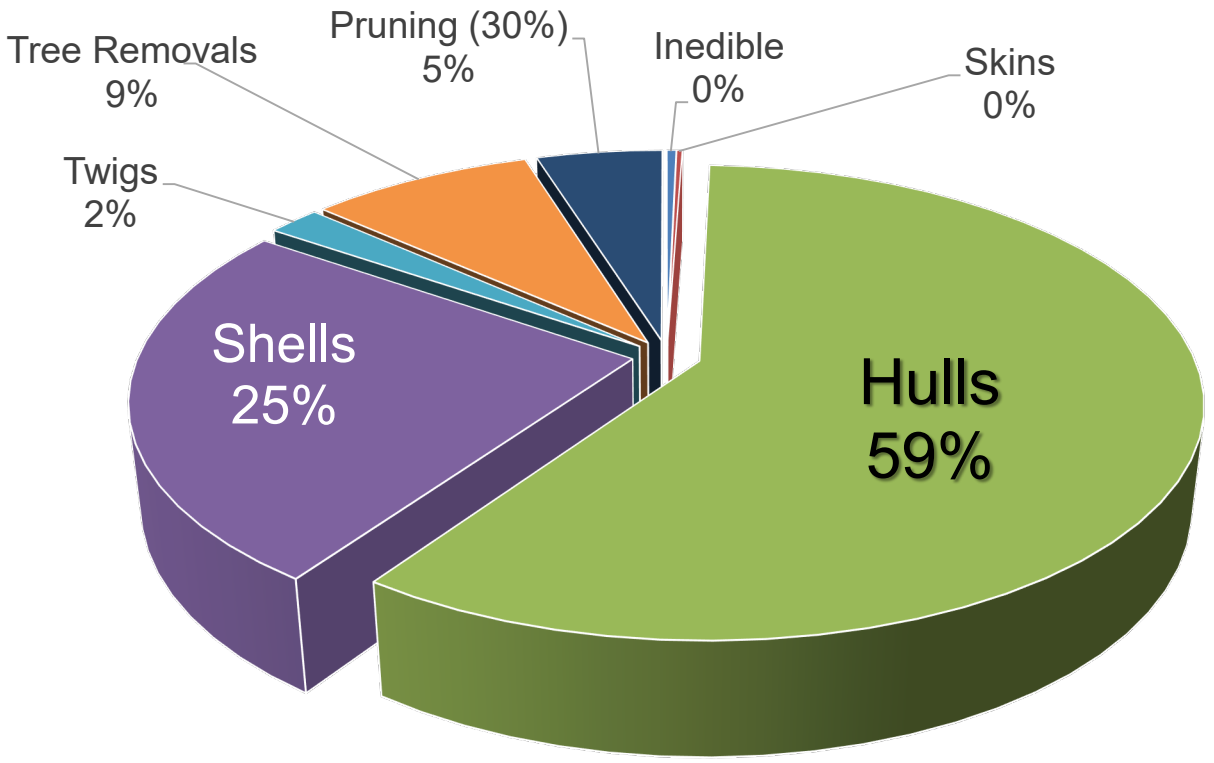
Guangwei Huang

Bor-Sen Chiou

Zach McCaffrey

Carl Eidsath & Steve Lindsay

Almond Biomass Estimation

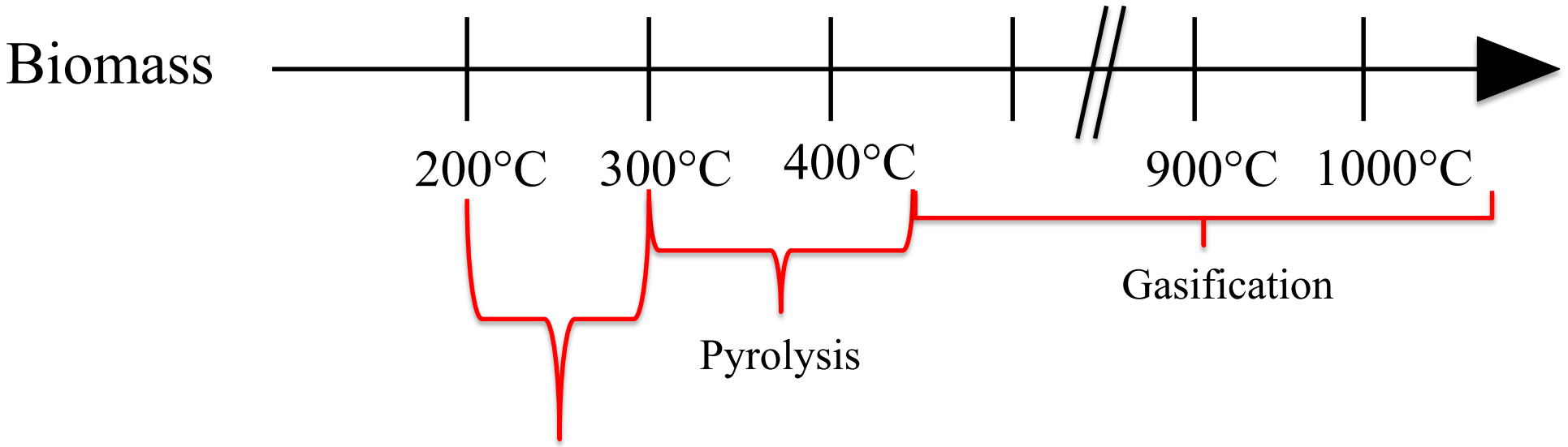


2017 Almond Biomass (2.5 million tons)

USDA

Guangwei Huang, ABC

Torrefaction, Pyrolysis & Gasification



Torrefaction

Densifies the biomass

Removes moisture and volatiles

USDA

Torrefied Almond Shells

230°C

260°C

290°C

60 min 80 min 100 min

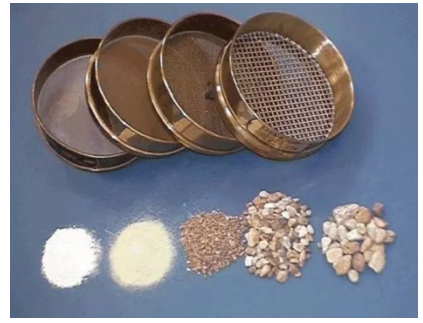
Composite Processing

Almond shells

Milling to 5mm

Torrefaction

Fine Milling



S

M

L

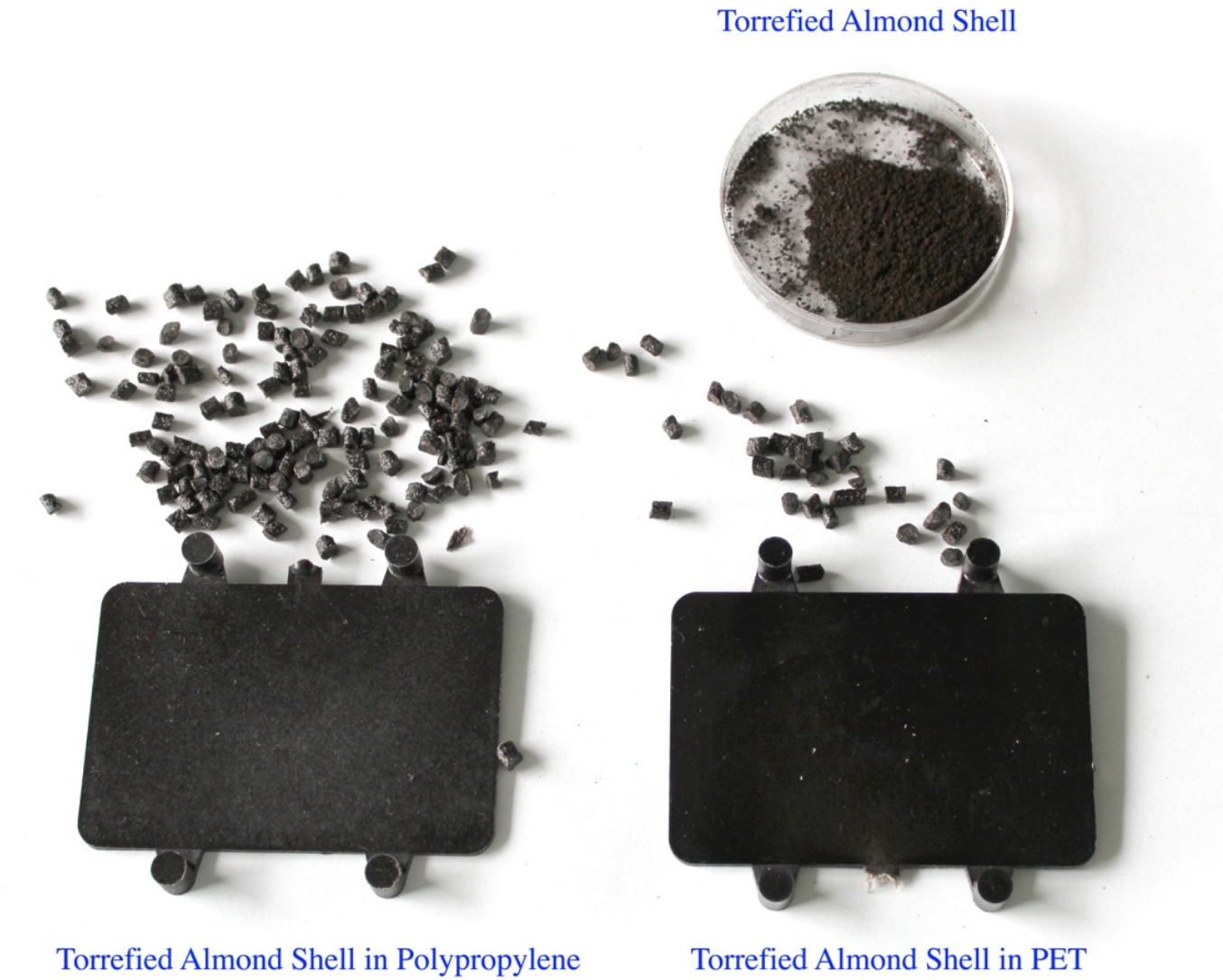
Sieving

Recycled plastic (Ecoplast)

