SUSTAINABLE BIOECONOMY FOR ARID REGIONS (SBAR)

Continuation Justification – June 2018

USDA-NIFA, Agriculture and Food Research Initiative
Competitive Grant No. 2017-68005-26867

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PREAMBLE & DISCLAIMER

This continuation justification and summary report was prepared by the University of Arizona and the Sustainable Bioeconomy for Arid Regions (SBAR) project research colleagues from New Mexico State University, Colorado State University, Colorado School of Mines, United States Department of Agriculture – Agricultural Research Service, and Bridgestone Americas, Inc. in the course of performing academic research supported by the USDA Agricultural and Food Research Initiative Competitive Grant No. 2017-68005-26867 from the United States Department of Agriculture National Institute of Food and Agriculture (USDA-NIFA).

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ACCOMPLISHMENTS
September 2017 – May 2018

Introduction and Project Administration

General Overview: Project Organization
The Sustainable Bioeconomy for Arid Regions (SBAR) Center receives project direction and oversight from Dr. Kimberly Ogden, who leads the overall research effort and ensures adequate progress toward meeting identified project goals. An SBAR Project Director (Alix Rogstad) was hired in November to handle project administration and business affairs as well as coordination, communication, and data sharing among partnering organizations and institutions. Other project responsibilities handled by Rogstad include: day-to-day project management; planning and preparation of reports; organizing and coordinating meetings; ensuring data sharing and management; maintenance of the project's website and social media accounts; and managing all project financial activities, including the development and implementation of administrative protocols to ensure effective financial operation and oversight of the project.

Advisory Board
Upon notification of award, Ogden initiated conversations with a number of potential scientific mentors - representing industry, grower, extension, and education sectors – to determine availability and interest in serving in an Advisory role for the project. Advisory Board recruitment was completed in January 2018 (Appendix 1), and consists of 17 members representing all facets of building a sustainable bioeconomy in the Southwest. Progress is underway to identify ways to engage the Advisory Board in a productive way, and in a manner that provides relevant feedback for SBAR implementation.

Project Kick-off
In anticipation of project funding arrival, a project kick-off meeting was hosted 30 August 2017 at the University of Arizona in Tucson, Arizona (Photo 1). During this meeting, each of the project component leaders were identified, component partners met to determine implementation details, confirm research schedules, and set working group meeting cadence.

Photo 1. *SBAR Team at the project kick-off meeting, August 2017.*

Budget and Financial Management
Funding was received by the University of Arizona in early September 2017, at which time the sub-award initiation process commenced for partners to receive grant funds. To date sub-awards have been fully activated with New Mexico State University (NMSU), Colorado State University (CSU), and the USDA-Agricultural Research Service (USDA-ARS); sub-awards with Bridgestone Americas, Inc. and Colorado School of Mines are still pending.

Sub-award activation has been slower than anticipated, which has resulted in slight delays in hiring supporting staff, students, and technicians for some components at two facilities (USDA-ARS, and NMSU).

LEADS Team Meetings

The seven component leaders and co-leaders (LEADS) meet with Ogden and Rogstad during a regularly scheduled twice monthly meeting held via SBAR's dedicated Zoom online meeting space. This virtual meeting allows for documents to be viewed by all, which enhances communication and dialogue among participants, and facilitates group decision-making. Other necessary communication with the LEADS Team is conducted primarily via email.

Component Working Group Meetings

All five SBAR component working groups participate in scheduled online meetings. The Feedstock Development & Production component holds multiple meetings to address feedstock differences for guayule and guar; and the Extension & Outreach component holds multiple meetings to address youth development (4-H) and grower extension needs separately (as these require different implementation mechanisms). Some working groups or smaller focus groups meet more frequently to facilitate and integrate research and extension progress. Meeting cadence will be adjusted as needed to accommodate research and training needs.

2018 SBAR Annual Retreat

Advance planning is underway for the inaugural SBAR Annual Retreat, which will occur Wednesday – Friday, 1-3 August, at the University of Arizona in Tucson. Specialized working group meetings are set for Wednesday, with a robust full-group meeting agenda to follow. (Appendix 2). A participant evaluation is in preparation to obtain participant feedback regarding the Retreat so that subsequent Annual Retreats may be improved.

We anticipate over 80 participants at the 2018 Annual Retreat, including most of the Advisory Board. Twenty (20) undergraduate and graduate students will attend the meeting, with 19 presenting posters for on-going project-related research. We will also have 4 posters presented by *Project Puente* interns who conducted SBAR project research during the summer.

Communication and Reporting

Reporting schedules and tools were initially developed in October/November 2017 and were refined in December 2017 to aid in project management, accomplishment tracking, and self-evaluation of progress toward goals (Appendix 3), and an Authorship Guidelines document was approved by the LEADS in February to facilitate future project-related authorship decisions (Appendix 4).

Website and Social Media

An SBAR Project website (www.sbar.arizona.edu) has been created and officially launched in May 2018 to serve both the needs of project collaborators and the interested general public. The website showcases each project component and will continue to be refined as research gets fully underway. There are three main website goals:

- Serve the needs of the SBAR Research Team by providing a repository of information that can be easily shared across project components;

- Provide a mechanism for advertising and announcing SBAR-related accomplishments, events, activities and student/K-12 teacher opportunities; and
- Allow the interested public maximum access to the research effort underway.

The website is used to disseminate research updates, fact sheets, Extension learning modules/outreach materials, K-12 biofuel learning modules, articles, and webinars. We also use the site to promote SBAR events and activities such as summer youth biofuel camps, graduate student fellowships, the UA bioenergy certification program, educational meetings, and networking opportunities.

Additionally, SBAR-related research results and activities will be showcased through the University of Arizona's *Institute for Energy Solutions* newsletter and social media networks.

- Instagram: UA Institute for Energy Solutions
- Twitter: @UA_IES
- Facebook: UA Energy Solutions
- YouTube Channel: Energy Solutions

Project Marketing Materials

In an effort to widely announce the SBAR project, an informational card entitled "Sustainable Bioeconomy for Arid Regions" was produced in December 2017 (Appendix 5), and immediately made available for wide dissemination through tabling events in Arizona, New Mexico, California, and in Washington D.C. Info Cards were also distributed through project researchers at their home institutions. Three (3) basic factsheets were also generated to provide specific guayule and guar information (Appendix 6).

To increase public visibility at tabling events, a retractable banner (Photo 2) was designed and distributed to key members of the Extension & Outreach component for their use in Arizona and New Mexico. An additional banner is available to all project collaborators and graduate student fellows through a check-out process to ensure banner accessibility and tracking/ documentation for its use.

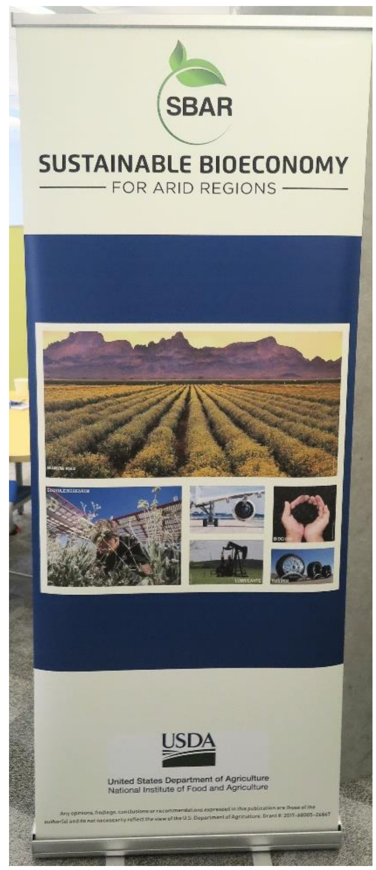


Photo 2. *SBAR display used for tabling events.*

Feedstock Development & Production

Executive Summary

The Feedstock Development and Production Team focuses on improving biomass quantity and quality through traditional breeding and high-throughput phenotyping characteristics; improving agronomic production practices for guayule and guar; developing comprehensive and broadly applicable irrigation apps; and developing soil quality and soil health knowledge for long-term environmental sustainability. In 2018, the research team concentrated efforts on the establishment of guayule and guar stands for evaluation field trials, and conducted lab analysis of existing samples to isolate flowering genes.

Component Leaders

- **Dennis T. Ray**, University of Arizona | dtray@email.arizona.edu | 520.621.7612
- **Colleen McMahan**, USDA-Agricultural Research Service – Western Regional Research Center | colleen.mcmahan@ars.usda.gov | 510.559.5816
- **Peter Waller**, University of Arizona | pwaller@email.arizona.edu | 520.440.5803

Other Key Collaborators

- **David Dierig**, Bridgestone Americas
- **Sangamesh Angadi**, New Mexico State University
- **Kulbhushan Grover**, New Mexico State University
- **Raina Maier**, University of Arizona
- **William McCloskey**, University of Arizona
- **Duke Pauli**, University of Arizona
- **Hussein Abdel-Haleem**, USDA-ARS – U.S. Arid Lands Research Center

Other Personnel

- **Bridgestone Americas –** Stefan Dittmar, Amber Lynch, Mark Von Cruz, and Sam Wang
- **New Mexico State University –** Sultan Begna and Jagdeep Singh
- **University of Arizona –** Nick Ashley, Megan Bennett, Kyle Brown, German Coronado, Diaa El-Shikha, Blase Evancho, Krista Farmer, Daryan Godfrey, Wolfgang Grunberg, Matthew Katterman, Kasia Kiela, Hadiqa Maqsood, Julie Neilson, Andrew Nelson, Bryan Pastor, Sam Pernu, Carl Schmalzel, Valerie Teetor, Quinn Waltz, John Willmon
- **USDA-ARS (WRRC) –** Niu Dong

Accomplishments – Year 1

- Field trial methodologies and protocols were determined for planting and establishment of guayule and guar, as well as sampling methodologies for soil health and environmental parameters.
- Guayule and guar irrigation field experiments were established in three (3) locations in Arizona and New Mexico to compare irrigation application methods and rates.
- The WINDS (irrigation) model was converted to python, and soil moisture probes, infrared cameras, and other sensors were programmed to provide feedback on irrigation, crop and soil status.
- Guayule and guar field trials were established in seven (7) different locations across Arizona and New Mexico for evaluating accession lines under varying conditions.

- Four (4) preemergence herbicide studies were initiated, using two (2) herbicide incorporation methods; five (5) herbicide application studies were started to examine topical application on guayule seedlings.
- Twenty-eight (28) unique candidate guayule genes were identified as promising targets for genetic modification of guayule to improve crop yield.

Planned Activities – Year 2

- Monitor growth of guayule and guar in seven (7) field trials across Arizona and New Mexico, including soil health and microbe sampling.
- Irrigation experiment results will be used to develop crop coefficients for guar in New Mexico.
- Continue to develop the WINDS app and automate the WINDS sensor and control system.
- Compile and generate/publish results from a variety of herbicide application studies on guayule.
- Genetically transform guayule to reduce flowering; evaluate plants in the laboratory.
- Screen guayule accessions for root rot resistance; add tolerant lines to the breeding programs.
- Cross two elite guar lines to partial male-sterile guar plants to develop new genetic combinations from which to make selections.

Explanation of Variance

No variance has been experienced and accomplishments are on schedule.

Objective 1. Improve biomass quantity and quality through genetics and traditional breeding.

Accomplishment Detail

- Being able to propagate guayule plants via cuttings is important to produce genetically pure lines of selected plants. Four lines (AZ-2, AZ-3, 593, R1100) were selected and the experiment was designed to evaluate different levels of the plant hormones IBA and NAA (including a mix of both and a control with no hormones added). The media was a 1:1 mixture of Coco coir and Perlite, and cuttings placed in a propagation greenhouse with a misting system and bottom heat.

  Guayule cuttings were scored from one to six: 0 – dead, 1 – no change, 2 – cell differentiation (but no rooting), 3 – root initiation, 4 – 1/3 of plug rooted, 5 – 2/3 of plug rooted, 6 – fully rooted plug. Rating scores were transformed to eliminate zeroes by adding one to each and adding the ten per rep/variety/treatment combination. There were no major significant differences between varieties. In many cases, the hormone treatments were not any different than plain water. Another experiment is underway with varying ratios of hormones and two varieties (AZ3 and 11693).

- To better screen lines for root rot resistance a second greenhouse experiment was initiated. Achenes/seed of lines 11591, AZ-1, AZ-2, AZ-5, and AZ-6 were treated and planted in 3.8 L pots in a greenhouse (using cotton as a control to check the inoculum). Five isolates of *P. omnivora* were collected from cotton roots in Marana, Arizona and sclerotia of each isolate produced. The lines were planted in a randomized complete block design, with 20 plants per line per replication (four replications). The experiment has just begun so no results to report at this time.

- Guayule biomass has been evaluated indirectly, since biomass is a destructive measure, by looking at height and width of plants (there is a high correlation of plant height with biomass production). Of the seven lines with the highest survival for heat and flooding, AZ-3 and AZ-2 had mean heights of about 49 cm. N566 and 11693 averaged about 34 cm in height, AZ-1 30 cm, and R1100 and R1101 a bit over 25 cm. There are certainly genes in these lines to improve guayule germplasm for heat tolerance, flooding resistance, and biomass production.

- The research team evaluated available germplasm from the USDA National Plant Germplasm System (NPGS) with respect to future use in the SBAR research. Sixty-eight (68) lines from the NPGS were identified for use in this project. Bridgestone hand cleaned all lines, completed 14-day laboratory germination tests, measured 100 seed weight, and estimated total seed number for planting amounts for all planting locations (Table 1). AZ-2 seed is provided by Bridgestone as a control at all field planting locations.

Table 1. *Results from germination tests and seed weights for 68 guayule accession lines.*

Line	Incoming Amount	HSW	Germ (7 Day)	Germ (14 Day)	Seed Amount (g)	Seed %	Est. Total Seed No.	Est. No. Plants[1]
11635	131.5	0.0627	53.3%	56.7%	89	67.68%	142021	**80526**
CAL1	1212	0.0321	8.7%	10.7%	184.53	15.23%	575457	**61574**
CFS21	459	0.0536	32.0%	56.0%	25	5.45%	46642	**26119**
PARL 917	390	0.0559	42.0%	44.0%	29.2	7.49%	52267	**22998**
PARL 919	181	0.0805	72.0%	72.0%	17.9	9.89%	22236	**16010**
PARL 920	274	0.0685	55.3%	55.3%	19.5	7.12%	28481	**15750**
PARL 916	171	0.0701	72.7%	73.3%	15	8.77%	21398	**15685**
CAL5	424	0.0421	15.3%	25.3%	25	5.90%	59382	**15024**
CAL7	538.5	0.0408	7.3%	10.7%	44.5	8.26%	109158	**11680**
CAL2	221	0.0355	10.0%	18.0%	22	9.95%	61972	**11155**
R1109	275	0.0391	14.7%	19.3%	21	7.64%	53754	**10375**
CFS18-2005	426	0.0364	9.3%	12.7%	29.1	6.83%	79945	**10153**
PARL 935	187	0.0478	56.0%	56.0%	7.1	3.80%	14843	**8312**
PARL 932	128	0.0655	80.0%	80.0%	6.4	5.00%	9771	**7817**
R1092	210	0.0490	40.7%	40.7%	8.6	4.10%	17563	**7148**
N565 II	219	0.0737	47.3%	49.3%	10.1	4.61%	13710	**6759**
R1093	331.5	0.0496	26.7%	27.3%	11.7	3.53%	23589	**6440**
PARL 923	248	0.0605	65.3%	77.3%	4.2	1.69%	6938	**5363**
PARL 921	221	0.0491	17.3%	18.0%	14	6.33%	28513	**5132**
11609	189.5	0.0458	22.7%	22.7%	9.2	4.85%	20102	**4563**

AZ5	129.5	0.0687	33.3%	34.0%	8.9	6.87%	12961	**4407**
593	198.5	0.0578	53.3%	61.3%	4.1	2.07%	7098	**4351**
PARL 922	131	0.0743	59.3%	59.3%	5.4	4.12%	7265	**4308**
11619	204	0.0498	28.0%	28.0%	6.9	3.38%	13865	**3882**
N576	199.5	0.0736	30.7%	40.7%	6.8	3.41%	9243	**3762**
R1110	96	0.0678	72.0%	72.0%	3.5	3.65%	5162	**3717**
11633	116.5	0.0527	17.3%	17.3%	6.9	5.92%	13093	**3666**
12231	177	0.0474	11.3%	15.3%	11.2	6.33%	23645	**3618**
11693	98	0.0516	31.3%	31.3%	5.7	5.82%	11054	**3460**
11646	117	0.0460	30.0%	33.3%	4.7	4.02%	10225	**3405**
11604	118.5	0.0744	87.3%	87.3%	2.9	2.45%	3898	**3403**
PARL 929	93	0.0731	52.7%	58.0%	4.1	4.41%	5609	**3253**
N396	185	0.0657	44.7%	48.0%	4.3	2.32%	6548	**3143**
11591	260.5	0.0745	42.0%	45.3%	5	1.92%	6708	**3039**
PARL 930	492	0.0462	4.0%	5.3%	25.9	5.26%	56101	**2973**
CAL3	90.5	0.0601	80.0%	80.7%	2.2	2.43%	3661	**2954**
R1103	2715	0.0530	34.0%	34.0%	4.5	0.17%	8485	**2885**
R1037	152	0.0482	10.0%	12.0%	11.5	7.57%	23859	**2863**
CFS24	101.5	0.0744	80.0%	80.0%	2.6	2.56%	3495	**2796**
AZ6	105.5	0.0791	80.7%	80.7%	2.69	2.55%	3399	**2743**
PARL 914	112.5	0.0833	70.0%	70.0%	3	2.67%	3600	**2520**
11605	137.5	0.0633	56.0%	61.3%	2.6	1.89%	4110	**2519**
N565	250	0.0585	14.7%	14.7%	9.6	3.84%	16410	**2412**
R1108	132.5	0.0474	22.7%	22.7%	4.5	3.40%	9500	**2157**
R1040	201	0.0466	16.7%	16.7%	5.1	2.54%	10936	**1826**
PARL 931	500	0.0417	2.0%	2.7%	28.2	5.64%	67626	**1826**
PARL 934	245.5	0.0234	0.7%	2.0%	19.6	7.98%	83880	**1678**
R1096	140	0.0618	30.0%	30.0%	3.3	2.36%	5343	**1603**
4265-X	102.5	0.0724	54.0%	54.0%	3.4	3.32%	4698	**1560**
R1044	164.5	0.0545	69.3%	69.3%	1.2	0.73%	2202	**1526**
PARL 924	188	0.0537	39.3%	41.3%	1.9	1.01%	3540	**1462**
PARL 915	202.5	0.0759	78.7%	78.7%	1.4	0.69%	1845	**1452**
PARL 925	121.5	0.0495	20.0%	26.7%	1.6	1.32%	3232	**863**
PARL 933	181	0.0553	10.7%	10.7%	3.8	2.10%	6876	**736**
CFS17-2005	93.5	0.0659	53.3%	54.0%	0.7	0.75%	1062	**573**
PARL 928	256	0.0524	1.3%	2.0%	11	4.30%	20979	**420**
PARL 912	233.5	0.0420	0.7%	0.7%	10	4.28%	23810	**167**
PARL 918	189	0.0442	0.7%	0.7%	9	4.76%	20347	**142**
PARL 913	167.5	0.0403	0.0%	0.0%	5.6	3.34%	13896	**0**
AZ1	528	0.0532	20.0%	30.7%				
12229	163	0.0480	9.3%	12.7%	low germination prevented these from being included.			
AZ2	909.5	0.0387	2.0%	3.3%				
AZ3	1670	0.0422	6.7%	10.0%				

CAL4	624	0.0330	6.7%	10.7%
N566	506.5	0.0474	6.7%	9.3%
PARL 926	721	0.0419	5.3%	5.3%
PARL 927	351.5	0.0392	0.7%	1.3%

[1] Accessions used for trials planted in Tucson, Arizona are shown in green; accessions used for trials in Maricopa, Arizona are shown in green and yellow; and accessions used for trials in Eloy, Arizona are shown in green. Accessions used for all of the trials planted in New Mexico are shown in green.