Press

USDA

Torrefied Biomass-Polymer Composites



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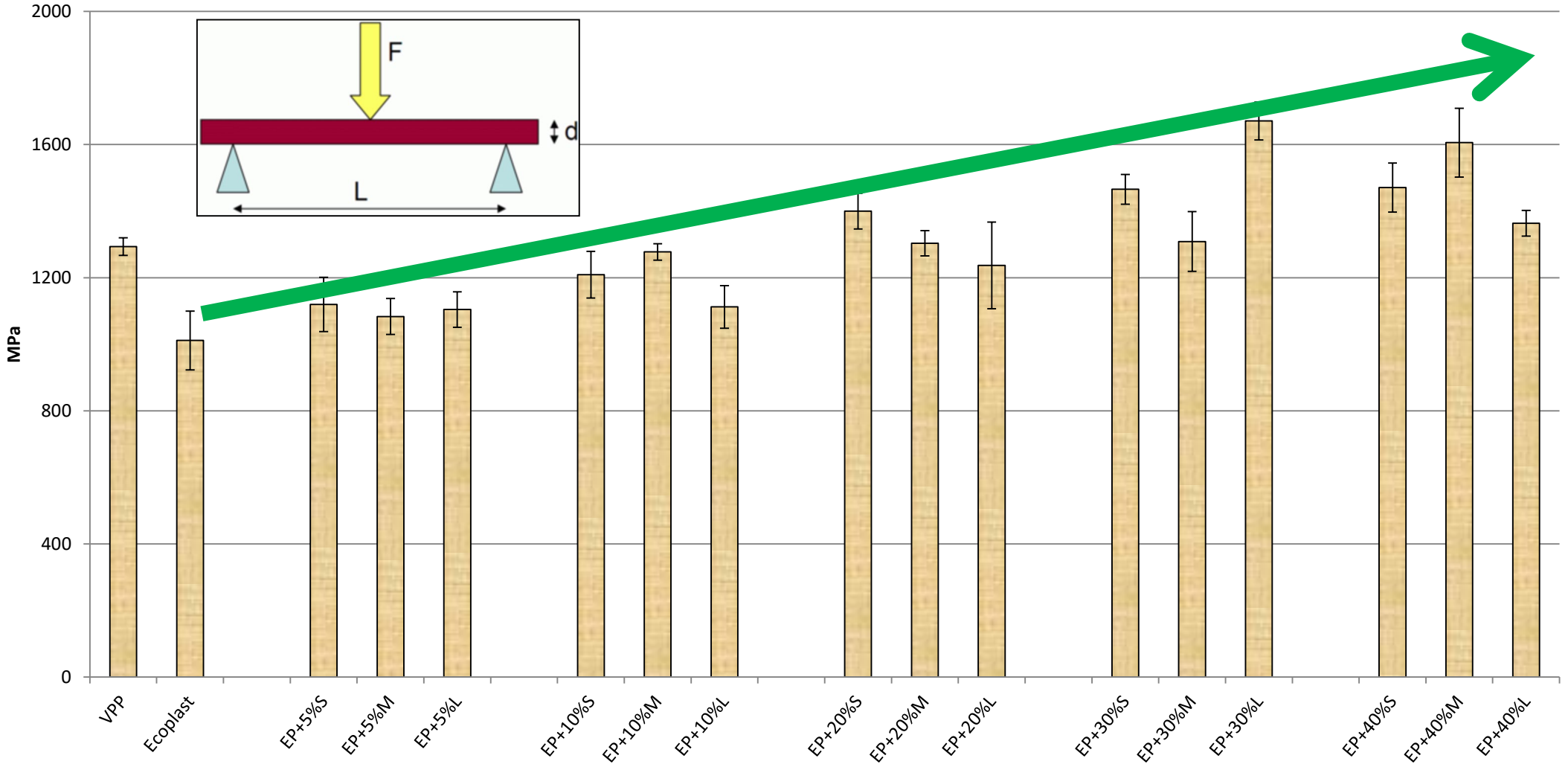
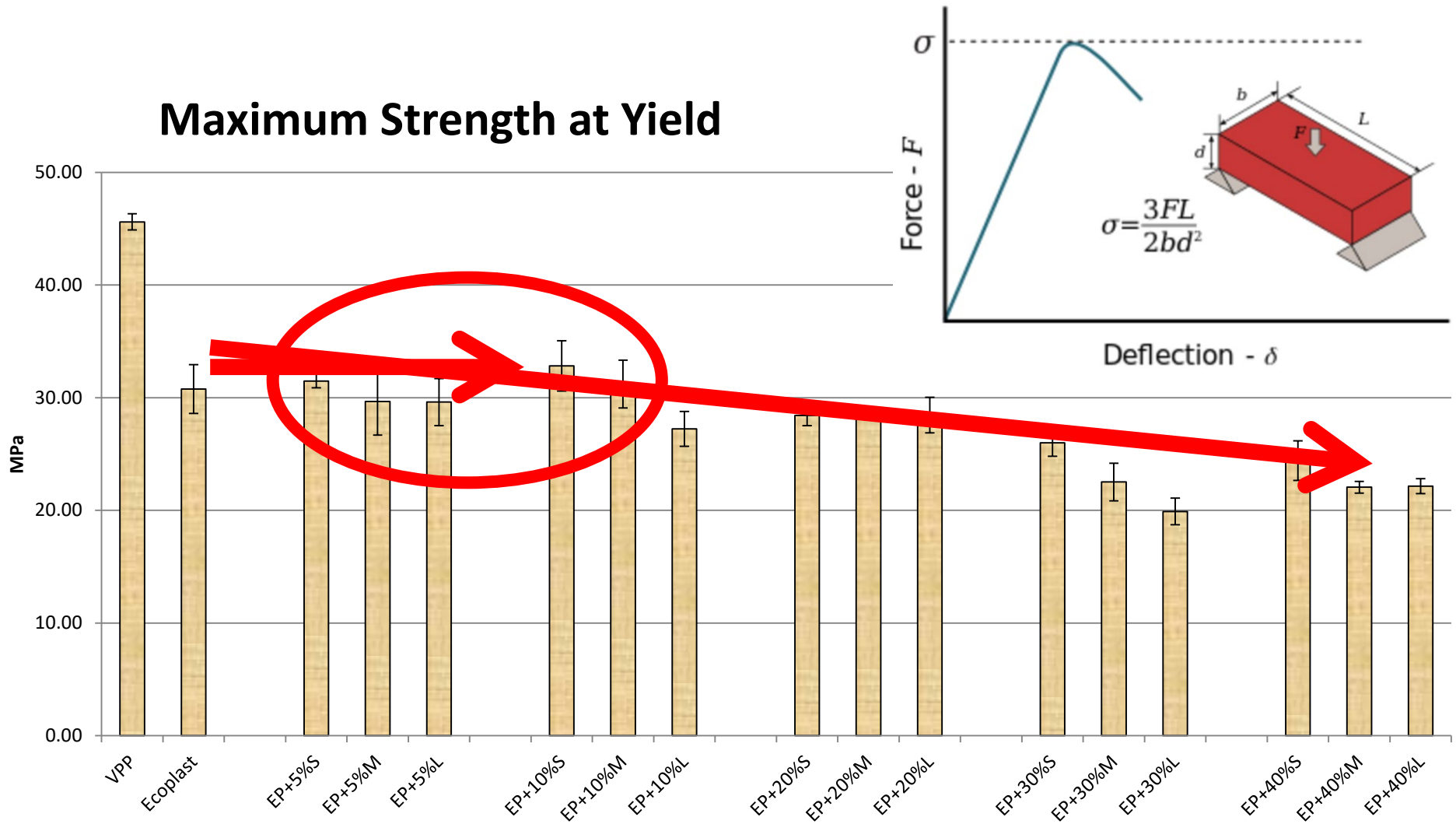
Mechanical Properties

Modulus



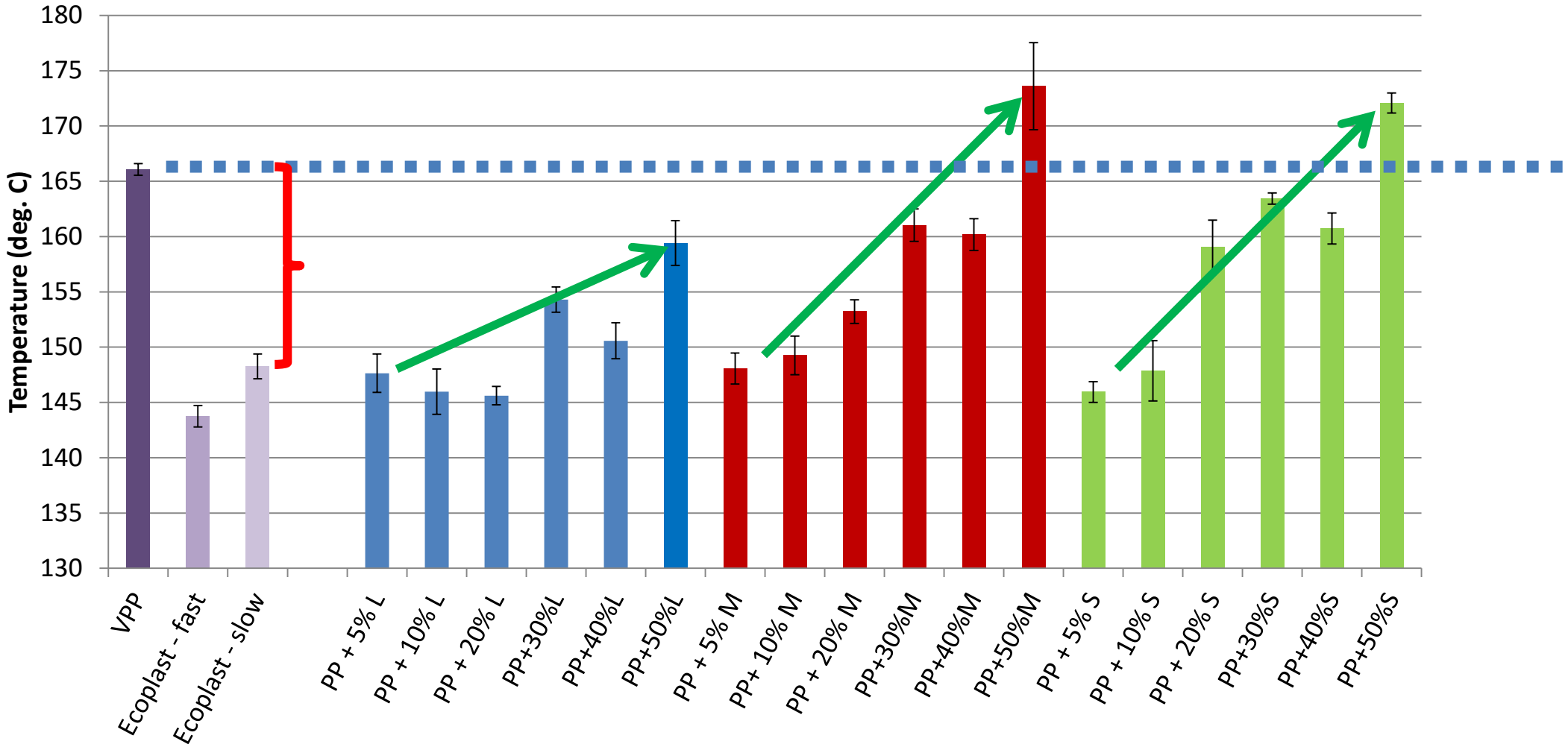
>> Higher loading produces stiffer material. Particle size has no effect.