The collaborating researchers decided all trials would be planted using the direct seed method developed by Bridgestone for small seed amounts. Bridgestone assisted the planting of all locations in March or April depending on soil temperatures. Sprinklers were used at Eloy, AZ and Maricopa, AZ locations for establishment and then were switched to furrow irrigation. Tucson used surface drip without sprinklers for germination. Field management was discussed at meetings as well as phenotypic measurements. Phenotypic data will be recorded after plant establishment.

- Seeds of 49 USDA NPGS guayule accessions were planted at the Maricopa Agricultural Center site on 12 April 2018 in a randomized complete block design with four replicates each. Each replicate consists of 4 rows spaced at 40 inches, within each row ten hills were planted and spaced at 12 inches. Total, approximately 8000 hills of guayule accessions plus control borders of AZ-2 cultivar were manually planted. Fourty-three (43) USDA NPGS guayule accessions were also planted at the University of Arizona field sites in Tucson on 12 April 2018 (Photo 3).

Photo 3. *Planting guayule field trials at study site in April 2018, Tucson, Arizona.*

- Preparation of a construct for the initial candidate gene – APETAL1 – has been completed. Transformations with an initial gene will commence by midyear. If the RNA Sequencing analysis identifies more likely candidate(s) they will also be used.

- A partial API1 gene sequence for guayule has been determined. Part of the sequence was not yet found in available ESTs, possibly because these data were obtained from cold-induced bark tissue, not flower tissue. Gene expression data from guayule flower/bud tissues is not available. Sufficient sequence was obtained for RNAi silencing, so construct pND6_AP1i has been prepared. We will next transfer it to an *Agrobacterium* vector.

  Meanwhile, based on a 2016 review article (Theißen et al. MADS-domain transcription factors and the floral quartet model of flower development: linking plant development and evolution. Published by The Company of Biologists Ltd. Development (2016) 143, 3259-3271 doi:10.1242/dev.134080) and the floral quartet model of plant development, we are reconsidering the importance of API1. Transcription factors in the MADS family include API and SEP proteins. According to the model, a complex of SEPALLATA (SEP) class E proteins (and other proteins) determines sepal, petal, stamen, carpel, and ovule identity at different points in flower development. API may only be involved in sepal and petal development. (Figure 1). So downregulation of the SEP class may be more effective. Determination of the sequence of the SEPALLATA (SEP3) gene from guayule cDNA has also returned only a partial sequence, but it may be sufficient for downregulation.

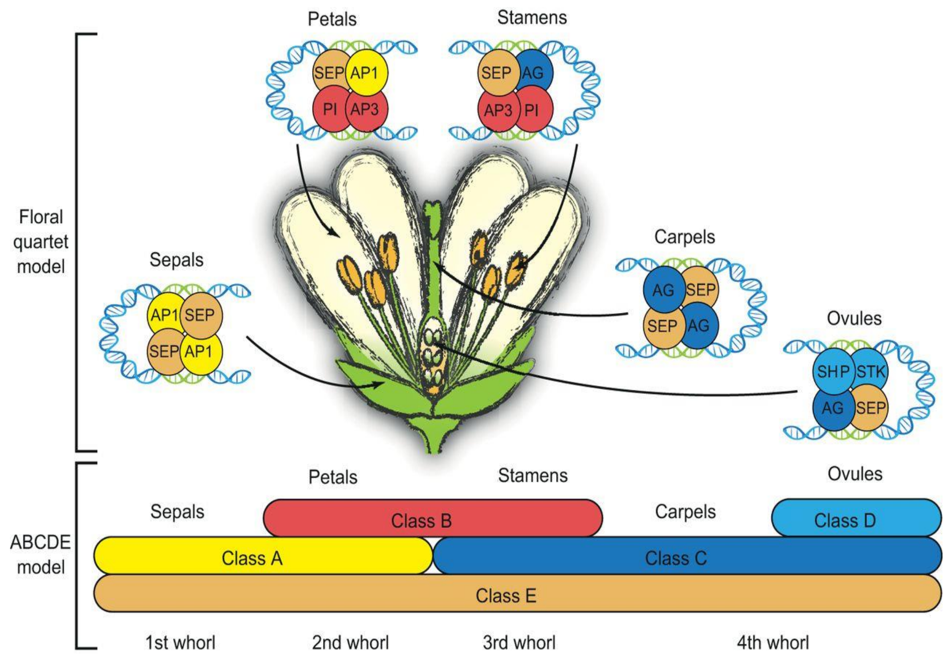


Figure 1. *Floral quartet model and the underlying ABCDE model of organ identity determination in Arabidopsis thaliana.*

Figure 1 Explanation. The top part of the figure depicts a version of the floral quartet model, which maintains that the five floral organ identities (sepals, petals, stamens, carpels and ovules) are specified by the formation of floral organ-specific tetrameric complexes of MIKC-type MADS-domain transcription factors that bind to two adjacent *cis*-regulatory DNA binding sites (CArG-boxes, green) and loop the DNA (blue) in between. A complex of two APETALA1 (AP1) class A proteins and two SEPALLATA (SEP) class E proteins determines sepal identity, a complex of one AP1 and one SEP protein together with one of each of the class B proteins APETALA3 (AP3) and PISTILLATA (PI) determines petal identity, a complex of one SEP, one AP3, one PI protein and the class C protein AGAMOUS (AG) determines stamen identity, a complex of two SEP proteins together with two AG proteins determines carpel identity, and a complex of one SEP and one AG protein together with one of each of the class D proteins SHATTERPROOF (SHP) and/or SEEDSTICK (STK) controls ovule identity. The bottom part of the figure illustrates the genetic ABCDE model. According to this model, organ identity during flower development in *A. thaliana* is controlled by five sets of floral homeotic genes providing overlapping floral homeotic functions: A, B, C, D and E. Class A genes are expressed in the organ primordia of the 1st and the 2nd whorl of the flower, class B genes in the 2nd and 3rd whorl, class C genes in whorls 3 and 4, class D genes in parts of the 4th whorl (ovule primordia), and class E genes are expressed throughout all four whorls. Class A and E genes specify first whorl sepals, class A, B and E genes specify second whorl petals, class B, C, and E genes specify third whorl stamens, class C and E genes specify fourth whorl carpels, and class C, D and E genes control the development of the ovules within the fourth whorl carpels.

- During year 1, we aimed to derive a list of candidate genes implicated or associated with flowering control and regulation. To do this, the recently published sunflower (*Helianthus annuus* L.) genome and associated resources were used as a starting point because this plant is in the same tribe (Heliantheae) as guayule. The overall steps taken during this phase of the work were:
    - A literature search was performed to identify genes involved in the control and regulation of flowering in various model organism and to identify available resources where this information has been cataloged. NCBI and other databases were consulted. Specifically, the "Flowering Interactive Database [FLOR-ID]" (http://www.phytosystems.ulg.ac.be/florid/), which hosts annotated genes involved/implicated in flowering.
    - This search generated a list of ~310 genes in *Arabidopsis* related to various aspects of flowering and served as the initial starting point for further work.
    - The gene identification information for these 310 genes were used to retrieve the respective DNA sequence information. These data were then used to perform BLAST (basic local alignment search tool) searches against the genomes of sunflower and lettuce (*Lactuca sativa* L.), another close relative of guayule in the Asteraceae family.
    - Through these analyses, 286 genes with orthologs in sunflower or lettuce were identified with having functions related to flowering and circadian clock rhythm (timing of plant development).

- After a list of candidate genes that might be implicated in the control of guayule flowering was established, analysis of the RNA sequence data collected by Dr. McMahan (USDA-ARS) was performed. For these analyses, RNAseq data from stem tissue of tetraploid guayule plants grown under contrasting irrigation levels were used.
    - Assembling the transcripts de novo for the RNAseq data was completed using "Trinity" software. Each of the RNAseq files were processed individually with the results being merged.
    - From these analyses, 240,000 transcript fragments were formed. It is important to note that these are not unique transcripts but instead represent fragments of assembled/overlapping reads.
    - The program "Salmon" was then used to map the individual reads back to the assembled transcript fragments which provided the metric "read fragments per transcript fragment."
    - This read count information was processed in the program "DEseq2" to determine the differential expression of transcript fragments between the irrigation regimes. A Bonferroni adjusted p-value of 0.01 was used to declare statistically significant differences in expression levels leading to 2,746 transcript fragments being identified as differentially expressed among the irrigation regimes.
    - These 2,746 candidate genes were then used to perform reciprocal best BLAST, using the software "EvoLinc," to identify sequence homologs in sunflower.

- Results were then compared to the list generated during the literature review to assess whether or not any of the differentially expressed transcript fragments were involved in flowering. From the intersection of these two analyses, 47 gene fragments that were differentially expressed between the irrigation regimes have hypothesized functions in sunflower flowering (this genome is not as well functionally characterized as the *Arabidopsis* genome leading to the ambiguity). Because of the similarities between guayule and sunflower, it is hypothesized that the differentially expressed gene fragments likely have similar functions in regulating flowering in guayule.
- The 47 candidate genes were compared with the annotated flowering genes identified in Arabidopsis to derive a list of 28 unique candidate genes (Table 2). This list of 28 represent the most promising targets of further research.

Table 2. *Arabidopsis flowering genes for which differentially expressed putative homologs in guayule were identified.*

Gene IDs	Functions & Pathways[1]
CCA1	Circadian clock
LHY	Circadian clock
PRR3	Circadian clock
PRR5	Circadian clock
TOC1	Circadian clock
RVE2	Circadian clock processes & seed germination
FKF1	Circadian clock, Photoperiod, Time-course regulation of photoperiodic pathway
UBC1	FLC regulation through protein complexes, General processes & autonomous pathway
VIP5	FLC regulation through protein complexes, General processes & autonomous pathway
YAF9A	FLC regulation through protein complexes, General processes & autonomous pathway
HTA11	General processes & autonomous pathway
PRP8	General processes & autonomous pathway
UBP12	General processes & autonomous pathway
VIM1	General processes & autonomous pathway
SPL3	Hormone pathway, Aging, Photoperiod, Sugar pathway
NF-YB1	Hormone pathway, Photoperiod, Time-course regulation of photoperiodic pathway
APL	Photoperiod
COL9	Photoperiod
HB16	Photoperiod & growth regulator
CRY1	Photoperiod, Time-course regulation of photoperiodic pathway
PHL	Photoperiod, Time-course regulation of photoperiodic pathway
PHYB	Photoperiod, Time-course regulation of photoperiodic pathway
CIB2	Promote flowering by activating FT expression
EFM	Temperature
JMJ30	Temperature pathway, Time-course regulation of photoperiodic pathway, General processes & autonomous pathway
EFS	Time-course regulation of photoperiodic pathway, FLC regulation through protein complexes, General processes & autonomous pathway
LDL1	Time-course regulation of photoperiodic pathway, General processes & autonomous pathway
CDKC;2	Vernalization, General processes & autonomous pathway

[1] Functional assignment and pathway involvement are based on the annotated genes of *Arabidopsis thaliana*.

Objective 2. Develop high-throughput phenotyping to support crop expansion using remote-sensing methods to create interactive database/tools.

Accomplishment Detail

Photo 4. *Hand-planting guayule variety trials in Tucson, Arizona.*

- Field study sites in seven (7) locations across Arizona and New Mexico were planted in April and May 2018. Study sites and study plants for phenotype characterization are the same as those used for the other portions of this study mentioned under Objective 1. Specific trials planted where phenotypic data will be collected include: density trials, irrigation trials and variety trials (Photo 4).

- By selecting for heat tolerance of guayule plants at establishment, the planting window will be increased, which is now between March and April. The only major disease problem in guayule is root rot in fields with standing water, thus selection for resistance to flooding. Twenty-one germplasm lines from the USDA-GRIN guayule collection were planted at the Campbell Avenue Farm (Campus Agricultural Center) by direct seeding. Plots were four 3.7 m rows (10 plants per row planted 30.5 cm apart) for 40 plants per plot. There were four replications (randomized complete plot design) of each line so 160 plants evaluated per line.

- Plants were screened for heat tolerance at establishment and the survivors screened for flooding resistance. Eighty-six percent of the AZ-2 plants, released previously as a germplasm line by this project, survived both the heat and flooding tests. About 50% of the plants of three lines (R1100, R1101, 11693), and 45% of another three lines (AZ-3, AZ-1, N566) survived both tests. The remaining 14 lines survived between 27% and 3%.

- Initial background data analysis has been initiated to understand the temperature and germination relationships already known in guar cultivars. Discussions are underway with Alex Muraviyov (Guar Resources) regarding available guar cultivars for this study and any known genetic variations among them. The research team is determining guar accession selection and study design for learning more about the accession characteristics and environmental limitations. This includes identification and evaluation of scientific incubators available that will be conducive for the necessary experimentation. Guar seeds will be sourced for the 2018 in June/July.

Objective 3. Deploy superior genotypes of guayule and guar to regional growers.

Accomplishment Detail

- Seed for guayule accessions to be studied was acquired from plants at the USDA-GRIN station in Parlier, California, and supplemented with seeds produced by Bridgestone. Field studies were initiated as described above (Objective 1) and will determine specific accessions most appropriate for soil and climate conditions in the arid Southwest.

- The preliminary protocol for Critical Stage Based Irrigation management has been developed and the plan was presented to the research team involving Drs. Waller, El-Shikha, Hunsaker and Grover. Discussions are underway with guar researchers to finalize cultivars for research. A material transfer agreement (MTA) between NMSU and Guar Resources has been initiated to acquire necessary guar seed. Once the cultivars are selected, the MTA will be signed by both parties.

- Working in conjunction with the USDA-GRIN station in Griffin, Georgia, 32 germplasm lines for guar were selected for further evaluation at Tucson, AZ; Las Cruces, NM; and Clovis, NM. There was not enough seed for three locations so the first-year seeding will be increased at Tucson, AZ and Las Cruces, NM. Each plot will be six 6 m rows, separated by 4 beds of sweet sorghum. Plantings will occur in June 2018.

Objective 4. Deploy agronomic production practices: provide irrigation apps that include salinity, herbicide, and nutrient algorithms to growers.

Accomplishment Detail

- A density experiment has been designed to examine guayule accession lines. The experimental plots were planted by tractor at West Campus Ag Center in Tucson, Arizona on 12 April 2018. The plantings were over-planted and will be thinned to the five densities in the experiment when plants are at about the four-leaf stage.

- All study sites and fields were prepped for the planned irrigation research. Spring oats were planted to improve uniformity of the trial location and to deplete the soil profile moisture, which will help to increase differences between pre-irrigated and non-pre-irrigated blocks. Late summer rains in 2017 refilled the soil profile, which requires an additional spring oat planting.

- ET coefficients will be developed using the Critical Stage Based Irrigation management study. Hadiqa Maqsood, a UA graduate student, will spend 2018 summer at the Agricultural Science Center at Clovis, NM, and intensively collect soil moisture content and other data to develop ET coefficients. She will complete necessary training prior to using the neutron gauge for observations.

- The drip irrigation system at Maricopa Agricultural Center, Maricopa, AZ, has been designed and installed for this project. The new system is an upgrade from what existed previously and will be an excellent system for research and demonstration (Photo 5). The system has six treatments with three replicates. There is one surface irrigation treatment with 100% irrigation level, and there are five drip treatments with 50%, 75%, 100%, 125%, and 150% irrigation levels. All of the controllers will be able to be monitored and regulated remotely, which will aid in data collection and consistency.

Photo 5. *New irrigation pump station installed in Fall 2017, and used for irrigation experiments at Maricopa Agriculture Center.*

- The WINDS model programming is currently at the filtering stage to clean out the data for each control site from the database and setting it at the correct time points in the arrays. The object-oriented approach facilitates the separation of data from each control site. We also added an automated sensor and control component with flow sensors, pressure sensors, and relays for turning valves on and off, infrared cameras, soil sensors, blue tooth for communication with sensors, and cell phone card to connect system to the internet. We have much of the code and hardware assembled, which will allow for controlling the guayule irrigation experiment from the internet. Nick Ashley, a chemical engineering graduate student, has been working very hard on this sensor and control system. The WINDS model should be online by June 15, and automatically controlling the Maricopa guayule irrigation experiment controller.

- Seed was planted and germinated in irrigation experiments at Eloy and Maricopa. Unfortunately, a strong wind and sand storm destroyed the seedlings in about 1/3 of the field at Maricopa. The field was replanted at Maricopa on Friday, 20 April 2018. This will require another round of sprinkling for germination with the temporary aluminum pipe sprinkler system. Bridgestone assisted with advice on the replanting decision and was helpful in advising on the irrigation and other processes.

- Ag and Biosystems Engineering (ABE) graduate student Matthew Katterman is actively involved in various aspects of the SBAR project. Matt will use the WINDS model for portions of the Education & Outreach deliverables and will adapt the WINDS model to a 2-D Google Earth format. He will be working with ABE remote sensing expert Kamel Didan, who is also working with Dr. El Shikha on processing the drone images coming from the Maricopa Agricultural Center.

- Letters of support were provided to the Arizona Department of Agriculture (ADA) in support of renewing 24c SLN herbicide registrations for paraquat and fluazifop-p-butyl for 5 years, and supported Syngenta's renewal requests with ADA's Environmental Services Division.

The paraquat and fluazifop-p-butyl 24c SLN labels were renewed for 5 years; work continues on additional 24c SLN labels for carfentrazone (Aim; a 5-year renewal) and other herbicides.

- Discussions with field scientists from FMC, Syngenta, and BASF were initiated to define the data (herbicide rates and application methods) needed to determine the tolerance of guayule seedlings to potential herbicides. Some of these industry scientists also viewed current research plots to provide feedback and expert advice.

- Four preemergence herbicide studies were started at the Bridgestone Eloy research farm using two herbicide incorporation methods; a rolling cultivator for shallow mechanical incorporation just prior to planting or sprinkler irrigation just after planting). In addition, five herbicide studies were started where various herbicides were sprayed topically on guayule seedlings at different growth stages (i.e., number of leaves). (Table 3)

Table 3. *Guayule preemergence herbicide experiments - herbicides applied at planting.*

Spray Date	Chemicals Applied	Field	Method of Incorporation	ARM File Name / Data Tables?	Data Collected to Date
9-26-2017	Dual Magnum Spartan 4F	B2E	Incorporvator	PPI-Fall-E1-Dual-Spartan 2017	11/3/2017 – Stand Counts and Avg. # Leaf 11/15 – Nadir Pictures 12/20 – Stand Counts and Nadir Pictures 1/30/2018 –Measure Gaps > 24 inches 1/31 –Stand Counts 2/26 – Nadir Pictures
9-26-2017	Dual Magnum Spartan 4F	B2E	Sprinkler	PREE-Fall-E3-Dual-Spartan 2017	11/9/2017 – Stand Counts and Avg. # Leaf 11/15 – Nadir Pictures 12/20 – Stand Counts and Nadir Pictures 1/30/2018 –Measure Gaps > 24 inches 2/1 –Stand Counts 2/26 – Nadir Pictures
9-26-2017	Prefar 4-E Prowl H2O	B2E	Incorporvator	PPI-Fall bedtop E2 Prowl Prefar Fall2017	11/3/2017 - Stand Counts and Avg. # Leaf 11/15 – Nadir Pictures 12/15 – Stand Counts 12/20 – Nadir Pictures 1/30/2018 –Measure Gaps > 24 inches -Stand Counts 2/26 – Nadir Pictures
9-26-2017	Prefar 4-E Prowl H2O	B2E	Sprinkler	PREE-Fall E4 Prowl Prefar Fall 2017	11/7/2017 - Pre-Spray Stand Counts - Avg. # Leaves/Plot 11/15 – Nadir Pictures 12/20 – Stand Counts and Nadir Pictures 1/30/2018 –Measure Gaps > 24 inches 1/31 –Stand Counts 2/26 – Nadir Pictures

- Data collected included pre- (where applicable) and post-spray stand counts (i.e., plant population counts), visual estimates of injury and nadir photographs of subplots. The nadir photographs require further computer analysis to determine guayule seedling ground cover which is a labor-intensive process.

- Stand counts and photographic data were collected in the ongoing fall 2017 experiments (Table 4). Bryan Pastor spend a considerable amount of time analyzing the digital nadir photographs. This analysis was nearly completed in the first quarter of 2018.

Table 4. *Guayule Experiments: Herbicides broadcast sprayed topically after guayule seedlings were established.*

Spray Date	Chemicals Applied	Field	Guayule Size at spray / Nozzle / GPA	ARM File Name	Data Collected to Date
10-24-2017	Prowl H2O Spartan 4F Aim EC ET Chateau	B4	2 to 5 leaf Avg. 4 leaf TT-11002 20.505 GPA	Guayule Eloy Fall_17 EPOST01	10/23/2017 – Pre-Spray Stand Counts 11/16 – Stand Counts and Nadir pictures 1/30/2018 –Measure Gaps > 24 inches 2/1 –Stand Counts 2/26 – Nadir Pictures
11-8-2017	Prefar 4-E Prowl H20 Dual Magnum Spartan 4F	A5	2 to 5 leaf Avg. 3.5 leaf AI-11002 20.946 GPA	PREE 4 leaf A5 Fall 2017	11/7 – Pre-Spray Stand Counts 11/7 – Average # Leaves/plant 11/20 – Stand Counts 11/20 – Nadir pictures1/30/2018 – Measure Gaps > 24 inches 2/5 –Stand Counts 2/26 – Nadir Pictures
11-9-2017	Prowl H20 Spartan 4F Aim EC ET Chateau	A5	1 to 4 leaf Avg. 3.3 leaf TT-11002 21.104 GPA	Guayule BS Eloy EPOST02_A5_Fall_2017	11/6 – Pre-Spray Stand Counts 11/6 – Average # Leaves/Plant 11/30 – Stand Counts 12/13 – Stand Counts 12/13 – Nadir pictures 1/30/2018 –Measure Gaps > 24 inches 2/6 –Stand Counts 2/9 – Nadir Pictures
11-17-2017	Spartan 4F Aim EC Butyrac 200	B4	4 to 10 leaf Avg. 8 leaf TT-11002 21 GPA	Guayule BS POST_Fall2017_B4N_exp2	11/17 – Pre-Spray Stand Counts 12/13 – Foliar Injury Rating 12/13 – Stand Counts 12/13 – Nadir pictures 12/13 –Phytotoxicity Ratings 1/30/2018 –Measure Gaps > 24 inches 2/1 –Stand Counts 2/26 – Nadir Pictures
11-17-2017	Spartan 4F Aim EC Butyrac 200	B2W	3 to 5 leaf Avg. 4.2 TT-11002 21 GPA	GuayuleBS POST_Fall2017_B2W_exp3	11/17 – Pre-Spray Stand Counts 11/17 – Avg. # Leaves/Plot 12/13 – Foliar Injury Rating 12/13 – Stand Counts 12/13 – Nadir pictures 12/13 –Phytotoxicity Ratings 2/6/2018 –Measure Gaps > 24 inches 2/6 –Stand Counts 2/26 – Nadir Pictures

Objective 5. Develop soil quality and health knowledge critical to environmental sustainability.

Accomplishment Detail

- Preliminary investigations were completed to develop field sampling protocols suitable for the guayule field trials to accommodate for the significant differences in soil type between the study sites. Appropriate soil augers were tested and purchased. A labeling system was developed in conjunction with the other researchers to ensure coordinated chain of custody for all field samples.

- Soil samples will be collected three times during the guayule growth cycle at planting, year 1, and prior to harvest at year 2. Soil samples collected at seeding in April 2018 will reveal baseline soil health values for each field based on the status of the soil microbiome. In March 2019, year 1 samples will be collected from the guayule rhizosphere from 3 1-m^2 plots per treatment replicate (18 treatment replicates/field location). Plant height, biomass, rubber, and resin content will be determined for each sample plot. This sampling procedure will be repeated in March 2020 immediately prior to harvest. The experimental field design is replicated at USDA Maricopa Ag Center and Bridgestone Eloy Ag Center. A total of 100 soil samples will be collected per year for chemical and microbiome analysis. The field trials include six treatments: flood irrigation at optimum rate (100), drip irrigation at 50%, 75%, 100%, 125% and 150% of optimum rate. Sample data to be correlated with soil microbiome health status are summarized in the sample collection table (Table 5).

Table 5. *Sample collection data that will be correlated with soil microbiome health status.*

Sample Collection Dates	Field Location	Plant Analysis[1]	Soil Analysis Chemical[2]	Soil Analysis Microbial
April 2018	Maricopa Eloy		pH Electrical conductivity (EC) organic matter (SOM) nitrate (NO_3-N) Phosphorus (P) Potassium (K) Cations (CEC) Sodium adsorption ratio (SAR) Texture analysis	Bacterial quantification Fungal quantification Bacterial diversity Fungal diversity Bacteria/archaeal phylogenetic profile Fungal phylogenetic profile
March 2019	Maricopa Eloy	Biomass Plant height Rubber content Resin content	pH Electrical conductivity (EC) organic matter (SOM) nitrate (NO_3-N) Phosphorus (P) Potassium (K) Cations (CEC) Sodium adsorption ratio (SAR) Texture analysis	Bacterial quantification Fungal quantification Bacterial diversity Fungal diversity Bacteria/archaeal phylogenetic profile Fungal phylogenetic profile
March 2020	Maricopa Eloy	Biomass Plant height Rubber content Resin content	pH Electrical conductivity (EC) organic matter (SOM) nitrate (NO_3-N) Phosphorus (P) Potassium (K) Cations (CEC) Sodium adsorption ratio (SAR) Texture analysis	Bacterial quantification Fungal quantification Bacterial diversity Fungal diversity Bacteria/archaeal phylogenetic profile Fungal phylogenetic profile

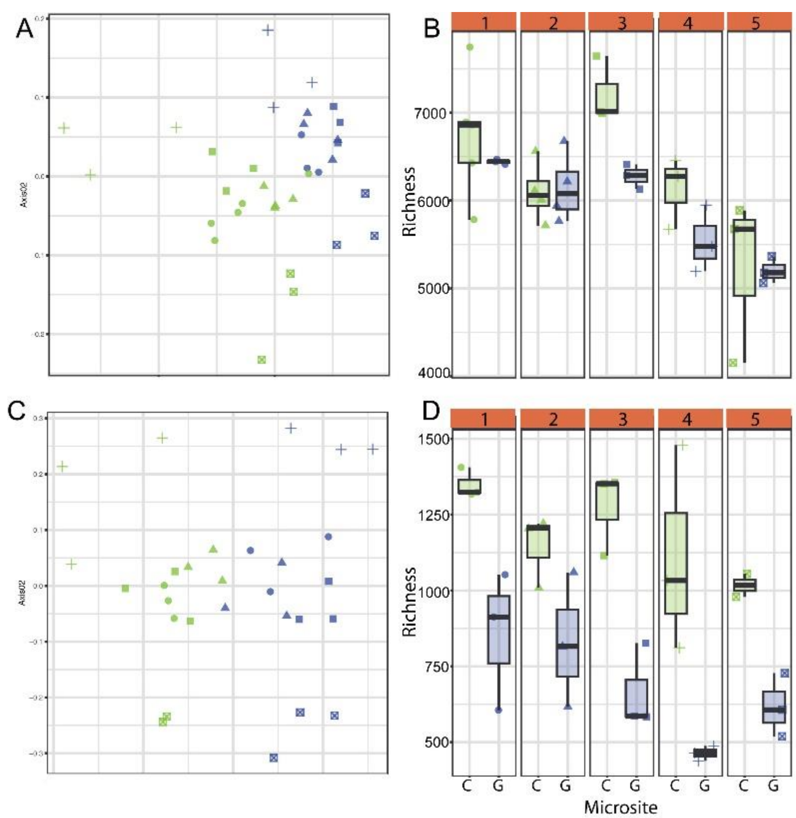
1. Guayule biomass, rubber and resin will be analyzed by Bridgestone
2. Soil analysis will be done by Omar Holguin at New Mexico State

- Price and services were evaluated at available analytical facilities to determine where soil sample chemical analyses would most cost effectively be performed. After consideration of a variety of options, chemical analysis will be done at New Mexico State University and protocols were established with the Holguin group for drying and shipping soils for chemical analysis.

- Graduate student, Kyle Brown, continued training for DNA extraction and processing of pre-plant soil samples to be collected for baseline characterization of the soil microbiome in fields being used for the guayule irrigation field trials. The research team decided that baseline soil samples should be collected during the initial irrigation period following seeding because the soil microbiome would respond significantly to soil wetting following the extended fallow period. By sampling immediately following seeding and initial irrigation, the baseline microbial data generated would reflect the status of the microbiome at the time of seed germination. Guayule planting was delayed due to weather conditions; thus, soil samples will be collected in May 2018. This represents a slight delay that will not impact the progress of the field study.

- A parallel study was conducted during 2017-Q4 and 2018-Q1 to obtain background profiles of the soil microbiome of undisturbed Sonoran Desert soils. The desert shrub ecosystem sampled was the *Larrea-Ambrosia* (creosote-bursage) vegetation that is native to the Sonoran Desert. This data set will provide background arid-soil microbiome information that can facilitate interpretation of microbial patterns unique to arid land agricultural systems. Five geographic locations were selected to represent the Sonoran Desert of southern AZ. Sites included Tumomoc Hill (TH) in Tucson, AZ; the Kofa National Wildlife Refuge of southwestern AZ (QZ1); Rt 60 east of Quartzite, AZ (QZ2); Rt 95 north of Quartzite (QZ3); and Parker, AZ (QZ4).

  Transects were sampled at each site and composite samples were collected representing areas beneath plant canopies (canopy) and the open spaces between plants (gap) at each site. Community analysis of the soil microbiome (16S rDNA and ITS Illumina MiSeq amplicon sequence and soil geochemistry) of these five creosote-bursage sites



Site symbols: site 1●, site 2▲, site 3 ■, site 4 +, and site 5 x .

Figure 2. *NMDS ordination analysis of bacterial/archaeal (panel A) and fungal (panel C) communities associated with canopy (C, green) and gap (G, blue) microsites located in five medium to high density creosote-bursage vegetation sites in the Sonoran Desert, AZ.*

(Figure 2) revealed that significant differences exist in the microbiome composition and richness of different geographic locations. In addition, within-site microsite type (canopy vs gap) significantly impacted both microbiome composition and richness at most sites. Site location explained 26% and 24% of the bacterial/archaeal and fungal community variation respectively, ($p=0.001$) and microsite (canopy vs gap) within the site location explained an additional 33% and 32%, respectively ($p=0.001$). Observed species richness varied significantly between locations for bacteria/archaea (panel B, $p<0.001$) and fungi (panel D, $p=0.02$) and for microsites within each location for fungi ($p<0.001$), but not bacteria/archaea. Geographic location and microsite type combined to explain 59% and 56% of the observed variation in bacterial/archaeal and fungal communities, respectively. This data reveals a strong plant-effect on both community composition and richness in arid soils. The plant-effect had a more significant impact on fungal community richness (panel D) than on bacterial/archaeal richness (panel B). The patterns observed in the Sonoran Desert natural systems will be used to generate hypotheses that will be addressed concerning plant-microbe interactions between guayule and the associated soil microbiome.

POST-HARVEST LOGISTICS & CO-PRODUCTS

Executive Summary

The Post-Harvest Logistics and Co-Products Team focuses on evaluating how seasonality, processing, and storage affect product quality, conversion efficiency, and economics; develop and optimize system-level logistics models for demand-driven harvest; demonstrate feasibility of farm to fuel conversion of bagasse; and identify economic co-products in guayule and guar. In 2018, the research team concentrated efforts on conducting comprehensive literature reviews to establish standard operating protocols, and on laboratory analysis of guayule resin and plant material.

Component Leader

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Other Key Collaborators

- **F.Omar Holguin**, New Mexico State University
- **Neng Fan**, University of Arizona
- **Leslie Gunatilaka**, University of Arizona

Other Personnel

- **New Mexico State University** – Hengameh Bayat, Feng Cheng, Barry Dungan, Travis Le-Doux, Sicilee Macklin, Sa'Rae Montoya, Nicolas Soliz, Brian Treftz, Jacob Usrey, Stephanie Willette, and Scott Woolf
- **University of Arizona** – Wolfgang Grunberg, Kasia Kiela, Ou Sun, and Ya-ming Xu

Accomplishments – Year 1

- Completed literature review for modeling and algorithm development to address feedstock logistics supply chain and transportation-related questions.
- Constructed preliminary mixed-integer harvest and economic models to serve as a basis for later large-scale algorithms.
- Initiated chemical characterization of guayule resin, which identified 17 major terpenes in the resin, including several new never-described compounds.
- Identified standard operating protocols for extraction and isolation of primary and secondary metabolites in guayule and guar.
- Isolated and characterized major metabolites of guayule.
- Completed literature review of bagasse-to-fuel conversion routes.
- Established protocols and processes for characterization of guar and guayule bagasse.

Planned Activities – Year 2

- Support guayule agronomic trials and rubber extraction studies by providing metabolite, resin, and bagasse characterization analyses.
- Screen isolated and identified resin fractions and metabolites for antimicrobial, antioxidant, and other activity for high-value applications.
- Conduct guayule and guar bagasse hydrothermal liquefaction trials with and without co-solvents and catalysts to characterize fuel potential of conversion products.

- Down-select bagasse-to-fuel conversion routes based on characterization data, transportation and conversion process models, and economic and sustainability predictions.

Explanation of Variance

The guar and guayule bagasse characterization and conversion down-selection tasks were delayed by 6 months due to issues with the subcontract process that delayed hires and acquisition of equipment and supplies.

Objective 1. Evaluate how seasonality, processing, age, and storage affect product quality, conversion efficiency, and economics.