Mechanical Properties



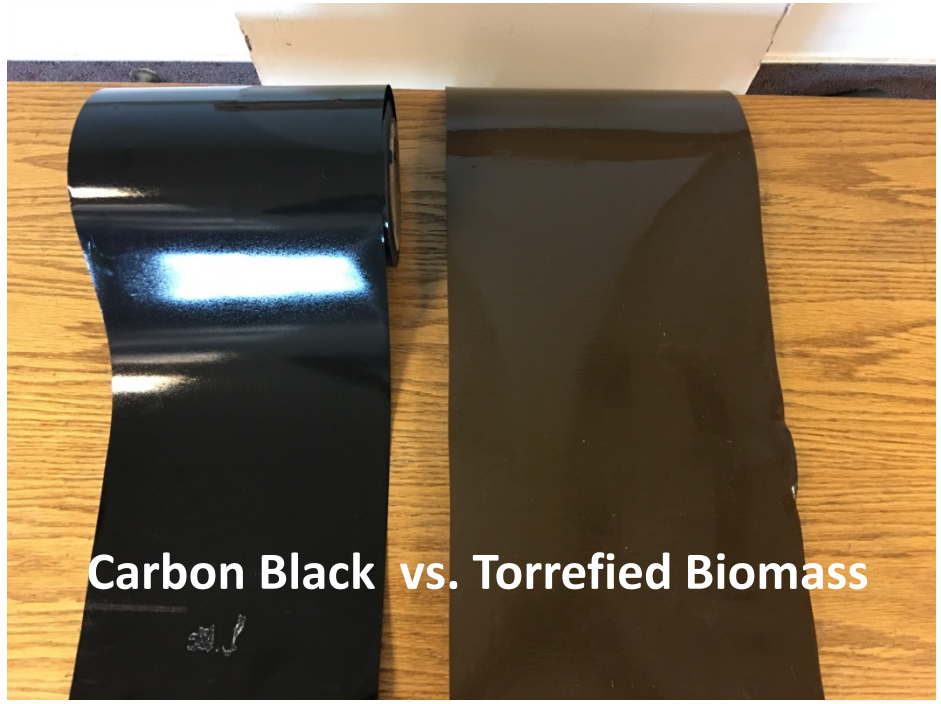
>> Higher loading produces lower maximum strength. Particle size has no effect.

HDT by Particle Size



>> Smaller size particles increase HDT >> Higher % loading increase HDT

Extrusion at the USDA



- Retrofit of our 18mm extruder.
- Can now make high quality sheet
- A potential commercial partner has been found for compounding sheets.

USDA

Torrefied Biomass in Plastics

F-D-S Manufacturing Co. Since 1950

Sullivan Grosz
Almond Leadership Program

TRANPAK

Acknowledgements

- California Department of Food and Agriculture (Grant # SCB11021)
- RPAC Almonds for donating almond shells

Scaling Up Torrefied Almond Shells

By Sullivan Grosz

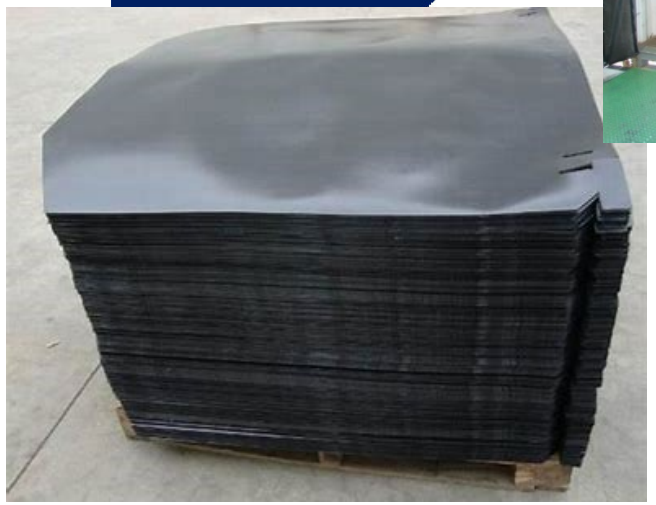
california almonds
Almond Board of California

Moving Train

New TAS Trials

- TranPak – Domestic supplier of plastic pallets & bins
  - Toured on February 5,th
- Repsco – Global manufacturer of LDPE slip sheets
  - Toured on May 25th

REPSCO



Slip Sheets

TRANPAK

Defining Plastic Pallets

Tranpak Trial #1 – August 21, 2018

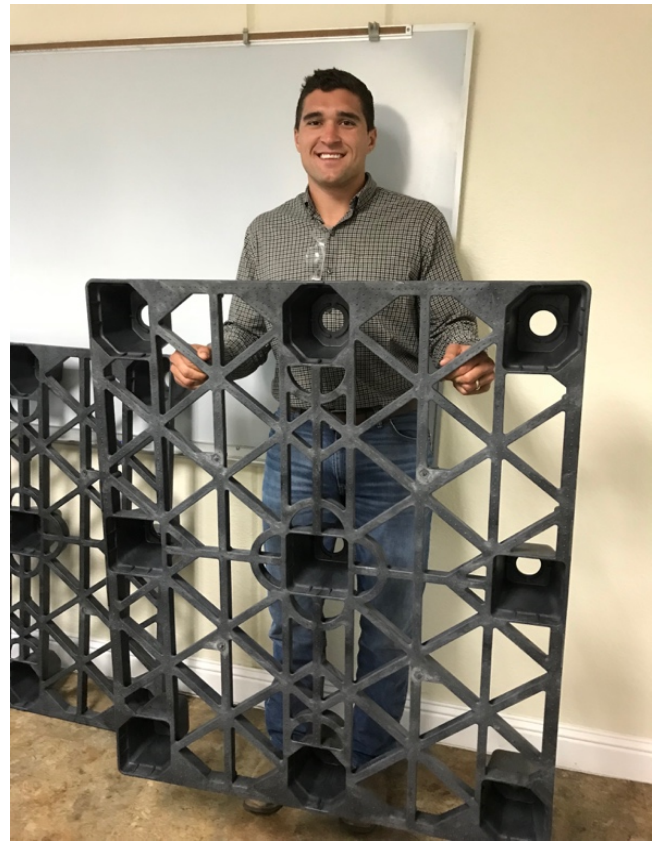
Materials

- 50lbs – 30% TAS & 70% recycled PP

Results

- 10 pallets at 6-7% torrefied
- Machine function – normal
- Pallets showed no change in pe
- Smells like bbq

Next Step???



Journey to Make Masterbatch Pellets from Almond Shells

Challenges for More Uses of Torrefied Shells – There is no 1 stop shop!

Cost examples to make small quantity of torrefied materials:

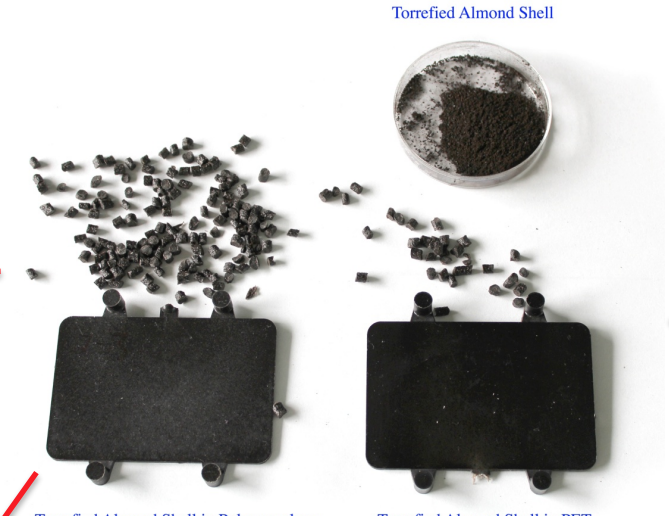
- Shipping shells from Modesto to Illinois for torrefaction $600
- Torrefaction of shells ...$6500 (two days run to make 1500lbs torrefied shells)
- Shipping torrefied shells for grinding from Illinois to Arkansas... $600
- Grinding of shells...$2000
- Shipping from Arkansas to Virginia or Oregon... $600
- Compounding cost… $3800 (2 days run)
- Shipping from compounding facility to end users… $600

Totalling almost $15,000!!!

Potential Applications of Torrefied Shells Being Explored

- Torrefied shells may be used as plastic filler and enhancer, black carbon replacer, etc.

Plastic lumber/decking with Trex



Irrigation equipment w/NDS

Planting Pots with FDS

Automotive Bins

Preliminary Techno-economic Analysis of Almond Shell Torrefaction

Ning Sun, Ling Liang, Gabriella Papa, Nawa Raj Baral, and Todd Pray

Research Scientist, Lawrence Berkeley National Laboratory

December 6, 2018 The Almond Conference

ABPDU's Mission

Partner with researchers from industry, the National Labs, and academia to optimize and scale technologies for bio-based chemicals / materials / fuels commercialization.

- Established by American Recovery and Reinvestment Act funds in 2009 – roughly $17 million invested in the 15,000 square foot bench-to-pilot demonstration Lab
- Managed by US DOE's Bioenergy Technologies Office (BETO) / Energy Efficiency & Renewable Energy (EERE)

Broad product, technology and industry collaborator base

ABPDU
ADVANCED BIOFUELS AND BIOPRODUCTS PROCESS DEVELOPMENT UNIT

Biofuels & biomass	Materials & chemicals	Food & health	Environment & Ag

Former contract partners

TOTAL COMMITTED TO BETTER ENERGY
AFINGEN
UNITED CATALYST
RHO Renewables, Inc.
ILLIUM TECHNOLOGIES
Sylvatex
Visolis
ardra
zymergen
Pareto Biotechnologies
Mosaic Materials
Kiverdi
LYGOS
MANGO MATERIALS
HelioBioSys, Inc.
Es-BioSolutions, Inc
AMYRIS
Hampton Creek
Clara Foods
FATER S.p.A.
Recology WASTE ZERO
Aequor

Ongoing

Microvi BIOTECHNOLOGIES
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ZYMOCHEM
GINKGO BIOWORKS™ THE ORGANISM COMPANY
greenlight BIOSCIENCES
KALION, INC.
Bolt Threads
CHECKERSPOT DESIGNED MATERIALS INNOVATION
INDIE BIO
Perfect Day
GELTOR
SUGARLOGIX
RIPPLE FOODS
assembly biosciences
inocucor
Allied Microbiota

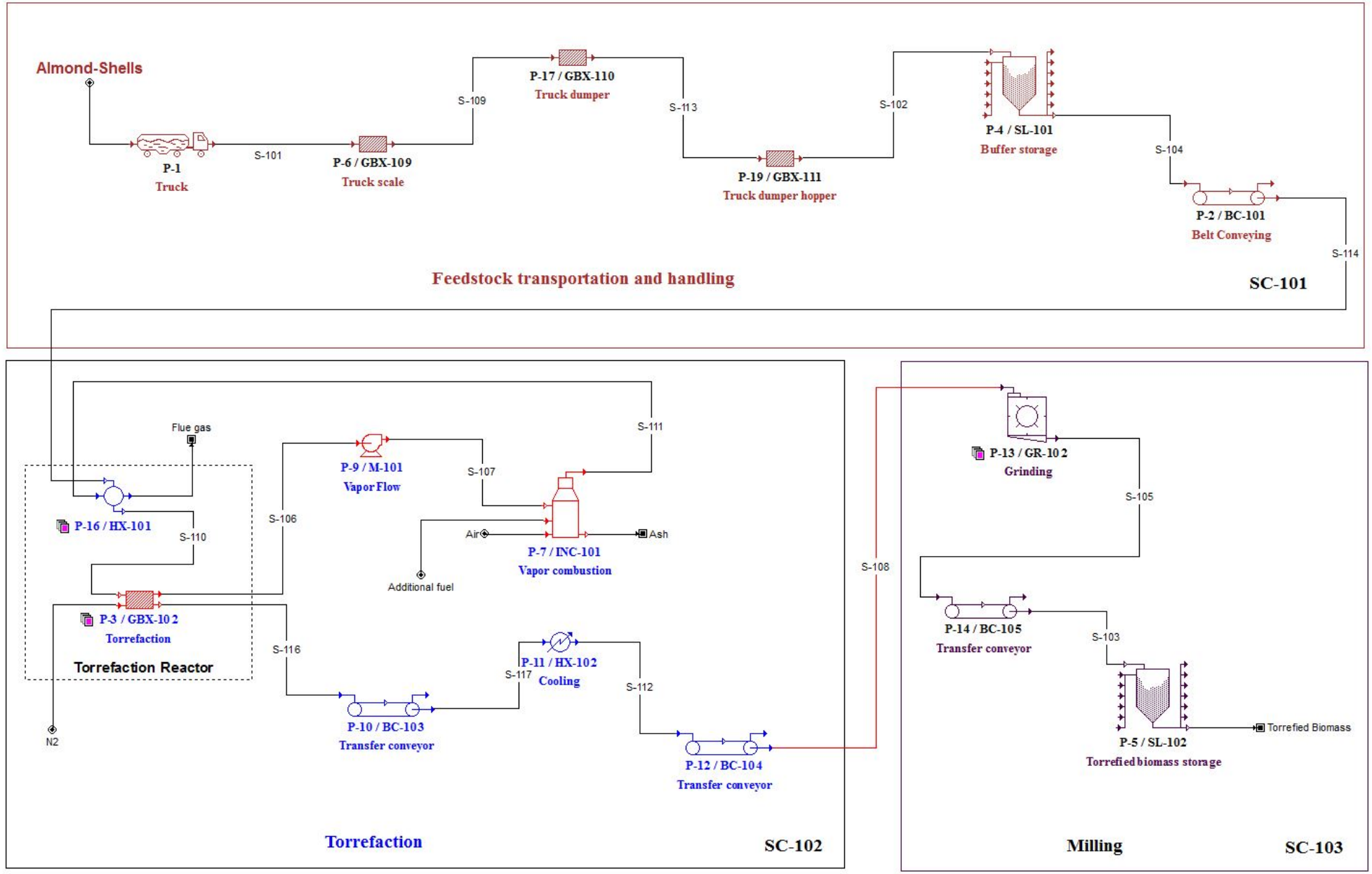
california almonds Almond Board of California