Accomplishment Detail

- Project initiation tasks were implemented in Fall 2017, including development of material and non-disclosure agreements, and visits with LanzaTech (to discuss fermentation of syn gas) and with Guar Resources (to supply data for modeling groups). Two field visits were discussed and planned to visit guayule and guar processing facilities. Dr. Holguin and representatives from his research staff were able to attend an Arizona visit where samples were collected from both Bridgestone facilities and another Arizona facility. During the same visit, the NMSU team received a small tour of the UA Natural Products Laboratory facilities, which helped in understanding how to better leverage the logistics team strengths across institutions.

- Project partners worked to set up the biomass characterization methods (ordering standards, training new students, etc.). Project partners attended the AICHE meeting in Minneapolis in November to better understand state-of-the-art biomass conversion technologies and incorporate these new methods where appropriate/possible.

- Group reviewed and provided input as needed for development of data/material handling diagrams for cooperative agreement. Woolf, Le-Doux, Treftz and Usrey collaborated with students in Holguin group to set up and train on NREL characterization methods, starting with moisture, carbohydrates and CHNS elemental content on the guar and guayule bagasse collected last quarter. Macklin performed initial guar seed hull extractions and anthocyanin measurements on multiple instruments.

- The National Renewable Energy Laboratory (NREL) biomass characterization methods were presented and discussed during component team meetings. Additional analytical challenges were identified that would need to be addressed in the polyolefin analysis. Dr. Brewer's group started biomass characterization on the bagasse material using NREL methods, and started to work with Dr. Mark Von Cruz and Dr. David Dierig (Bridgestone) on characterization of guayule leaf material. Characterization was performed using a standard primary metabolomic screen performed on a GC/MS. Frozen leaf material was received from Dr. Von Cruz and lyophilized immediately on arrival. The lyophilized tissue was ground and ~15mg of tissue was weighed and extracted with a miscible solution of cholorom:methanol:water. The extracts were dried in a speed vacuum and derivatized. Data was collected and matched to commercially available library. More than 150 individual metabolites were putatively identified in the extracts (Figure 3). Preliminary results are being used to plan future experiments to evaluate cold tolerant phenotypes of guayule. We also performed CHNS analysis of the leaf material on three samples. The mean values for leaves are as follows 44.3% C, 5.9% H, 3.2% N, 2% S. We also collected FTIR data of the leaf samples. Final data analysis is pending.

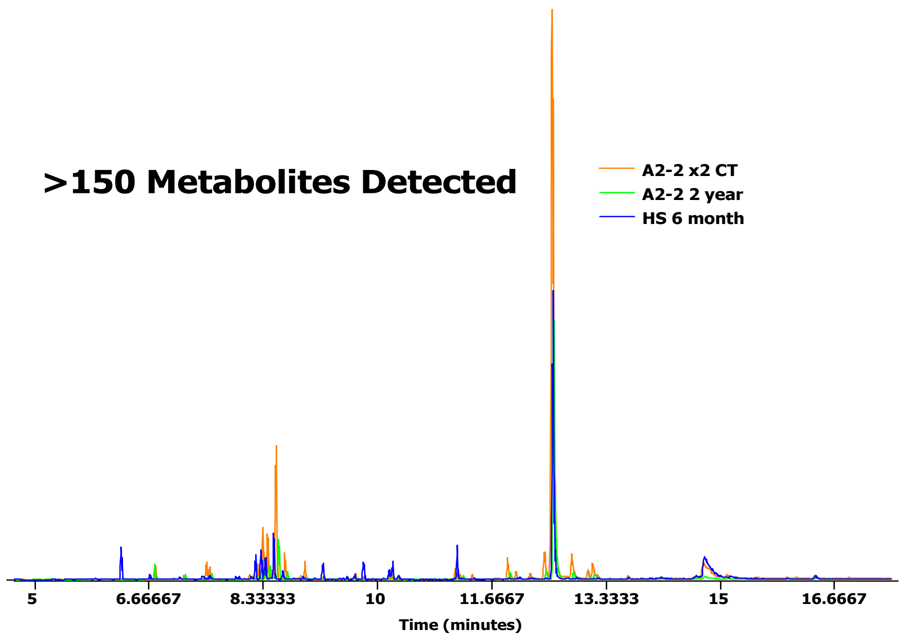

Figure 3. *Primary metabolic screening by GC/MS. Chromatographic elution profile of metabolites found in guayule leaf tissue.*

- Biochemical characterization of guayule resin is underway. Resin was dissolved in carbon disulfide and analyzed by GC/MS for the terpene content (Figure 4). Preliminary data putatively identified 17 major terpenes in the resin. In addition, the resin was also analyzed

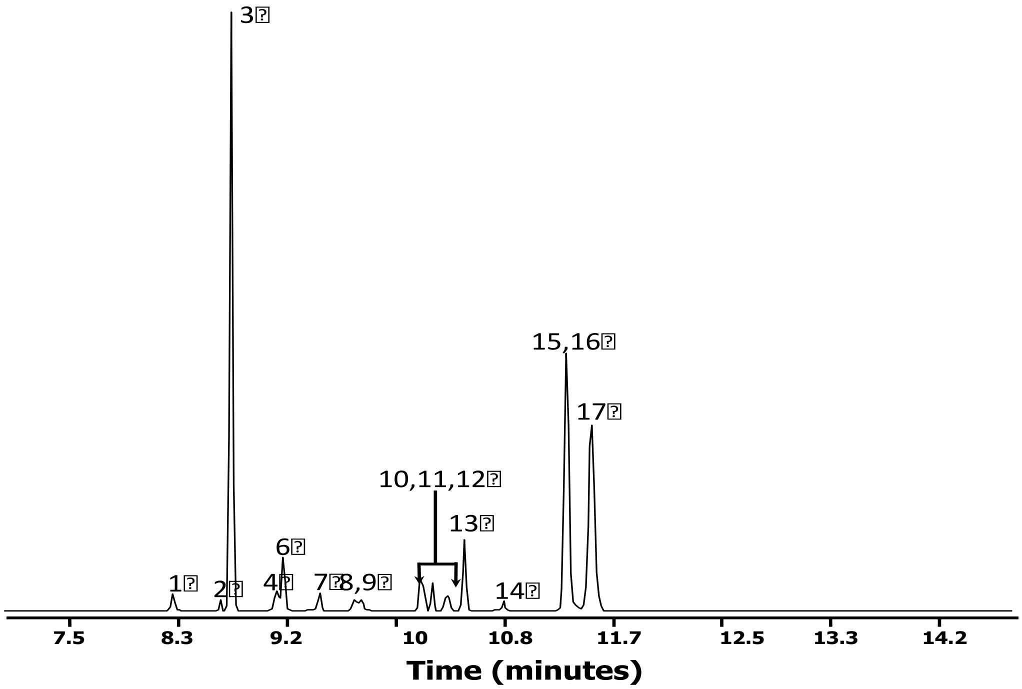

Figure 4. *Terpene Analysis of GC/MS. Chromatographic elution of profile of 17 major terpenes found in guayule resin.*

by CHNS. The results indicated that the overall content of N was very low <1% in the resin followed by sulfur at ~2%. The percent O content by difference is calculated to be 7.24%. This suggests that the resin is mainly composed of hydrocarbons with very low degree heteroatom composition in the molecules. We then followed this analysis by evaluating the resin by positive ion electrospray ionization. Our results were interesting, it appears that small molecules less than 500m/z are relatively the most abundant ions in the extract. But upon further inspection there is a large distribution of hydrocarbons with a mean molecular weight of ~850 m/z units. These compounds are likely the cause of the resin's physical appearance as a solid at room temperature.

Objective 2. Develop and optimize value-added, system-level models for demand-driven harvesting, collection, storage, and transportation.

Accomplishment Detail

- For the literature review on modeling and algorithms of optimization for feedstock logistics, we have initially divided the typical logistics supply chain into 4 components: harvesting, collection, and pre-treatment; storage; conversion; and transportation. Each component follows some similar requirements and limitations in optimization models. A literature review paper is under the way. Besides comprehensively identifying the related problem on guar and guayule feedstock supply chain, the survey paper will discuss existing optimization approaches and limitations of current methods.

- Starting with two specific problems, optimally locating biorefinery plants and harvesting scheduling, partial information and data were collected through discussions with Bridgestone and other research teams. Among them, harvesting information and economics analysis from Dr. Paul Gutierrez and Mr. Trent Teegerstrom will be input for part of our models. Some preliminary models based mixed integer programming formulations were constructed. Before numerical experiments, more data will be collected, especially the GIS-based data for farms with potential to shift to plant Guar and Guayule. Related issues on regional economic analysis were discussed on March 9 Sustainability Team In-Person Meeting at UA.

- In order to solve the developed large-scale mixed integer programs, some efficient algorithms have been developed and tested on other problems. Among them, we have successfully completed the C++/CPLEX code for the decomposition algorithm with Lazy constraints in CPLEX. Future application of the code on feedstock logistics optimization will need to make modifications based on the developed version.

Objective 3. Demonstrate feasibility of farm to fuel conversion of bagasse.

Accomplishment Detail

- Graduate student, Feng Cheng, outlined and assembled an annotated bibliography on two topics: guayule biomass conversion and characteristics, and high-protein biomass conversion (since nothing is available on guar bagasse directly). These annotated bibliographies and data tables were shared with the Sustainability working group for further integration.

- Dr. Brewer attended the Advanced Biofuels Leadership Conference in Washington, D.C. in February. That meeting resulted in three new company contacts: one for biomass conversion bolt-on technology, one for pilot scale equipment and testing, and one for biomass characterization high-throughput methods.

Objective 4. Identify economic co-products in guayule and guar, e.g., biologically active components.

Accomplishment Detail

- Method development work on guayule was continued with a resin sample received from Bridgestone. The objectives were to characterize and quantify its constituents with the goal of (a) using this information for comparison of samples obtained from different lines of guayule by various agronomic treatments and rubber/resin extraction methods; and (b) determine their biological activities.

- Fractionation of the sample labeled 320 ^{o}F was continued for the characterization of resin constituents. A small quantity of the resin (1.45 g) was fractionated by solvent-solvent partitioning, gel-permeation chromatography, silica gel chromatography, and finally purified by reversed-phase (RP) high-pressure liquid chromatography (HPLC) to afford the major constituents.

- In addition to above known compounds, seven new metabolites isolated from guayule resin were tentatively identified. Definitive identification of these seven new metabolites, large-scale isolation of the constituents of guayule resin and bagasse and evaluation of their biological activities are in progress.

System Performance & Sustainability

Executive Summary

The System Performance and Sustainability team focuses on developing a scalable engineering process model for crop production and processing that is coupled with Techno-Economic Analysis (TEA) and Life Cycle Analysis (LCA) to understand the economic impact to rural communities through input-output methods; integrating regionally appropriate metrics and combining results from SBAR-developed data into sustainability models to provide a path to commercialization of biofuels and bioproducts; and interfacing with regional growers to de-risk production of guayule and guar in the United States while evaluating social impacts. In 2018, the research team concentrated efforts on conducting comprehensive literature reviews to establish social, environmental and economic parameters to formulate the Comprehensive Life Cycle dataset, and initial development of a *Whole Farm Economic Analysis* for guayule and guar production, as well as generation of downstream processing models.

Component Leaders

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Other Key Collaborators

- **Amy Landis**, Colorado School of Mines
- **Paul Gutierrez**, New Mexico State University
- **Neng Fan**, University of Arizona
- **Clark Seavert**, Oregon State University
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Other Personnel

- **Colorado School of Mines** – Pragnya Eranki and VeeAnder Mealing
- **Colorado State University** – Jack Johnson, Evan Sproul, and Hailey Summers
- **New Mexico State University** – Ram Acharya, Sarah Acquah, and Joram Robbs
- **University of Arizona** – Wolfgang Grunberg, Kasia Kiela, and Ou Sun

Accomplishments – Year 1

- Literature review for identifying social, environmental and economic parameters was completed, which will formulate the Comprehensive Life Cycle dataset.
- Initiated and diagrammed the sub-process models for guar and guayule processing, including detailed unit operation analysis of feedstock to intermediate products.
- Initiated development of a farm-level economic analysis that characterizes the impact of internal and external factors influencing production and profitability for growing guayule and guar.

Planned Activities – Year 2

- Assemble production costs/prices to develop enterprise budget for guayule and guar to be used in the development of farm-level scenarios for Arizona and New Mexico.
- Model integration with preliminary results for the viability and environmental impact of various processing pathways.
- Data feedback to team members for focused research and development driving towards commercial viability and sustainable production.

Explanation of Variance

No variance has been experienced and accomplishments are on schedule.

Objective 1. Develop a scalable engineering system model for crop bioproduct and biorefinery concepts, ensuring financial feasibility by Techno-Economic Analysis (TEA) while evaluating economic impact to rural communities through input-output methods.

Accomplishment Detail

- A social sustainability literature review was initiated as well as close collaboration with the education and outreach team to develop social sustainability specific questions to be added to the needs assessment survey that will be given to the farmers.

- A general guar and guayule agriculture literature reviews were started and are ongoing. A tour of the Guar Resources facility in Brownfield, TX was completed, which provided a greater understanding of the guar agriculture and processing methods. Literature reviews and facility tour were used to mine data to be used in the preliminary life cycle assessment. Data for guar agriculture processes are limited in the literature and so contacts made during the facility tour will be used to schedule interviews with Guar Resources agriculture specialists to have a more complete process model and collect more data. Most recently a social sustainability literature was initiated as well as a collaboration with the education and outreach team to develop social sustainability specific questions to be added to the needs assessment survey that will be given to the farmers.

- The literature review and guar resources facility tour were used to develop preliminary guar and guayule process models. Graduate student, VeeAnder Mealing plans to refine this process model as well as pursue more relevant data collection through interviews with guar resources and local farmers now that the non-disclosure agreement (NDA) is securely in place.

- Existing guayule data and knowledge was used to setup a preliminary guayule excel model as well as outline a guar excel model. A LCA mini-workshop/tutorial was also lead by Dr. Eranki to assist with the setup of the model. Additional research on general agricultural models was completed to explore simple to complex model options that may benefit this project, specific to field emission simulations. Preliminary results were produced for guar agricultural impacts from the Excel-based model. Refinement of model inputs is currently in progress.

- During this reporting period, the focus has been on continued development and validation of individual sub-process models for the processing of guar and guayule. These sub-process models will be integrated with further sub-process models for further downstream processing as well as up-stream feedstock production models to complete the engineering system model. The modularity in construction will facilitate the plug and play of various processing steps. The focus of this work is to accurately track energy and mass of each sub-process.

The following two section give further details on the work that has been completed on the two feedstock process sub-models. Currently the primary focus has been on developing bagasse processing models with a focus on pyrolysis. This sub-process model will be used with both guar and guayule modeling.

- In an effort to coordinate modeling work, multiple group working sessions were held early on. The first was a face to face meeting between CSU and Colorado School of Mines held in Golden, CO. This working session was focused on understanding the interconnection points for LCA work. The second was organized by NMSU and UofA with CSU joining virtually. The focus of this session was to understand the economic modeling being completed at the farm level by NMSU and UofA.

- Guar gum processing information is limited in the literature and thus a visit to Guar Resources was arranged to better understand the process. Team members from CSM and CSU visited Guar Resources, located in Brownfield, TX. The team met with Mr. Alex Muraviyov, General Manager, for an informative discussion followed by a facility tour.

- Combining the Guar Resources tour with information available in literature, a first-order process model tracking mass and energy flow for the production of guar gum has been developed (Figure 5). Recent work has focused on validation of this model and improving usability. From preliminary results, efforts are focused on optimizing heat and moisture amounts in processing of guar gum as these are showing as the initial large contributors to overall process energy requirements. Additionally, both process models for guar and guayule are being developed simultaneously and continual iteration on model design is preparing for complex functionality that will come in later stages of this project.

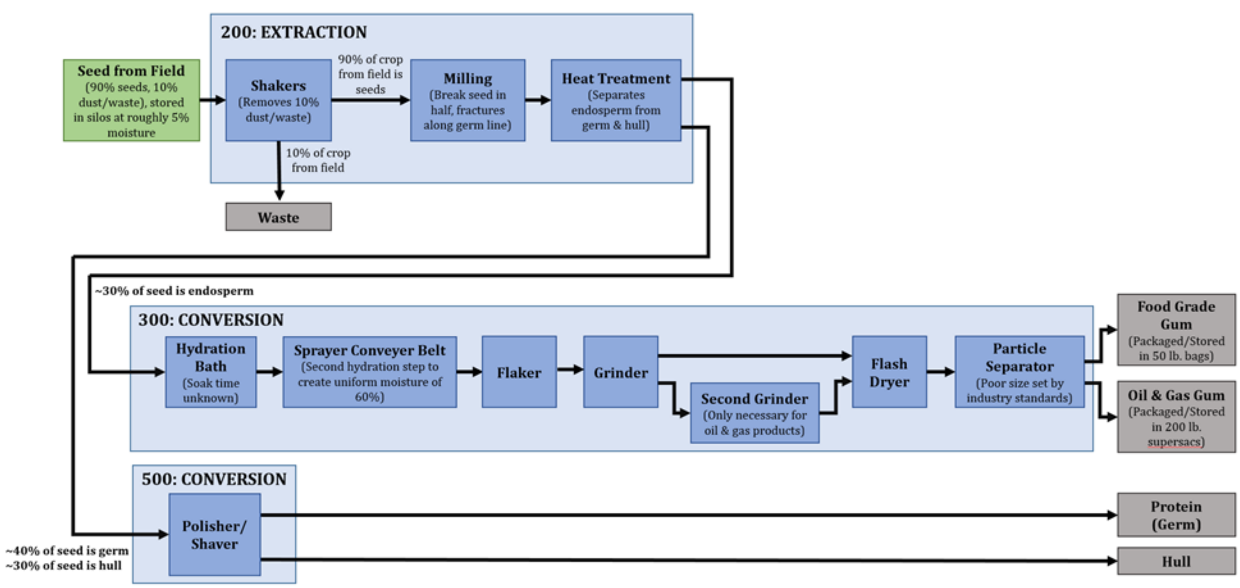

Figure 5. *Process model tracking mass and energy flow for guar gum production.*

Describing the mass process flow diagram in more detail, guar seed is harvested from the field and stored in silos until fed into the first processing steps. Residual plant matter remains from the combine harvest and thus the seeds must first go through a shaker table for purification. The seeds then run through a mill where they are cracked open and then are heat treated to remove the hull and germ from the endosperm. The endosperm is the source for the primary product guar gum and the germ and hull generate a secondary product used for animal feed. The endosperm is brought to 60% moisture via a hydration bath and sprayer conveyer belt. The hydrated endosperm is then flaked and ground into a powder. The powder is then flash dried and run through a particle separator to filter out any imperfections. The final guar gum is packaged in 50 lb. bags or 200 lb. supersacs, depending on the industry. The germ, high in protein, and hull are sent through a shaver and then packaged for use as an additive to animal feed.

- Preparation for Guayule process modeling started with a full day visit to Bridgestone's agricultural and bio-processing operations in Arizona. The tour provided insight into Bridgestone's solvent extraction processes including the scale, equipment, materials, and personnel involved with standard operations. Additionally, the tour established reliable contacts at Bridgestone who have been key in verifying models with existing industrial processes. Building off information gained in the tour, two initial modeling steps have been completed. First, a high-level biomass balance was carried out to estimate the amount of rubber, resin, and bagasse produced from one acre of land over the course of a year. Results of this effort were compared to results of other existing studies, as well as estimates of Bridgestone's current production. Second, a mass flow diagram for Guayule solvent extraction (Figure 6) has been created and is currently under a second round of review with Bridgestone.

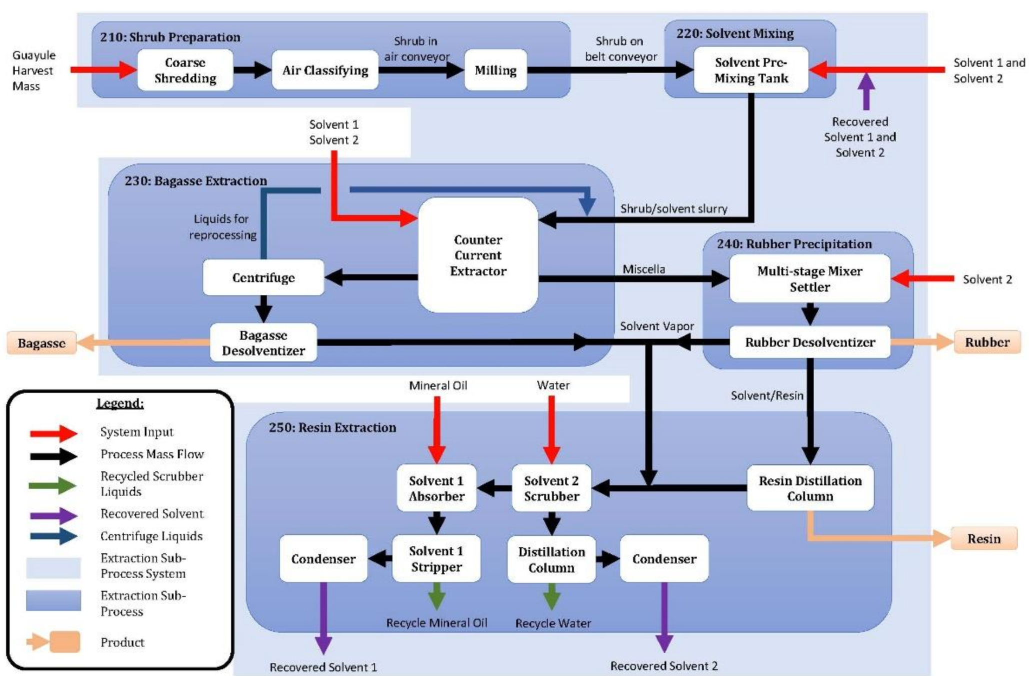

Figure 6. *Mass flow diagram for guayule solvent extraction.*

Expanding upon these two initial steps, detailed work towards a first order solvent extraction model has started. The structure of the model has been defined and is consistent with the Guar processing model in order to limit variation in methodology. With the model structure defined, work has begun towards filling out mass flows (including biomass, solvents and water) and defining primary processing equipment. As processing equipment is defined, energy consumption estimates are being put in place in preparation for the energy balance portion of the model. In addition to extraction modeling, preliminary efforts have started to identify and model key downstream conversion processes that may be able to convert bagasse into fuel and offset energy consumed in production.

- A first-order process model for extraction of rubber, resin, and bagasse from Guayule biomass has been completed. The model indicates that heat used in solvent recovery makes up the largest energy consumption across the extraction process. As a result, work has started on modeling heat integration and energy optimization within the solvent recovery sub-process. In parallel with this energy modeling, initial economic efforts are underway to estimate processing plant capital costs. The initial step in this effort is determining appropriate purchase costs for equipment in the process model. Lastly, downstream bagasse to fuels conversion processes have been integrated into modeling. First-order estimates for pyrolysis, hydrothermal liquefaction, and gasification to Fischer-Tropsch have been completed and compared for overall energy efficiency.

- Downstream Pyrolysis modeling has been completed for the guayule biomass. An excel model was built that allows inputs such as yield, energy, and flow rate which then manipulates the inputs into the economic model. The economic model is a 30 year discounted cash flow rate of return that is run to find the minimum fuel selling price of the fuels exiting the pyrolysis system. Operational costs and production yields have been identified as the most sensitive variables to change in the sensitivity analysis. Results for this process presented in Figures 7-9.

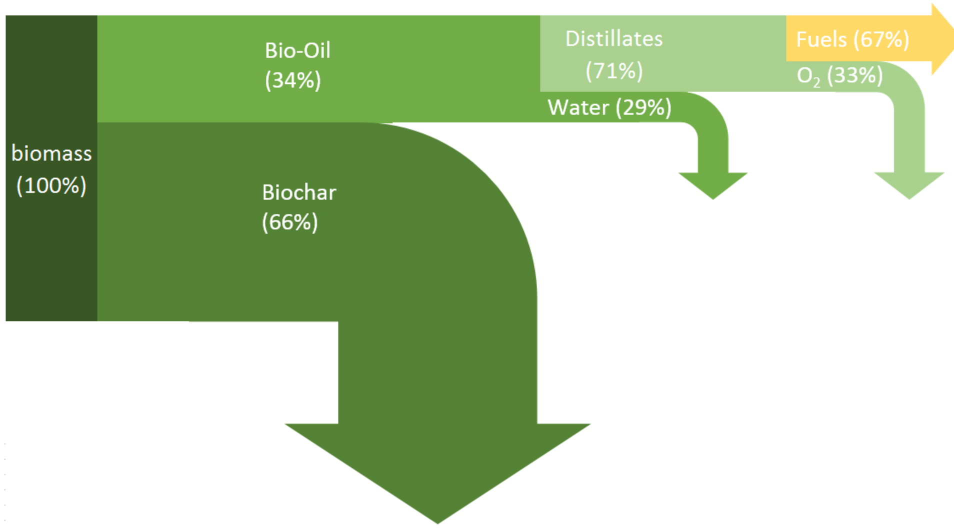

Figure 7. *Product yields based on mass for the baseline pyrolysis of guayule biomass. Inputs will change the over-all flows of the products.*

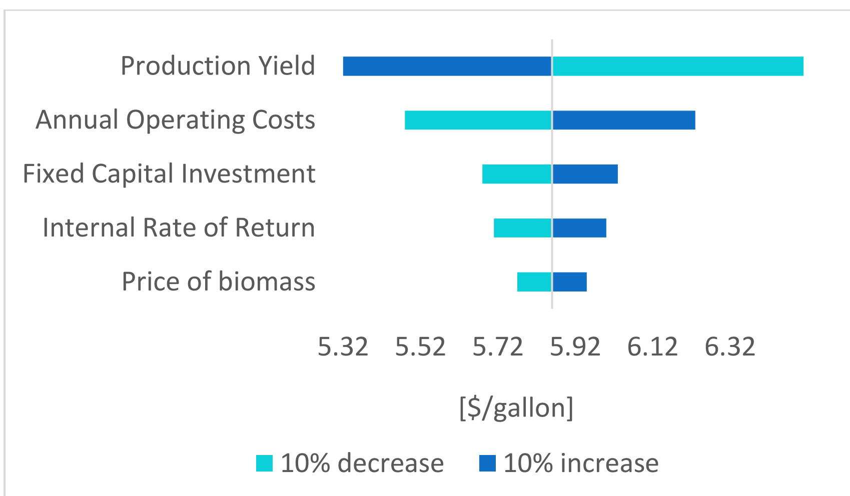

Figure 8. *Sensitivity analysis to 5 foundational inputs for the pyrolysis sub-process model.*

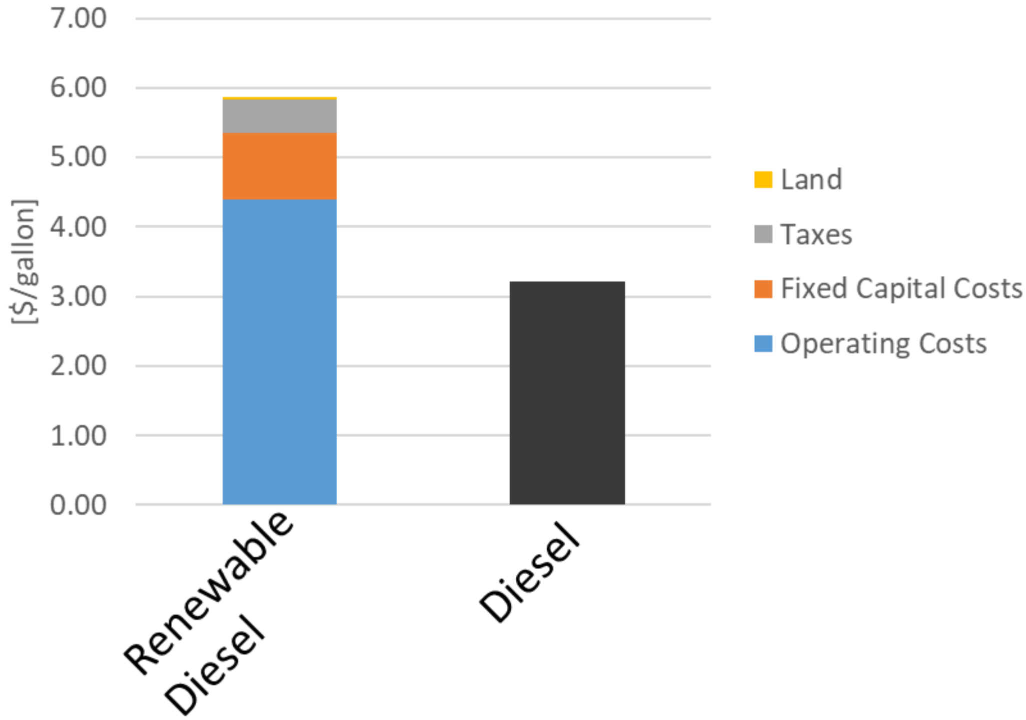

Figure 9. *Preliminary results for the economic analysis of processing bagasse to renewable diesel through pyrolysis.*

Objective 2. Integrate regionally appropriate metrics and combine results from SBAR-developed data into sustainability models to inform ongoing experiments and provide a path to commercialization of biofuels and bioproducts.

Accomplishment Detail

- The UA and NMSU Sustainability team members, have revised the enterprise budgets for guayule production in AZ, CA, NM and TX for a four-year period. Both the enterprise and partial budgets are being adapted to integrate into the whole farm level economic analysis of guayule and guar production for each state. The integration of the tools will provide decision analysis materials for producer's allowing them to look at the potential of adding in one of the crops to their current crop rotation and/or crop replacement.

- The team identified appropriate methods for whole farm economic analysis and gave a brief presentation on each method to project partners for feedback. The selected methods of analysis include Break-Even Analysis, Cost – Benefit Analysis and Stochastic Frontier Analysis. The motivation for using the above-mentioned methods, is to characterize external and internal factors at the farm level that could potentially influence guar and guayule production and economic efficiency.

- An in-depth literature review on guar has been conducted to secure relevant data on production practices, yields, and production costs. Relevant articles secured from the literature search have been shared with other SBAR team members. Work on the literature search initially began with guar and is expected to expand to include guayule.

- Preliminary guar enterprise budgets for New Mexico were developed, first using pump irrigation and then using pivot irrigation. Further work saw estimated net returns based on preliminary enterprise budget.

Objective 3. Interface with regional growers to de-risk U.S. production of guayule and guar while evaluating social impacts.

Accomplishment Detail

- Progress was made updating the costs and returns of establishing and producing guayule in Arizona. Team members met with Bridgestone at their experimental farm in Eloy, Arizona to collect representative inputs and prices for many of the costs for a 2+2+2 guayule production system. The team members at Bridgestone are now reviewing the return and cost information.

- *AgProfit* budgets for alfalfa hay, cotton, corn, wheat and grain sorghum were developed for Otero County, New Mexico. Budgets for similar crops in Maricopa County, Arizona are in the process of development. These farm-level scenarios use different average farm sizes, irrigation technologies and different crop mixes for evaluation purposes. An outline describing the components required for a case study was developed, which can show the financial statements for typical irrigated farms in Arizona and New Mexico. When complete, a whole farm analysis can compare the financial ratios and performance measures for a farm operation when implementing new cropping systems, such as guayule. The Otero County, New Mexico budget was used to generate a whole farm cash flow analysis in *AgFinance*.

- Further outlined the components required for developing an acceptable case study was constructed. The case studies can show the financial statements for typical irrigated farms in Arizona and New Mexico. When finally complete, a whole farm analysis can compare the financial ratios and performance measures for a farm operation when implementing new cropping systems, such as guayule.

EDUCATION

Executive Summary

The Education Team focuses on training teams of students and teacher mentors with a focus on rural and under-represented groups; and develops and disseminates agricultural bioenergy and bioproduct K-12 modules. In 2018, the education team concentrated efforts on identifying existing biofuel curriculum and activities, and preparing to host a summer 2-week training for the first cohort of graduate student-teacher mentor teams.

Component Leaders

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Other Key Collaborators

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- **Istvan Molnar**, University of Arizona

Other Personnel

- **New Mexico State University –** Sarah Fox, Esai Lopez, and Sicilee Macklin
- **University of Arizona –** Torran Anderson, Craig Bal, Cara Duncan, Jennifer Fields, Wolfgang Grunberg, Matthew Katterman, Kasia Kiela, Corey Knox, and Stephanie Sikora

Accomplishments – Year 1

- Comprehensive review of existing classroom lessons and activities completed; identification of curriculum that can be easily adapted for use in Arizona and New Mexico.
- Complete run-through of existing bioenergy modules with a high school agriculture classroom to identify issues or challenges.
- Finalized the summer workshop design and coordinated development of a graduate student course for the academic year.
- First cohort of graduate student fellows and teacher mentors were recruited and trained for integrating biofuel curriculum modules into K-12 classrooms beginning in Fall 2018.
- Initiated development of graduate student opportunities at the University of Arizona around the theme of sustainable bioeconomy including course and project development.

Planned Activities – Year 2

- Place graduate students in classrooms with mentor teachers; begin to design and test lessons; and begin compiling teacher/fellow lesson modules.
- Develop and lead a graduate student seminar during the academic year for Graduate Fellows related to teaching skills and biofuel lessons.
- Expand website content to include a gallery of lessons, videos, and Fellow vignettes about teaching concepts or lab demonstrations.
- Develop and host additional learning activities for teachers during the academic year and for Summer 2019.

Explanation of Variance

No variance has been experienced and accomplishments are on schedule.

Objective 1. Train teams of students and teachers with a focus on rural and underrepresented groups.

Accomplishment Detail

- Two BS/MS students in chemical engineering currently in their senior year were identified as GK12 assistants for next year; both have expressed interest in secondary/post-secondary education careers. Two undergraduate students with interests in GK12 outreach were recruited to assist with resource mining/annotation. These two students focused on NM education/science standards and activities related to chemistry, physics, engineering, and renewable energy to complement work at UA focusing on AZ standards and life sciences/biofuels. In early December, NMSU hosted a two-day EEO event where a timeline for Year 1 was developed to coordinate events and efforts. That timeline included teacher professional development workshop planning and recruiting, with a focus on 4-H outreach and after school teachers. A prioritized list of learning objectives was drafted for education/outreach and extension participants to help guide resource development.

- One teacher was identified in December, though recruitment was hampered by confusion about program eligibility/components. Those issues were addressed at a meeting with a plan to start with 4-H afterschool teachers and to piggy-back the teacher professional development week at UA following the 4-H outreach event in June. New Mexico participants (teachers, students, researchers) will attend the event at UA in 2018 to use it as a template for hosting their own events at NMSU in 2019, 2020 and 2021.

- Two graduate students were hired (UA) to research and identify resources on bioenergy curriculum, including reviewing career lessons around sustainability and bioenergy. A simple database and data storage was established for the team to deposit lesson plan/ curriculum resources. The students conducted extensive searches for existing bioenergy GK12 programming and an Excel spreadsheet was developed to record all resources and relevancy to project as well as State (AZ) and National standards (NGSS).

- Initial development for the graduate student K-12 training program began in January, with the focus being on development of activities and lessons for a two-week summer workshop for selected graduate fellows and professional teacher mentors. The program will include a graduate-level seminar offered during the next academic year.

- A teacher mentor recruitment plan and a graduate fellowship recruitment plan was developed and implemented in preparation for the 2018-2019 academic year. The first Graduate Fellow cohort of 6 students was selected (4 Graduate Fellows at the University of Arizona, Tucson, AZ; 2 Graduate Fellows at New Mexico State University, Las Cruces, NM), and participated in a Fellowship Orientation in early June 2018 (Photo 6).