Project Introduction

- Berkeley Labs in collaboration with Almond Board of California and United States Department of Agriculture (USDA) in Albany, CA

- Software: SuperPro Designer
- Three case studies with different plant sizes

Almond Shell Torrefaction Process Flow



Torrefaction Process Parameters for Modeling

Temperature	**(°C)**	**250**
Duration	**(min)**	**30**
Torrefaction yield of solid	**(%)**	**50%**
Torrefaction yield of vapor	**(%)**	**50%**
Energy density before	(MJ/kg)	19
Energy density after	(MJ/kg)	25
Nitrogen purge before reaction	(min)	20
Average density of shells, at 20 °C, 1 atm	(kg/m^3)	0.20
Density of milled shells/hulls, at 20 °C, 1 atm	(kg/m^3)	0.43

- Torrefaction of biomass involves heating between 200 ~ 300 °C for 1 hour or less. This removes most moisture and volatile components.
- Biomass after torrefaction can be used as a filler in polymer composites
- According to USDA report, the filler concentrations were 5, 10, and 20% (w/w). The filler sizes were 163, 854, and 1545 um.

Processing Plant Size Selection

Category	Flow	Unit	Whole industry	Satellite center	Medium size plant	Small size plant
Yearly	Mass Flow	(MT/yr)	520,000	200,000	50,000	10,000
Yearly	Mass Flow	(lb/yr)	1,146,392,000	440,920,000	110,230,000	22,046,000
Daily	Mass Flow	(MT/day)	1,576	606	152	30
Daily	Mass Flow	(lb/day)	3,473,915	1,336,121	334,030	66,806
Hourly	Mass Flow	(MT/h)	66	25	6	1.3
Hourly	Mass Flow	(lb/h)	144,746	55,672	13,918	2,784
Number of plants needed	/	(EA)	1	2.6	10.4	20.0
Farm land coverage	/	(acre)	1,330,000	511,538	127,885	25,577

Economic Evaluation Case 1:

Satellite Processing Centers 200,000 MT/year

Key Assumptions for Each Plant

- **Plant site selection**
- ideally close to large almond handlers
- capacity: 200,000 dry MT/year, 24 hours/day, 330 days per year
- feedstock shipping distance: <140 miles per round trip, with 70-mile collection radius

- **Feedstock transportation and handling**
- quantity per shipment: 20 dry MT
- frequency: 10,000 shipments per year
- almond shells process flow rate: 25 MT/hour
- 4 drivers per 8 hour shift, depend on distance

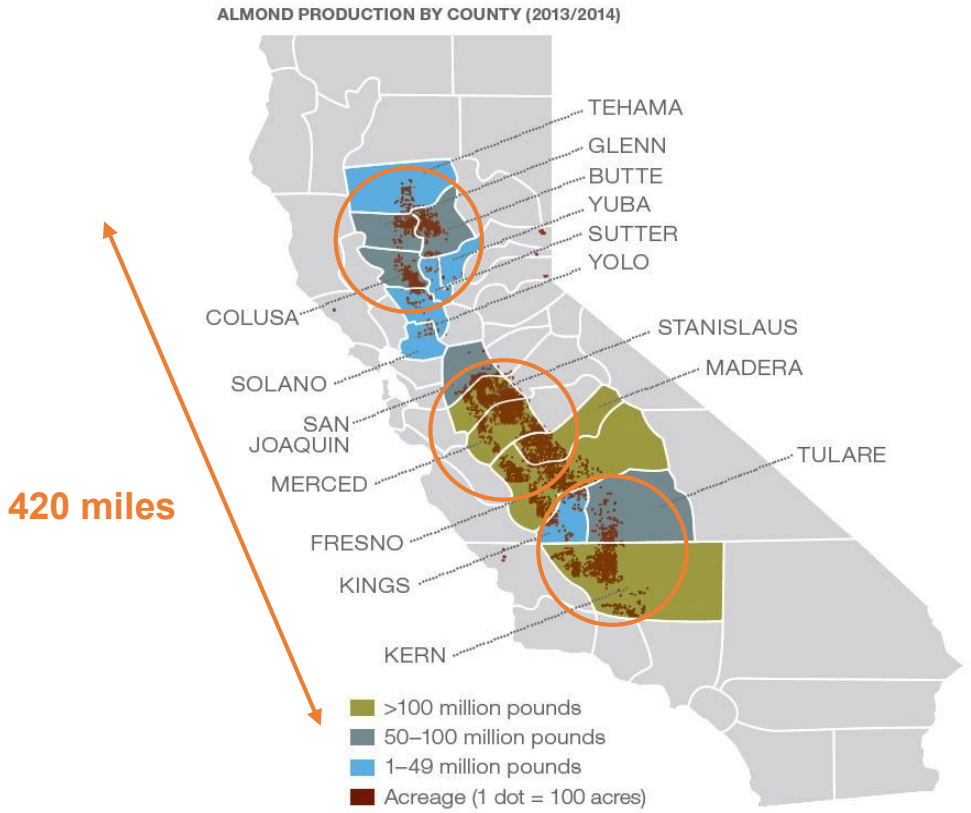
- **The torrefaction process**
- 9 reactors for torrefaction
- rated throughput: 3 MT/hour each, 24 hours/day
- mass yield : 50 % torrefied biomass, 50% vapor
- Nitrogen: 10 kg/h, 80 MT/year
- 2 technical staff per 8 hour shift
- vapor is utilized to generate heat

- **Milling/grinding/size reduction**
- 2 reactors
- rated throughput: 10 MT/hour each, 24 hours/day
- 2 technical staff per 8 hour shift

Satellite Processing Centers

- In total **3 satellite centers** (northern, central valley, southern) can process the whole industry's 520,000 metric ton (MT) almond shells. The annual production is projected to increase.
- Feedstock is assumed to be delivered to the satellite storage near the plant, each storage/plant represents a **70-mile** feedstock collection radius. Assuming 100% of the feedstock within that radius was available to the plant. The satellite plant size in present design is: 200,000 dry metric ton/year, (606 metric ton/day). With 12-months operation per year (24 hour/day).