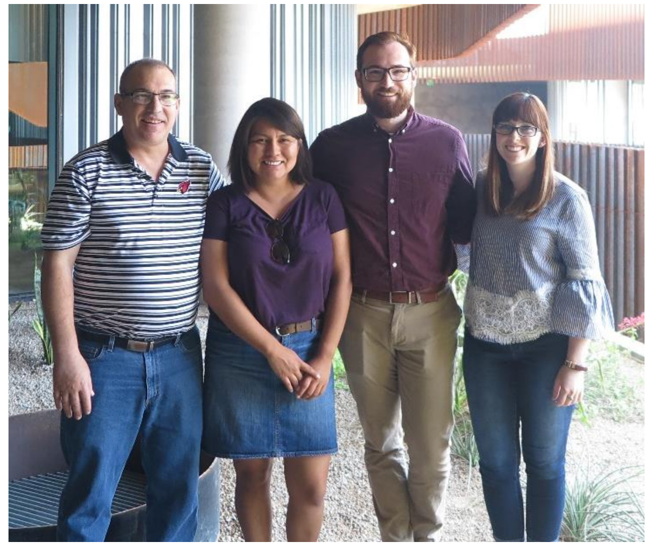

Photo 6. *University of Arizona SBAR Graduate Fellows, 2018-2019 cohort.*

- Dr. Chavarria attended several planning group meetings to integrate activities with other Education and Extension & Outreach component team members. Joint working meetings between the teacher professional development and 4-H teams were held January through March in preparation for camps and training sessions to be hosted in Summer 2018. Specific meeting times were used to design the teacher and fellow application forms, promotional fliers (different for New Mexico) (Appendix 7), and landing webpages for each element. Once materials were finalized, Cara Duncan promoted the program via listservs and boards. Dr. Chavarria promoted via College of Education listservs to existing teacher partners and student alumni. Simultaneously, a professional teacher mentor recruitment process was initiated to identify the first cohort of teachers that will be paired with the selected graduate fellows during the 2018-2019 academic year (Appendix 8). All information generated was posted to the SBAR website for broad dissemination. Review of teacher and fellow applicants was completed in April. New Mexico successfully recruited two graduate fellows and two teacher mentors for the first cohort.

- The teacher professional development team is meeting weekly to report on status of the 2-week summer program design. Corey Knox, a PhD student, has been helping with the design of the teacher professional development elements. Reflection activities are being designed for teachers to use during week 1 of the summer program, and collaborative activities for week 2. A protocol for designing new lessons is also being finalized. Finally, additional lessons are under development for how to contextualize the biofuel-related topics into real world settings around social justice and science literacy (for week 2).

- Graduate students (Lopez, Fox and Macklin) tested two guar gum activities: guar gum super bubbles, which was successfully incorporated into two outreach events, one for the general public at the local science museum and one for middle school students; and guar gum slime, which did not work as well and is currently being reformulated.

- Evaluation plan is now moving forward at a faster pace and is on track for summer implementation of evaluation tools, followed by analysis and final report for end of project year.

- Preparatory work continued on a future proposal to create tracks (study concentration areas) for sustainable bioeconomy within the existing Professional Science Master's in Applied Biosciences (PSM-ABS) Graduate Interdisciplinary Program (GIDP) for MS students, and within the Arid Lands Resource Sciences (ALRS) GIDP for PhD students. Compilation of appropriate curricula has started, and discussions with GIDP faculty have been conducted on the feasibility and the requirements of such tracks.

Objective 2. Develop and disseminate agricultural bioenergy and bioproduct K-12 modules.

Accomplishment Detail

- A meta-analysis of existing 4-H STEM curriculum and educational activities has provided sufficient information to initiate planning for the Bioenergy 4-H Camp, though literature review will continue as the planning progresses. The Extension & Outreach component team has agreed on a pathway forward to effectively integrate the efforts of the Education component and 4-H focus into a comprehensive process of curriculum development and GK-12 teacher and graduate student professional development opportunities. Additional faculty and students have been identified at NMSU that will be brought into the project in the coming months.

- Graduate students completed a comprehensive review of existing bioenergy curriculum and their adaptability for NM and AZ conditions. A spreadsheet was developed that mapped each lesson/activity to grade level and to the Next Generation Science Standard (NGSS) so that the information would be easily searched by teachers.

- Graduate students produced a model schedule for a 4-H summer camp and draft model for envisioning classroom lesson development. Initial design was also completed for the 4-H summer camp program components, which will include the teacher professional development. One graduate student was recruited to facilitate the GK-12 training.

Extension & Outreach

Executive Summary

The Extension & Outreach Team focuses on producing extension bulletins and web materials to inform growers of agronomic and irrigation requirements; holding workshops throughout the region on sustainable practices to expand crop production to new rural regions and Native Nation lands; and involving youth in internships, 4-H projects, and STEM summer camps. In 2018, the Extension & Outreach Team concentrated efforts on data gathering through a grower-focused needs assessment tool, and coordinating a summer 4-H biofuels camp program.

Component Leaders

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Other Key Collaborators

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- **Kulbhushan Grover**, New Mexico State University
- **Paul Gutierrez**, New Mexico State University
- **F.Omar Holguin**, New Mexico State University
- **Sara Chavarria**, University of Arizona
- **Gerardo Lopez**, University of Arizona
- **Channah Rock**, University of Arizona

Other Personnel

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- **University of Arizona** – Torran Anderson, Nick Ashley, Craig Bal, Natalie Brassill, Daniela Cabrera, Cara Duncan, Jennifer Fields, Wolfgang Grunberg, Matthew Katterman, Kasia Kiela, and Stevi Zozoya

Accomplishments – Year 1

- A Needs Assessment for growers was developed and deployed in Arizona and New Mexico to determine gaps in information and how best to generate interest around guayule and guar production.
- Began introducing guayule and guar as a potential crop for biofuel production in the Southwest. Presentations and tabling events were conducted reaching over 1,095 growers and the interested public.
- Extension Advisory Committees (comprised of growers and producers) have been established in New Mexico.
- Selected first SBAR cohort of four (4) high school/undergraduate student interns for project work during summer 2018.
- In collaboration with Education Team, designed and hosted a one-week biofuel summer camp for 4-H participants in Tucson, Arizona.

Planned Activities – Year 2

- Continue to increase awareness to growers and stakeholders about the potential for guayule and guar as a future crop to New Mexico and Arizona.

- Use the Extension Field Station demonstration trials as a tool during field meetings and workshops.
- Farmer demonstration site hosts will be identified in New Mexico and Arizona to showcase potential guayule and guar production.
- Develop extension bulletins and outreach materials to highlight SBAR-focused research results and tools (irrigation app, economic models, etc.).
- Conduct evaluation of on-going SBAR extension-related activities.
- Select second SBAR cohort of six (6) high school/undergraduate student interns for project work during summer 2019.

Explanation of Variance

No variance has been experienced and accomplishments are on schedule.

Objective 1. Produce Extension bulletins and web materials to inform growers of agronomic and irrigation requirements.

Accomplishment Detail

- Served on the advisory committee of the Western Sustainable Agricultural Research and Education (WSARE) and planned for a field day at NMSU. The NMSU Extension team is planning for an extension field day focused on guar in 2018. We also presented a poster on guar at NMSU University Research Council meeting, and at NMSU College of Agricultural, Consumer and Environmental Sciences Open House. We also continue to provide information and answer queries from growers/clientele about guar cultivation and other related topics.

- Information about the SBAR project was disseminated to stakeholder within New Mexico throughout the first 6 months of the project. A press release on SBAR was distributed in New Mexico on February 21, 2018, highlighting the participation of the New Mexico State University in the project. The press release also contained information about the project objectives and funding agency.

- Guayule demonstration plots were established at the NMSU Extension Agricultural Center (Photo 7) in May 2018. The demonstration plots will be used for educational field days targeted to regional growers.

- A local New Mexico advisory committee is being formulated, which will provide input to future guar and guayule production in the state. Three (3) Extension agents and 3 area growers

Photo 7. *Guayule 1-week growth, New Mexico.*

have committed. The target advisory committee consists of 4-5 agents and 4-5 growers, which is achievable by the end of first year.

- Drs. Idowu, Grover and Angadi visited Mr. Alex Muraviyov, General Manager of Guar Resources to discuss guar extension needs in an effort to increase guar acreage and production in the region. Discussion topics also included a possible field day and tour to inform growers about guar production and use as a regional alternative crop. The SBAR project and the possible development of guar as an industrial crop in the region will be presented in the upcoming field day of Clovis Agricultural Science Center on August 9, 2018. Discussions with guar researchers in Brownfield, Texas included breeding, agronomic issues, and developing new/adoption of an existing crop growth model for guar.

- The full Extension & Outreach component team worked collectively to develop a needs assessment for producers that was initially deployed in AZ in Spring 2018, and will be deployed in NM beginning in the Fall 2018. The UA Extension team finalized the tool, which was reviewed by both the Integrated Crop Management (ICM) Extension Working Group and the UA Institutional Review Board (IRB). The final survey tool was first deployed during the Southwest Agricultural Summit held in Yuma, AZ in March 2018.

- As of the end of March 2018, the UA Extension team surveyed over 60 growers in Arizona using the online platform Qualtrix. Example stakeholder needs assessment questions focus on awareness of the crops guayule and guar, common terminology, how stakeholders prefer information, questions/concerns, willingness to support biofuels, and alternative crop research. Additionally, questions targeting growers' sustainability "ethic" as well as changes in growing practices as a result of impacts of variable climates and changing weather patterns were asked. An overview of select stakeholder needs assessment questions and responses to-date is provided below.

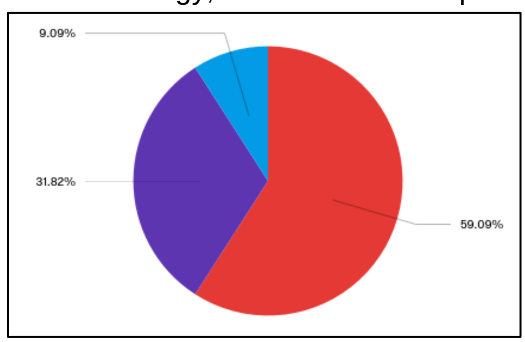


Figure 10. *Guayule awareness among Arizona growers.*

Question 1 (Figure 10): *Have you heard of the crop Guayule (pronounced why-YOU-lee)? [Red=Yes(59.09%); Purple=No (31.82%); and Blue=Not sure (9.09%)]*
Question 2 (Figure 11): *Are you aware that Arizona Cooperative Extension is supporting new biofuel and bio-product research on Guayule? [Top=Yes; Middle=No; Bottom=Not Sure]*

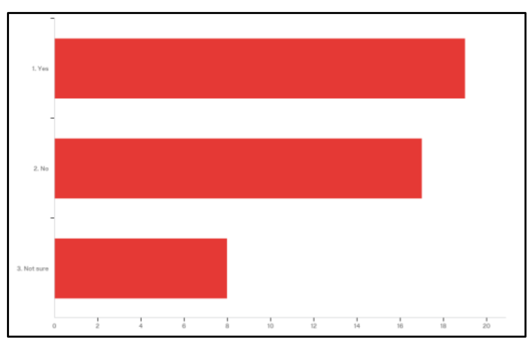


Figure 11. *Arizona Cooperative Extension biofuel and bio-product research awareness.*

Question 3: *Some suggested benefits of the production of biofuel and bio-product crops include promoting America's energy security, reduction in greenhouse gas emissions, protection of the environment, and financial benefits for farmers and agricultural businesses. Taking that into consideration, are you interested in the production of biofuel and bio-product crops as a sustainable resource?*

- 65.91% responded "Yes",
- 25% responded "Not sure", and
- 9.09% responded "No".

While generally respondents were supportive, when asked "*What are some of the questions that you will likely have, if converting some of your current farm land into Guayule?"* , top responses included (1) crop growth cycle; (2) cultural practices (fertilizer, soil health, herbicide/pesticide management); (3) market demand and access; and (4) irrigation management (quantity and salinity). Additional opened-ended responses included comments related to pest management and economic viability.

Needs assessment questions were also tailored to help Cooperative Extension learn best ways to communicate findings to these select grower stakeholders. When asked to rank resources related to the following question, "*What would help answer your questions regarding biofuel or bio-product crops such as Guayule?",* the top responses are as follows:

1. Crop production information (pamphlets, factsheets, reports, etc.)
2. Informational workshops
3. One-on-one farm advice
4. Field demonstration sites

Nearly 77% of respondents noted that they have seen changes or changed their farming practices, techniques or methods in the last 5 years with 52.27% responding that they had adopted new or different management practices to better manage climate variability.

Objective 2. Hold workshops throughout the region on sustainable practices to expand crop production to new rural regional and Native Nation lands.

Accomplishment Detail

- The interest and number of producers that would like to host a guayule and guar demonstration site in New Mexico continues to grow as producers learn about the SBAR project. However, with limited seed available, the selected demonstration sites will initially be few.

- Discussions and needs evaluation are underway in preparation for establishing educational field days for growers and other stakeholders to learn more about guar and guayule production. Field extension days are likely to be hosted in early 2019.

Objective 3. Involve youth in internships, 4-H projects and STEM summer camps.

Accomplishment Detail

- Graduate students, Craig Bal and Matthew Katterman, completed a comprehensive evaluation of existing biofuel lessons/curriculum. Upon review, 9-lessons have been identified for use during the summer camp activities.

- The 9-biofuel lessons and the biofuel project have been beta-tested by Craig Bal in his Middle School classroom where he is completing student teaching. Several other lessons and the biofuel project have been beta-tested at Dr. Kim Ogden's on-campus laboratory.

- The design and planning of the 4-H Camp was finalized. Minor changes were necessary in the schedule after careful review of the activities and timelines.

Photo 8. *Graduate student, Craig Bal, providing an overview of 4-H Summer Camp program.*

- The 4-H Camp flyer (Figure 12) was finalized by Cara Duncan with input from Education/4-H teams, and then broadly disseminated to identify interested students. The student application was finalized by Ms. Daniela Cabrera with input from Education/4-H team, and the camp schedule was finalized by Craig Bal, Matthew Katterman, Dr. Chavarria and Dr. G. Lopez.

- Dr. Chavarria assisted the 4-H graduate students in a comprehensive review of the 4-H summer camp lessons and activities for "camp" friendliness to reduce the "classroom-like" feel of certain activities.

- The summer camp cost estimate budget was developed and updated to reflect actual costs, which is searchable based on lesson/activity. This will be the basis for future module kit development and for teacher planning.

- Successfully recruited four (4) students for the *Project Puente* internship program. Students will conduct SBAR-related

Figure 12. *Flyer for the 4-H Summer Camp: Biofuels Powering Your World.*

summer research at the Maricopa Agricultural Center and at the University of Arizona in Tucson.

- Template materials were designed and developed for the *Project Puente* interns to utilize during their summer research session. All research results generated from these internships will be presented as posters during the 2018 SBAR Retreat in August.

- NMSU will use portions of the SBAR 4-H Biofuels Camp curriculum for workshops at the NMSU 4-H in-service provided to instructors in youth development. Portions of the 2018 SBAR 4-H Biofuels Camp curriculum for youth will be used to host a day-long camp for participants on Navajo Nation and in Dona Ana County during the summer of 2018.

- Evaluation tasks are moving forward at a faster pace and they are on track for summer implementation of evaluation tools, followed by analysis and final report for end of project year.

PRODUCTS GENERATED.
September 2017 – March 2018

PUBLICATIONS, CONFERENCE PAPERS AND PRESENTATIONS

Publications

None this reporting period.

Conference Papers

None this reporting period.

Scholarly Presentations

1. **Brewer, C.E. 2018**. *Pairing biomass residues with conversion technologies*. Advanced Bioeconomy Leadership Conference, Washington, D.C. 28 February 2018.
2. **Brown, K.S., Neilson, J.W., Waller, P.M., Ray D.T., Dierig, D., Maier, R.M. 2018.** *Microbial contributions to soil health: Optimizing guayule (Parthenium argentatum) production in an arid environment*. SWESx Earthday Symposium. Tucson, Arizona. 15 April 2018.
3. **Brown, K.S., Neilson, J.W. 2018.** *Microbial contributions*. SBAR UA Research Team Seminar. University of Arizona. Tucson, Arizona. April 2018.
4. **Deirig, D. 2017.** *Bridgestone's perspective on a domestic source of natural rubber in the desert.* Invited Speaker at the New Mexico Sustainable Agriculture Conference. Los Lunas, New Mexico. 13 December 2017.
5. **Godfrey, D., Willmon, J., Teetor, V.H., Schmalzel, C., and Ray, D.T. 2018.** *Vegetative propagation of guayule*. 2018 Annual Conference, American Society for Horticultural Science, Washington D.C. 30 July – 3 August 2018.
6. **Grover, K. 2017.** *Guar as a potential alternative crop in New Mexico*. Invited Speaker at the New Mexico Sustainable Agriculture Conference. Los Lunas, New Mexico. 13 December 2017.
7. **Grover, K. and Garcia, A. 2018.** *Evaluating guar as a potential alternative crop in New Mexico*. University Research Council Meeting, New Mexico State University. Las Cruces, New Mexico. 15 February 2018.
8. **Idowu, O.J. 2018.** *Introduction to the SBAR Project*. Las Cruces, New Mexico. 6 Feb 2018.
9. **Lopez, E. 2018.** *Sustainable Bioeconomy for Arid Regions: Activities for education, extension and outreach*. American Institute of Chemical Engineers Rocky Mountain Regional Student Conference. Provo, Utah. 23 March 2018.
10. **Niu, D., 2018.** *Partial cloning of APETALA1 (AP1) gene from guayule*. cDNA Lab Seminar, USDA-ARS Western Regional Research Laboratory. 28 March 2018.
11. **Mealing, V. 2018.** *An overview of sustainability analysis methods of a new biofuel feedstock: bagasse from guar*. 6th Colorado School of Mines Graduate and Discovery Symposium. Golden, Colorado. 5 April 2018.
12. **Ogden, K. 2017**. *Introducing new USDA NIFA CAP grant awardees – Developing regional AJF supply chains: Sustainable Bioeconomy for Arid Regions*. Invited Panel Speaker at the CAAFI-SOAP Jet Webinar. Hosted online. 13 October 2017.