Category	Unit	Whole industry	Satellite process center
Yearly	(MT/yr)	520,000	200,000
Yearly	(lb/yr)	1,146,392,000	440,920,000
Daily	(MT/day)	5,778	606
Daily	(lb/day)	12,737,689	1,336,121
Hourly	(MT/h)	722	25
Hourly	(lb/h)	1,592,211	55,671
Farm land coverage	(acre)	1,330,000	511,538



Economic Evaluation - Almond Shells Torrefaction

Executive Summary (2018 prices)	
Total Capital Investment	17,849,000 $
Operating Cost	17,217,000 $/yr
Revenues from torrefied biomass	18,839,000 $/yr
Unit Production Cost	173.64 $/MT MP
Selling price of torrefied biomass	**190** $/MT
Gross Margin	8.61 %
Return On Investment	13.88 %
Payback Time	7.20 years

Preliminary Data for Discussion Only

Economics for 330 Days of Operation/year

SUMMARY PER COST ITEM (Entire Process)				
Cost Item	**$/MT MP**	**$/day**	**$/year**	**%**
Raw Materials	100.30	30,137	9,945,223	57.77
Facility	19.64	5,901	1,947,389	11.31
Labor	22.64	6,801	2,244,471	13.04
Consumables	0.00	0	0	0.00
Lab/QC/QA	0.54	163	53,672	0.31
Utilities	12.38	3,720	1,227,558	7.13
Waste Trtmt/Disp	0.00	0	0	0.00
Transportation	18.14	5,449	1,798,303	10.45
Miscellaneous	0.00	0	0	0.00
TOTAL	173.64	52,172	17,216,616	100.00

SUMMARY PER SECTION				
Section	**$/MT MP**	**$/day**	**$/year**	**%**
Transportation	124.72	37,474	12,366,472	71.83
Torrefaction	24.47	7,352	2,426,126	14.09
Post Milling	13.38	4,021	1,326,823	7.71
Vapor combustion & heat recover	11.07	3,325	1,097,196	6.37
TOTAL	173.64	52,172	17,216,616	100.00

Torrefied shell cost: $ 173.64/MT

Potential cost cut in:

- Transportation-shorter distance
- Labor – more automation, fewer operators, fewer drivers
- Shell purchase price – from $50 to $20 per MT
- Scale up – from 200,000 to 500,00 MT/yr

Economic Evaluation Case 2

Medium Size Plants - 50,000 MT/yr

Modified Assumptions for 50K MT Plant - Case 2

- **Plant site selection**
- closer to large almond handlers
- capacity: **50,000** dry MT/year, 24 hours/day, 330 days per year
- feedstock shipping distance: <70 miles per round trip, with **35**-mile collection radius

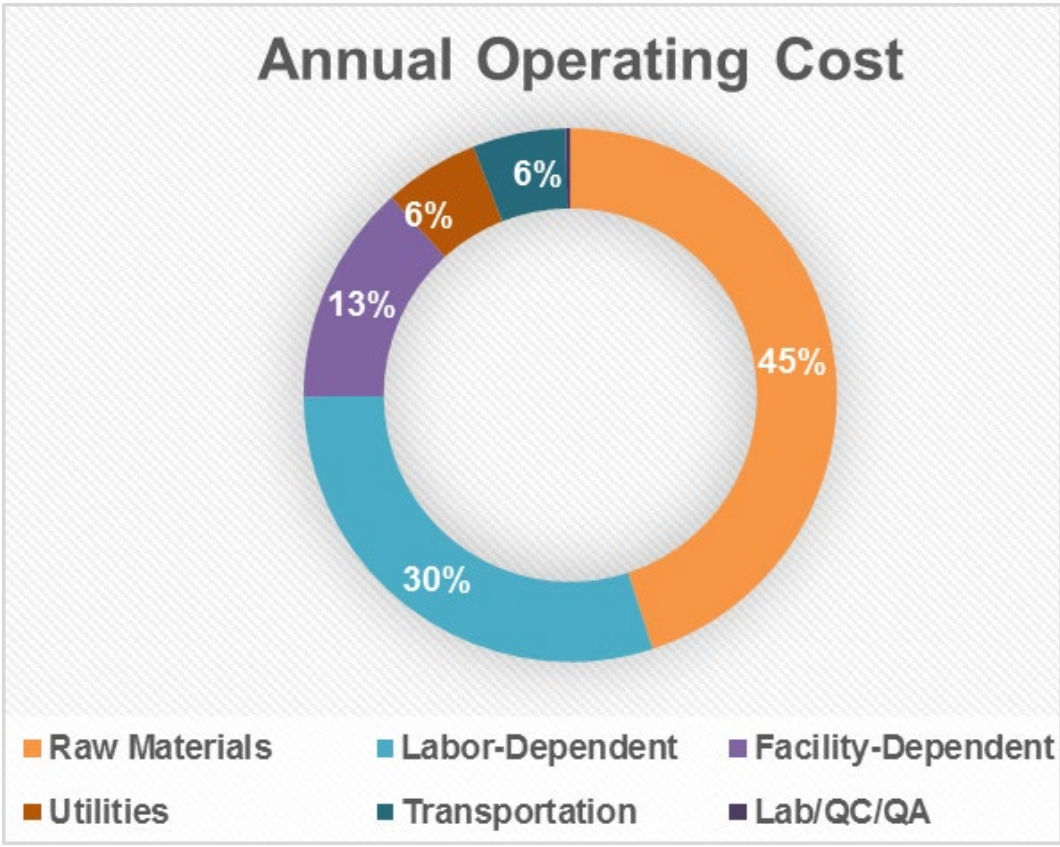
- **Feedstock transportation and handling**
- quantity per shipment: 20 dry MT
- frequency: **2,500** shipments per year
- almond shells process flow rate: **6** MT/hour
- **2** drivers per day, depend on distance

- **The torrefaction process**
- **3** reactors for torrefaction
- rated throughput: 2 MT/hour each, 24 hours/day
- mass yield : 50 % torrefied biomass, 50% vapor
- Nitrogen: 2.5 kg/h, 20 MT/year
- **1** technical staff per 8 hour shift
- vapor is utilized to generate heat

- **Milling/grinding/size reduction**
- **1** reactor
- rated throughput: 2.83 MT/hour each, 24 hours/day
- **1** technical staff per 8 hour shift

Economic Evaluation - Case 2

Executive Summary (2018 prices)	
Total Capital Investment	6,052,000 $
Operating Cost	5,002,000 $/yr
Revenues from torrefied biomass	5,653,000 $/yr
Unit Production Cost	222.98 $/MT MP
Selling price of torrefied biomass	**252** $/MT
Gross Margin	11.52 %
Return On Investment	14.95 %
Payback Time	6.69 years