13. **Ogden, K. 2017.** *Sustainable Bioeconomy for Arid Regions*. Invited Speaker at the Biomass Research and Development Technical Advisory Board Meeting. 15 November 2017.
14. **Ogden, K. 2018.** *Sustainable Bio-economy for Arid Regions*. Southwest Indian Agricultural Association. Laughlin, Nevada. 16-18 January 2018.
15. **Ogden, K., White, R., Brewer, C.E. 2018.** *Public Private Partnerships*. ABLC Conference. Washington, D.C. 27-28 February 2018.
16. **Rock, C., and Brassill, N. 2018.** *Importance of Cooperative Extension in University Research*. University of Arizona, Tucson, Arizona. 14 March 2018.
17. **Sun, O., and Fan, N. 2018.** *Harvest scheduling*. SBAR Logistics Team Group Meeting. (webinar) New Mexico State University. Las Cruces, New Mexico. 5 February 2018.
18. **Sun, O., and Fan, N. 2018.** *Optimization of feedstock logistics*. SBAR UA Research Seminar. University of Arizona. Tucson, Arizona. 14 February 2018.
19. **Sun, O., and Fan, N. 2018.** *Optimally locating biorefineries*. SBAR Sustainability Working Group Seminar. (webinar) Colorado State University. Lakewood, Colorado. 8 March 2018.
20. **Summers, H.M., Sproul, E., Johnson, J., Quinn, J.C. 2017.** *Sustainability assessment of bioproducts from southwest arid crops*. 21st Century Energy Transition Symposium, Colorado State University, Fort Collins, CO, October 2017.
21. **Summers, H.M., Sproul, E., Johnson, J., Quinn, J.C. 2017.** *Sustainability assessment of bioproducts from southwest arid crops*. Colorado State University Graduate Student Showcase, Colorado State University, Fort Collins, CO, November 2017.
22. **Willmon, J., Hu, J., Teetor, V.H., and Ray, D.T. 2018.** *Screening Parthenium argentatum for resistance to Phymatotrichum omnivorum*. 2018 Annual Conference, American Society for Horticultural Science, Washington, D.C. 30 July – 3 August 2018.

Table 6. *Total Audience Demographics for Project-Related Presentations (when captured).*

Audience Demographic Parameter	Previous Report Total	This Report Total	Cumulative Project Total
Gender			
Males	0	338	***338***
Females	0	186	***186***
Race/Ethnicity			
Hispanic	0	69	***69***
Asian	0	45	***45***
Native American	0	106	***106***
African American	0	25	***25***
Anglo/White	0	279	***279***
Total People Reached through SBAR Activities			***524***

WEBSITE(S) OR INTERNET SITE(S)

SBAR Project Website

1. .https://sbar.arizona.edu

NEW TECHNOLOGIES OR TECHNIQUES GENERATED

None this reporting period.

INVENTIONS, PATENT APPLICATIONS, AND/OR LICENSES

1. **Dec 2017.** 24c SLN Label for Gramoxone SL 2.0 Herbicide (Paraquat dichloride), for control of weeds in guayule. SLN Registration Number: AZ120005. Expiration: 31 Dec 2022. Arizona Department of Agriculture, Environmental Services Division.

2. **Dec 2017.** 24c SLN Label for Fusilade DX Herbicide (*Propanoic acid, 2-(4-((5-(trifluoromethyl)-2-pyridinyl)oxy)phenoxy)-, butyl ester, (R)-*), for control of emerged weeds in guayule. SLN Registration Number: AZ070006. Expiration: 31 Dec 2022. Arizona Department of Agriculture, Environmental Services Division.

OTHER PRODUCTS GENERATED

Brochures, Factsheets, and Flyers

1. **Duncan, C.M. 2018.** SBAR USDA-NIFA graduate student fellowship: UA Students. One page promotional flyer. February and March.
2. **Duncan, C.M. 2018.** SBAR USDA-NIFA graduate student fellowship: NMSU Students. One page promotional flyer. February and March.
3. **Duncan, C.M. 2018.** SBAR call for middle and high school science teachers. One page promotional flyer. February and March.
4. **Duncan, C.M. 2018.** SBAR 4-H summer camp: Biofuels powering your world. One page promotional flyer. March.
5. **Grover, K. 2018**. Guar – A potential alternative crop in New Mexico. Two page informational handout. January.
6. **Kiela, C. 2018.** Guayule. SBAR Project two-page fact sheet. March.
7. **Kiela, C. 2018.** Guar. SBAR Project two-page fact sheet. April.
8. **Kiela, C. 2018.** History of Guayule. SBAR Project two-page fact sheet. April.
9. **Rogstad, A. 2017.** SBAR – Sustainable Bioeconomy for Arid Regions. One-page informational and promotional card. November.

Press Releases and News Articles

1. 26 Sep 2017. "As NIFA awards $21.1M to grow the bioeconomy, CABLE debuts to bridge students and industry." BiofuelsDigest. http://www.biofuelsdigest.com/bdigest/2017/09/26/as-nifa-awards-21-1m-to-grow-the-bioeconomy-cable-debuts-to-bridge-students-and-industry/

2. 16 Oct 2017. “UA to Head New Center Focusing on Biofuels and Bioproducts.” UA News. https://uanews.arizona.edu/story/ua-head-new-center-focusing-biofuels-and-bioproducts

3. 4 Nov 2017. “Biofuels, bioproducts, and an Arizona bioeconomy?” Arizona Daily Wildcat. http://www.wildcat.arizona.edu/article/2017/11/science-biofuels-and-bioproducts

4. 29 Nov 2017. “NMSU to host state sustainable agriculture conference in Los Lunas.” News Bulletin. http://www.news-bulletin.com/news/nmsu-to-host-state-sustainable-agriculture-conference-in-los-lunas/article_a45281f6-d540-11e7-9530-27dc93258a79.html

5. 16 Jan 2018. “Dr. Quinn’s Sustainability Expertise Recruited for Multi-Million Dollar DOE and USDA Grants.” Colorado State University, Mechanical Engineering Featured Projects. http://www.engr.colostate.edu/me/2018/01/16/dr-quinns-sustainability-expertise-recruited-for-multi-million-dollar-doe-and-usda-grants/

6. 21 Feb 2018. “NMSU collaborating in Sustainable Bio-economy for Arid Regions project.” New Mexico State University News Center. http://newscenter.nmsu.edu/Articles/view/12961/nmsu-collaborating-in-sustainable-bio-economy-for-arid-regions-project

7. 27 Feb 2018. “Bridgestone receives guayule research grant from USDA.” The Smithers Report - A daily and weekly tire industry news source. (4,500 daily subscribers) https://www.smithersrapra.com/publications/the-smithers-report

8. 27 Feb 2018. “Bridgestone and research partners earn $15 Million grant for guayule work.” MTD (Modern Tire Dealer). UMV: 62,085. http://www.moderntiredealer.com/news/728673/bridgestone-and-research-partners-earn-15-million-grant-for-guayule-work

Tabling Events and Workshops – Marketing and Outreach

1. 14 July 2017. New Mexico Cotton Ginners Conference. New Mexico.
2. 17 Aug 2017. SBAR Project Kick-off Meeting. Tucson, Arizona.
3. 28 Oct 2017. Rocky Mountain Zone Summit (sustainability focus). Denver, Colorado.
4. 05 Dec 2017. Valencia County (New Mexico) Forage Conference. New Mexico.
5. 13 Dec 2017. New Mexico Sustainable Agriculture Conference. Los Lunas, New Mexico.
6. 15-17 Feb 2018. SBAR Display Table. New Mexico Organic Farming Conference. Albuquerque, New Mexico.
7. 24 Feb 2018. Farm Science Day. USDA-ARS, Arid-Land Agricultural Resource Center. Maricopa, Arizona.
8. 24 Feb 2018. 2018 Engineering Fair – Recycled papermaking and guar gum bubbles activity. Las Cruces Museum of Science and Nature. Las Cruces, New Mexico.
9. 22-24 Feb 2018. Southwest Ag Summit. Yuma, Arizona.
10. 15 Mar 2018. Zia Middle School Project – Lead the Way NMSU College of Engineering Day. Recycled papermaking and guar gum bubbles activity. Las Cruces, New Mexico.

11. 19 Mar 2018. Roosevelt Irrigation District Board Meeting. Buckeye, Arizona.
12. 28 Mar 2018. Alfalfa and Forage Workshop. Maricopa, Arizona.

→*Total Reach via Tabling Events and Workshops (when captured):* ***1,095 participants***

PARTICIPANTS AND COLLABORATING ORGANIZATIONS
September 2017 – March 2018

PARTNER ORGANIZATIONS

Organization Person	Project Role	Project Component (Objective Number)
Bridgestone Americas,		
David Dierig	Key Collaborator	FD (1,3,4)
Stefan Dittmar	Professional	FD (1,3,4)
Amber Lynch	Professional	FD (1,3,4)
Mark Von Cruz	Professional	FD (1,3,4)
Sam Wang	Professional	FD (1,3,4)
Colorado School of Mines		
Pragnya Eranki	Professional	SUS (1)
Amy Landis	Key Collaborator	SUS (1)
VeeAnder Mealing	Graduate Student	SUS (1)
Colorado State University		
Jack Johnson	Undergrad Student	SUS (1)
Jason Quinn	Key Collaborator	SUS (1)
Evan Sproul	Graduate Student	SUS (1)
Hailey Summers	Graduate Student	SUS (1)
New Mexico State University		
Ram Acharya	Professional	SUS (2)
Sarah Acquah	Post-doc	EO (1, 2, 3) SUS (2)
Sangu Angadi	Key Collaborator	FD (2, 3) EO (1)
Sultan Begna	Professional	FD (2, 3)
Catherine E. Brewer	Key Collaborator	E (1, 2) LOG (1, 3)
Feng Cheng	Graduate Student	LOG (1,3)
Barry Dungan	Professional	LOG (1)
Sarah Fox	Undergrad Student	E (1, 2)
Kulbhushan Grover	Key Collaborator	EO (1) FD (2, 3)
Paul H Gutierrez	Key Collaborator	EO (1, 2, 3) SUS (2)
F. Omar Holguin	Key Collaborator	LOG (1)
John Idowu	Key Collaborator	EO (1)
Travis Le-Doux	Undergrad Student	LOG (1,3)
Esai Lopez	Undergrad Student	E (1, 2)
Sicilee Macklin	Undergrad Student	E (1, 2) LOG (1,3)
Sa’Rae Montoya	Graduate Student	LOG (1)
Darien Pruitt	Professional	EO (1)

Joram Robbs	Graduate Student	EO (1, 2, 3) SUS (2)
Jagdeep Singh	Graduate Student	FD (2, 3)
Peter Skelton	Professional	EO (1, 2, 3)
Brian Treftz	Undergrad Student	LOG (1,3)
Jacob Usrey	Undergrad Student	LOG (1,3)
Stephanie Willette	Graduate Student	LOG (1)
Scott Woolf	Undergrad Student	LOG (1,3)
Other		
Jennifer Fields	Professional	E (1) EO (2, 3)
Oregon State University		
Clark Seavert	Key Collaborator	SUS (3)
University of Arizona		
Torran Anderson	Professional	E (1, 2) EO (1, 3)
Nick Ashley	Graduate Student	EO (1) FD (5)
Craig Bal	Graduate Student	E (1, 2) EO (3)
Megan Bennett	Undergrad Student	FD (1,3,4)
Natalie Brassill	Professional	EO (1, 3)
Kyle Brown	Graduate Student	FD (6)
Daniela Cabrera	Professional	EO (3)
Sara Chavarria	Key Collaborator	E (1,2) EO (3)
German Coronado	Undergrad Student	FD (1,3,4)
Cara Duncan	Professional	E (1, 2) EO (3)
Diaa El-Shikha	Post-doc	FD (5)
Blase Evancho	Graduate Student	FD (1,3,4)
Neng Fan	Key Collaborator	LOG (2)
Krista Farmer	Undergrad Student	FD (3, 4)
Daryan Godfrey	Undergrad Student	FD (1,3,4)
Leslie Gunatilaka	Key Collaborator	LOG (4)
Wolfgang Grunberg	Professional	ALL AREAS
Matthew Katterman	Graduate Student	E (1, 2) EO (3) FD (5)
C. Kasia Kiela	Undergrad Student	ALL AREAS
Corey Knox	Graduate Student	E (1, 2)
Gerardo Lopez	Key Collaborator	EO (3)
Raina Maier	Key Collaborator	FD (6)
Hadiqa Maqsood	Graduate Student	FD (5)
William McCloskey	Key Collaborator	FD (5)
Istvan Molnar	Key Collaborator	E (1)
Julie Neilson	Professional	FD (6)
Andrew Nelson	Post-doc	FD (1)
Kim Ogden	Key Collaborator	ALL AREAS

Bryan Pastor	Professional	FD (5)
Duke Pauli	Key Collaborator	FD (1)
Sam Pernu	Undergrad Student	PROD (1)
Dennis Ray	Key Collaborator	FD (1,3,4)
Channah Rock	Key Collaborator	EO (1, 3)
Alix Rogstad	Professional	ALL AREAS
Carl Schmalzel	Professional	FD (1,3,4)
Stephanie Sikora	Professional	E (1,2)
Ou Sun	Graduate Student	LOG (2)
Trent Teegerstrom	Key Collaborator	SUS (3)
Valerie Teetor	Professional	FD (1,3,4)
Peter Waller	Key Collaborator	EO (1) FD (5)
Quinn Waltz	Undergrad Student	FD (1,3,4)
John Willmon	Undergrad Student	FD (1,3,4)
Ya-ming Xu	Post-doc	LOG (4)
Stevi Zozoya	Undergrad Student	EO (1, 3)
USDA Agriculture Research Service – US Arid Lands Research Center, Maricopa AZ		
Hussein Abdel-Haleem	Key Collaborator	FD (2)
USDA Agriculture Research Service – Western Regional Research Center, Albany CA		
Niu Dong	Professional	FD (1)
Colleen McMahan	Key Collaborator	FD (1)

Total Key Collaborators: ***25***
Total Professional Staff: ***23***
Total Postdoctoral Researchers: ***4***
Total Graduate Students: ***16***
Total Undergraduate Students: ***17***

COLLABORATIONS AND OTHER CONTACTS

Collaborations:

Academic Institutions:	CSM (Colorado School of Mines) - Dept. of Civil and Environmental Engineering CSU (Colorado State University) - Dept. of Mechanical Engineering NMSU (New Mexico State University) - Cooperative Extension - Dept. of Agricultural Economics and Agricultural Business - Dept. of Chemical Engineering - Dept. of Plant and Environmental Sciences OSU (Oregon State University) - Dept. of Applied Economics UA (University of Arizona) - Agricultural and Biosystems Engineering - College of Education - Cooperative Extension - Dept. of Agriculture and Resource Economics - Dept. of Chemical and Environmental Engineering - Dept. of Soil, Water and Environmental Sciences - Dept. of Systems and Industrial Engineering - Natural Products Center - School of Natural Resources and the Environment - School of Plant Sciences
Nonprofits:	
Industrial or Commercial Firms:	BASF Bridgestone Americas, Inc. FMC Guar Resources Syngenta
Federal Government	USDA – Agricultural Research Service, Arid Land Agricultural Center - Plant Physiology and Genetics USDA – Agricultural Research Service, Western Regional Research Center - Chemistry (Bioproducts) - Plant Genetics
State or Local Governments:	Arizona Department of Agriculture, Environmental Services Division

Tribal Governments:	
Schools or School Systems:	BASIS Charter Schools, BASIS Tucson North (high school), Tucson Arizona
Other Organizations (foreign or domestic):	

Other Contacts:

Contacts with others within recipient's organization (interdepartmental or interdisciplinary collaborations):	UA (University of Arizona) - Applied Biosciences - Arid Lands Resource Sciences - College of Agriculture and Life Sciences
Contacts with others outside the organization:	Denver Museum of Nature and Science, Denver Colorado Central Arizona College
Contacts with others outside the United States or with an international organization:	

APPENDICES

APPENDIX 1. SBAR ADVISORY BOARD MEMBERS

Name	Title // Organization
Chris Cassidy	National Business Renewable Energy Advisor U.S. Department of Agriculture
Matthew Chavez	Independent Grower and Landowner
Steve Csonka	Executive Director, Commercial Aviation Alternative Fuels Initiative (CAAFI)
Mark DeDecker	Chemical Engineer, Bridgestone Americas, Inc.
Gary Deen	Independent Grower, Double D Farms Partnership
William Goldner	National Program Leader – Biomass Feedstock Development and Production Systems, U.S. Department of Agriculture - NIFA
Mark Ingratta	Group Leader – Application Research, Eastman Chemical Company
Ignatius Kadoma	Advanced Research Specialist, 3M Corporate Research and Analytical Lab
Chris Kuzdas	Project Manager, Water Program Environmental Defense Fund
Homer Marks	President, Southwest Indian Agriculture Association
Newton McCarty	Agricultural Extension Agent/Assistant Professor New Mexico State University
JJ McGlasson	Engineer Elite Wells Service
Jaroy Moore	Resident Director Texas A&M AgriLife Research and Extension Center
Alex Muravijov	General Manager Guar Resources
Matt Payne	Principal – Southwest Office West Water Research
Richard Sayre	Senior Research Scientist New Mexico Consortium
Robert White	Section Manager – Biorubber Processing Research Plant Bridgestone Americas, Inc.