Preliminary Data for Discussion Only

Economic Evaluation Case 3

Small Size Plants - 10,000 MT/yr

Modified Assumptions for 10K MT/yr Plant - Case 3

- **Plant site selection**
- capacity: **10,000** dry MT/year, 24 hours/day, 330 days per year
- feedstock shipping distance: <70 miles per round trip, with 35-mile collection radius

- **Feedstock transportation and handling**
- quantity per shipment: 20 dry MT
- frequency: **500** shipments per year
- almond shells process flow rate: **1.2** MT/hour
- **1** driver per day

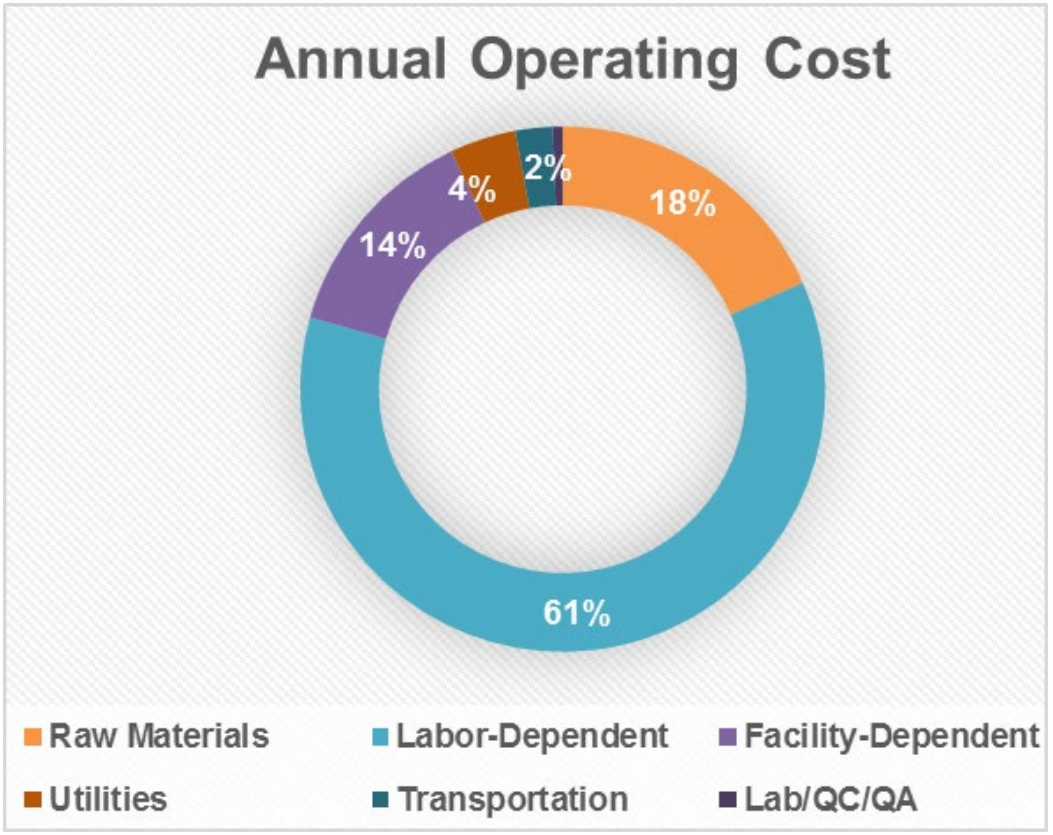
- **The torrefaction process**
- **1** reactors for torrefaction
- rated throughput: 1.2 MT/hour each, 24 hours/day

- mass yield : 50 % torrefied biomass, 50% vapor
- Nitrogen: 0.5 kg/h, 4 MT/year
- **1** technical staff per 8 hour shift
- vapor is utilized to generate heat

- **Milling/grinding/size reduction**
- **1** reactor
- rated throughput: 0.6 MT/hour each, 24 hours/day
- **1** technical staff per 8 hour shift

Economic Evaluation - 10K MT/yr Plant

Executive Summary (2018 prices)	
Total Capital Investment	3,116,000 $
Operating Cost	2,451,000 $/yr
Revenues from torrefied biomass	3,769,000 $/yr
Unit Production Cost	546.30 $/MT MP
Selling price of torrefied biomass	**639** $/MT
Gross Margin	14.51 %
Return On Investment	16.52 %
Payback Time	6.05 years



Preliminary Data for Discussion Only

Summary of the Models

Executive Summary (200,000 MT/yr)	
Total Capital Investment	17,849,000 $
Operating Cost	17,217,000 $/yr
Revenues from torrefied biomass	18,839,000 $/yr
Unit Production Cost	173.64 $/MT MP
Selling price of torrefied biomass	**190** $/MT
Gross Margin	8.61 %
Return On Investment	13.88 %
Payback Time	7.20 years

Executive Summary (50,000 MT/yr)	
Total Capital Investment	6,052,000 $
Operating Cost	5,002,000 $/yr
Revenues from torrefied biomass	5,653,000 $/yr
Unit Production Cost	222.98 $/MT MP
Selling price of torrefied biomass	**252** $/MT
Gross Margin	11.52 %
Return On Investment	14.95 %
Payback Time	6.69 years

Executive Summary (10,000 MT/yr)	
Total Capital Investment	3,116,000 $
Operating Cost	2,451,000 $/yr
Revenues from torrefied biomass	3,769,000 $/yr
Unit Production Cost	546.30 $/MT MP
Selling price of torrefied biomass	**639** $/MT
Gross Margin	14.51 %
Return On Investment	16.52 %
Payback Time	6.05 years

Preliminary Data for Discussion Only

Capital Investment Breakdown Comparison

Capital Cost Summary (200,000 MT/yr)	
Section Name	**DFC ($)**
Torrefaction	5,794,000
Milling	5,651,000
Vapor combustion	4,392,000
Direct Fixed Capital Cost	**15,838,000**
Working Capital	1,220,000
Startup Cost	792,000
Total Investment	**17,849,000**

Capital Cost Summary (50,000 MT/yr)	
Section Name	**DFC ($)**
Torrefaction	2,144,000
Milling	1,681,000
Vapor combustion	1,589,000
Direct Fixed Capital Cost	**5,415,000**
Working Capital	367,000
Startup Cost	271,000
Total Investment	**6,052,000**

Capital Cost Summary (10,000 MT/yr)	
Section Name	**DFC ($)**
Torrefaction	1,151,000
Milling	1,106,000
Vapor combustion	534,000
Direct Fixed Capital Cost	**2,791,000**
Working Capital	186,000
Startup Cost	140,000
Total Investment	**3,116,000**

Thank you!

http://abpdu.lbl.gov/
nsun@lbl.gov

Fun Video ☺

(https://www.youtube.com/watch?v=YdJ87OQHu-k)


Almond Leadership Program
Applications due 12/7/18
Visit the Almond Board booth to learn more