APPENDIX 2. 2018 SBAR ANNUAL RETREAT DRAFT AGENDA

Wednesday, 1 August 2018	**PRE-RETREAT SESSION**
1000 – 1200	SBAR Project Component Working Sessions (*Scheduled and facilitated by Component LEADS or other teams, as desired*)
1200-1330	Lunch (*on your own*)
1330-1630	SBAR Project Component Working Sessions *cont*.
Thursday, 2 August 2018	**RETREAT SESSION – DAY 1**
0745 - 0845	**Continental Breakfast** with coffee/tea *(provided on site)*
0800 – 0815	**Welcome** ~ *Kim Ogden* - Quick introductions/ice breaker - Overview of schedule; intended retreat outcomes
0815 – 0830	**SBAR Evaluation Plan** … Overview and Expectations (Setting the stage for Retreat) - Three Levels of Excellence - Key Questions per component - Advisory Committee Feedback Loop
0830 – 0930 *0830 – 0850* *0855 – 0915* *0920 – 0940*	**Component Status Updates**… lightening-round <u>Accomplishments Overview</u> per Team (~20min report of what was completed in 2017-2018) Feedstock Development & Production ~ *Dennis Ray* Post-Harvest Logistics & Co-Products ~ *Catie Brewer* System Performance & Sustainability ~ *Jason Quinn*
0940 – 1000	~BREAK~
1000 – 1045 *1000 – 1020* *1025 – 1045*	**Component Status Updates, cont.**… lightening-round <u>Accomplishments Overview</u> per Team (~20min report of what was completed in 2017-2018) Education ~ *Sara Chavarria / Catie Brewer* Extension & Outreach ~ *John Idowu*
1045 – 1215	**Student Lightening Round Session** … - Quick Student presentation on their project and results obtained - What was the most exciting part of your work? - Why should people come by your poster?
	Student Poster Session I …Visit the student posters; review accomplishments; Q&A (opportunity to film/photograph/take statements for outreach materials)
1215 – 1300	Lunch (*provided on site*)

1300 – 1400	**Future Steps**… lightening-round discussion for your next steps in extension, education, and outreach (EEO) and how they get us closer to meeting the project goals of integrating research and EEO. (max 2 slides per person: (1) how you fit into the SBAR mission; (2) what you need from collaborators in the next year = ~5min ea) **Extension & Outreach** *<u>Presenters</u>: Channah Rock, Sangu Angadi, Paul Gutierrez, Kulbhushan Grover, John Idowu, Jerry Lopez* **Education** *<u>Presenters</u>: Sara Chavarria, Catie Brewer, Istvan Molnar, Kim Ogden (Stephanie Sikora)*
1400 – 1420	~BREAK~
1420 – 1630	**Future Steps**… lightening-round discussion for your next steps in research and how they get us closer to meeting the project goals. (max 2 slides per person: (1) how you fit into the SBAR mission; (2) what you need from collaborators in the next year = ~5min ea) **System Performance & Sustainability** *<u>Presenters</u>: Amy Landis, Jason Quinn, Neng Fan, Trent Teegerstrom (Clark Seavert), Catie Brewer, Paul Gutierrez* **Post-Harvest Logistics & Co-Products** *<u>Presenters</u>: Neng Fan, Leslie Gunatilaka, Catie Brewer, Istvan Molnar, Omar Holguin, Sangu Angadi, Kulbhushan Grover* **Feedstock Development & Production** *<u>Presenters</u>: Dennis Ray, Peter Waller, Raina Maier (Julie Neilson), Diaa El-Shikha, Omar Holguin, Kim Ogden, David Dierig, Colleen McMahan, Hussein Abdel-Haleem, Duke Pauli, Bill McCloskey, Kulbhushan Grover*
1630 – 1700	**Student Poster Session II** …Visit the student posters; review accomplishments; Q&A (opportunity to film/photograph/take statements for outreach materials)
1700 – 1830	~BREAK~
1830 - ??	**Happy Hour & Group Supper** (off-site location; Downtown Tucson near the street car)

<table>
<tr><th colspan="2">Friday, 3 August 2018</th><th colspan="2">RETREAT SESSION – DAY 2</th></tr>
<tr><td>0745 – 0845</td><td colspan="3">Continental Breakfast with coffee/tea (provided on site)</td></tr>
<tr><td></td><td>SBAR PROJECT TEAM</td><td>SBAR STUDENTS</td><td>ADVISORY BOARD</td></tr>
<tr><td>0830-1015</td><td>Working Session… thoughts, ideas, concerns, questions generated from presentation sessions
- “Ah-ha” moments? Places where further integration among project components may be possible?
- Are there new opportunities that could benefit the project outcomes?
- How will you integrate your work with other project components?

Facilitator: Colleen McMahan</td><td>Working Session… SBAR students across all institutions

- “Ah-ha” moments from this project retreat?
- What information do you need from others in the next year?
- How will you integrate your work with other project components?

Facilitator: Torran Anderson</td><td>Working Session… SBAR Advisory Board will conduct a working session for evaluating and advising project implementation
- What are the key challenges this project is addressing?
- Are these challenges still relevant today?
- Evaluation discussion for all components
- Are there new challenges to consider that could be addressed?
- Develop recommendations for future study/action

Facilitator: Bill Goldner</td></tr>
<tr><td>1015 – 1030</td><td colspan="3">~BREAK~</td></tr>
<tr><td>1030 – 1100</td><td colspan="3">Reflections ~ Bill Goldner & SBAR Advisory Board
- General Thoughts (overall picture)
- Areas of Excellence (achieving project objectives)
- Suggestions for Improvement
- Outlook – adjustments to overall mission/goals to meet current conditions and expectations (in industry, government, or public perception)</td></tr>
<tr><td>1100 – 1200</td><td colspan="3">Project Team Discussion ~ Kim Ogden (facilitates)
- Feedback Loop … scope :: are we still on track? Do we need to make adjustments in direction or process?
- Looking Forward … schedule review for 2018-2019

Next Steps & Assignments
- Key Questions per Component for Year 2
- Revisit Parking Lot</td></tr>
<tr><td>1200 – 1245</td><td colspan="3">Lunch (provided on site)</td></tr>
<tr><td>1245 – 1315</td><td colspan="3">Student Poster Results ~ Kim Ogden and Bill Goldner (facilitates)
- Prizes awarded to top 3 posters (as scored/ranked by SBAR Team)</td></tr>
<tr><td>1315 – 1345</td><td colspan="3">Meeting Evaluation (Please complete before you leave!) See link.</td></tr>
<tr><td>1345</td><td colspan="3">~ Safe Travels; Safe Home ~</td></tr>
</table>

APPENDIX 3. SBAR QUARTERLY REPORTING FORM & INSTRUCTIONS

Documents Included

1. **SBAR Quarterly Report Form** – A fillable Word document that all researchers can complete easily. These forms are submitted within 2 weeks following the end of each calendar quarter.
2. **SBAR Quarterly Report Form Instructions** – Clear instructions for how to complete the quarterly report form. Examples are provided where necessary for clarification.

Quarterly Status Report, IES-SBAR

REPORT INFORMATION:			
Contract Number(s)			
Project/Program:	Sustainable Bioeconomy for Arid Regions Center (SBAR)		
Institution/Organization:			
Calendar Year:		**Calendar Quarter Q1** (Jan-Mar), **Q2, Q3, Q4:**	
Principal Investigator:			
Personnel & Post-Docs:			
Students:			

GOALS/MILESTONES THIS QUARTER: Provide a description of the specific tasks/deliverables based on Annual Scope of Work; include target completion dates and a self-evaluation of current status per task. (Describe any YELLOW or RED self-evaluations in the Issues & Risks section below.)

Task #	Task Description	Deliverable	Target Completion Date	Self-Evaluation

PROJECT STATUS: Describe progress in meeting defined project goals/milestones within the most recent quarter. (One page maximum, include additional materials – such as graphs or tables – to fully describe the work completed.)

ISSUES & RISKS: Describe any issues (<6-month delay) or risks (>6-month delay) identified and how they will be managed. Include a detail explanation of potential impact.

SCHOLARLY WORKS: List all presentations, publications and documents provided this quarter, and total number of students/participants reached. Attach a list of participants separately for all EEO activities.

IES Quarterly Report Form Instructions … DUE DATES: 15 Jan, 15 Apr, 15 Jul and 15 Oct

REPORT INFORMATION:

Contract Number(s) – This is the number assigned to your sub-award (or sibling account) by the University of Arizona. If you have an internal organizational contract/tracking number for this project, please include it as well.

Project/Program – This corresponds to the main funded project name, and won't change over the course of the project.

Institution/Organization – This is the institution or organization that corresponds with the sub-award recipient. Each principal investigator at the institution should complete a separate quarterly report specific to their individual work. The quarterly reports submitted for each institution will be synthesized over the life of the project.

Calendar Year – This is the current calendar year.

Calendar Quarter – Insert the appropriate choice from the following options. (**Q1**=Jan – Mar; **Q2**=Apr – Jun; **Q3**=Jul – Sep; **Q4**=Oct – Dec)

Principal Investigator – First and last name of the principal investigator listed on the sub-award materials.

Personnel & Post-Docs – Please list all other professional personnel/post-docs that participated in project work during this quarter. Provide full names where possible, and indicate FTE level in parenthesis following the name. *Example: Jackalope Arizona (0.5)*
[1= full time equivalent; 0.5= half-time equivalent; 0.25= quarter-time equivalent]

Students – Please list all students that participated in project work during this quarter. Provide full names where possible, and indicate student status in parenthesis following the name. *Example: Jackalope Arizona (U), Sunshine Desert (G)*
[U=undergraduate student; G=graduate student]

GOALS/MILESTONES THIS QUARTER

Refer to your Annual Scope of Work to complete this section. Provide an *itemized description* of tasks, deliverables that were started, worked on, or completed during this reporting quarter, as well as the target completion date and a self-evaluation of current status per task.

Self-evaluation should be described as **GREEN** – on target; **YELLOW** – slightly behind schedule for meeting target completion date; RED – behind schedule for meeting target completion date. (Describe all YELLOW or RED self-evaluations in the Issues & Risks section below.) See the example below:

Task #	Description of Task	Deliverable	Target Completion Date	Self-Evaluation
1	Development of Guayule Fact Sheet	Guayule 2-page Fact Sheet	23 March 2018	GREEN
2	Development of Guar Fact Sheet	Guar 2-page Fact Sheet	30 March 2018	YELLOW

3	Development of SBAR Project Website	Stand-alone Project Website with appropriate sections	15 April 2018	RED

PROJECT STATUS

Enter a short narrative description (maximum 1 page) about what was accomplished during this reporting quarter. Please provide a description for the completed tasks, along with an explanation as to why planned tasks were not accomplished as originally projected; include plans for completing un-met goals. Include enough detail within the description to clearly show how project resources were used and what specific tasks/deliverables were worked on or completed.

Please include a summary of personnel time dedicated and charged to this project; include sufficient detail as to the tasks accomplished by the personnel listed. This narrative does not need to be extensive, but should include as much *qualitative* detail as possible. Please attach additional materials (such as a graph or table of results) as necessary to fully describe the work completed during this reporting period.

ISSUES & RISKS

Describe any YELLOW issues (causing <6-month delay) or RED risks (causing >6-month delay) that were identified during this reporting period, and include a description of how these issues/risks will be managed. Include a detail explanation of the potential impact. Issues/Risks identified should have a direct implication to the overall project accomplishments and/or outcomes.

SCHOLARLY WORKS

Provide a list of all publications, factsheets, or other written documents generated during this reporting period, include proper citation as appropriate. Also include a list of any databases generated, presentations, seminars, classes, workshops or camps hosted (including total number of participants) specifically under identified project objectives/tasks. Provide a separate attached list of participants for all Education/Extension/Outreach activities.

When possible, please attach copies of the publications or presentations, along with photos.

READY TO SUBMIT?

- Save your quarterly report as a Word document using the following file naming convention: **Ogden_Q1_2017.doc**
- Please submit by the due date (see top); Email your completed Quarterly Report to: **Alix Rogstad – alix@email.arizona.edu**

APPENDIX 4. SBAR PROJECT – AUTHORSHIP GUIDELINES

Documents Included

1. **SBAR Project – Authorship Guidelines –** A document generated to address potential questions and/or concerns related to authorship of materials produced through implementation of the SBAR project.

Sustainable Bioeconomy for Arid Regions (SBAR) Project
Authorship Guidelines

1. Why it Matters and Purpose of this Document

Authorship is a way of giving credit for intellectual work, and comes with the responsibility for ensuring content accuracy and acknowledging responsibility for addressing questions related to the content. Authorship usually refers to published reports of original, scientific research; however, the same principles apply to all intellectual products: words or images; in paper or electronic media; whether published or prepared for local use; in scientific disciplines or the humanities; and whether intended for the dissemination of new discoveries and ideas, for published reviews of existing knowledge, or for educational programs.

Because the SBAR Project has many investigators contributing to the whole, these authorship guidelines have been created to facilitate the decision-making process related to appropriate authorship of works generated.

2. Determining Authorship

Authorship credit for peer-reviewed publications should meet all of the following 3 criteria:

- Planning and substantial contributions to the conception and design or analysis and interpretation of data for the work;
- Drafting the article or revising it critically for important intellectual content;
- Final approval of the version to be published.

3. Authorship Responsibility

Any part of a work critical to its main conclusions must be the responsibility of at least one author, and authors should have confidence in the integrity of the contributions of their co-authors.

4. Order of Authorship

The authors should decide the order of authorship together. The primary author should prepare a written description of how authorship order was decided. And when possible, authors should specify in the work a description of the contributions of each author and how order was determined.

5. Other Considerations & Non-Author Contributors/Acknowledgements

Participation solely in the acquisition of funding or the collection of data does not justify authorship, and general supervision of the research group is also not sufficient for authorship. Participation in data collection may be deemed sufficient for authorship in activities that are highly time intensive, which will be determined by the Co-PI(s).

Individuals who do not meet the requirements for authorship but who have provided a valuable contribution to the work should be acknowledged for their contributing role as appropriate to the work.

6. Dispute Resolution

In the event that there is a dispute on authorship credit or order that cannot be resolved by the Co-PI(s) involved, the matter will be taken under consideration by the SBAR LEAD Team members. A majority vote by the SBAR LEAD Team will conclude the issue.

7. Disclosure of Research Funding and Other Support

All works submitted for publication should acknowledge the sources of support for all activities leading to and facilitating preparation of the work.

Two distinct statements must appear in their entirety in all works generated from the SBAR project:

- Funding provided by the **USDA-NIFA, Grant # 2017-68005-26867**
- *"Any opinions, findings, conclusions, or recommendations expressed in this publication/work are those of the author(s) and do not necessarily reflect the view of the U.S. Department of Agriculture."*

8. References

Colorado State University, Vice President for Research. 2016. Guidance on Authorship Practices and Dispute Resolution. https://drive.google.com/file/d/0B-Q7fFcWeihxWEVxVTg0SFdyUm8/view

Harvard Medical School Ombuds Office. 1999. Authorship Guidelines. https://hms.harvard.edu/sites/default/files/assets/Sites/Ombuds/files/AUTHORSHIP%20GUIDELINES.pdf

International Committee of Medical Journal Editors (ICMJE). 2018. Defining the Role of Authors and Contributors. http://www.icmje.org/recommendations/browse/roles-and-responsibilities/defining-the-role-of-authors-and-contributors.html

Yale University, Office of the Provost. 2018. Guidance on Authorship in Scholarly or Scientific Publications. https://provost.yale.edu/policies/academic-integrity/guidance-authorship-scholarly-or-scientific-publications

APPENDIX 5. SBAR INFORMATIONAL CARD

Documents Included

1. **SBAR Informational Card –** An informational card generated to help explain and showcase the SBAR project, including the funding source and a general description of project goals. This card is disseminated at events, conferences and other meetings by all project partners, and is available for download via the SBAR Project website.

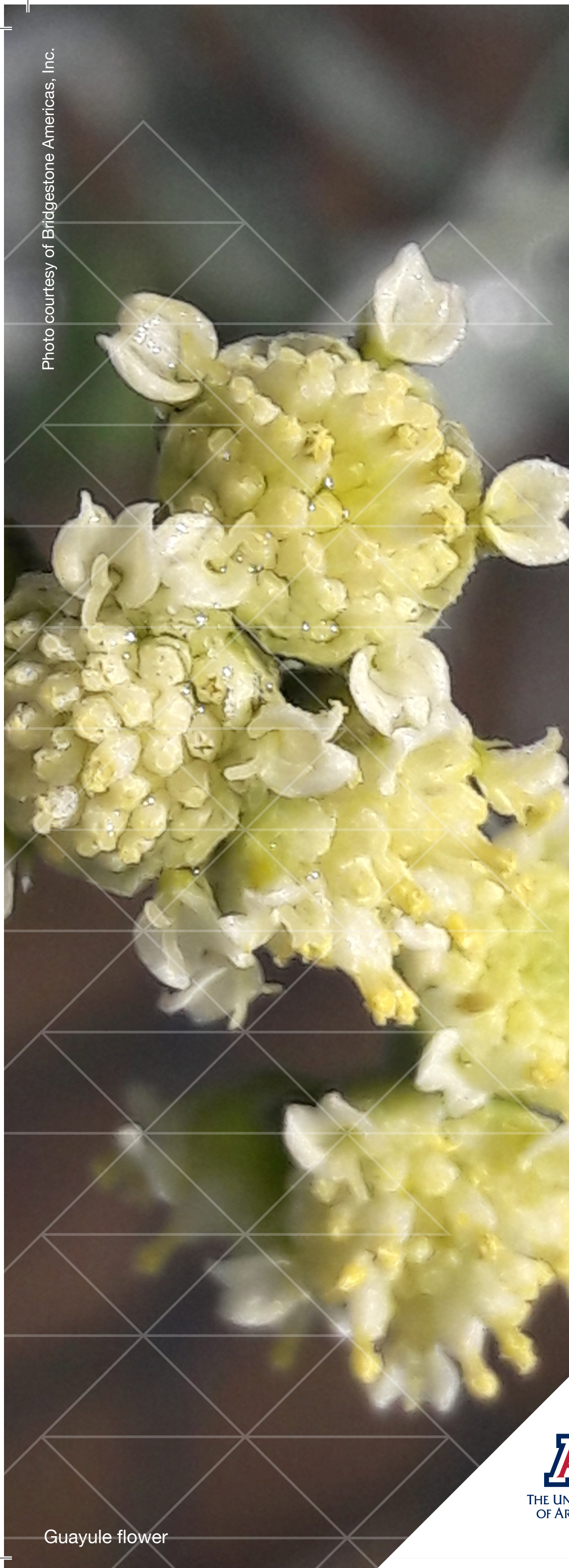


Photo courtesy of Bridgestone Americas, Inc.

Guayule flower

SBAR

SUSTAINABLE BIOECONOMY
FOR ARID REGIONS

Through a $14.8M 5-year USDA-NIFA Grant (2017-2022) researchers, Extension Specialists and graduate students at four universities and the USDA will team with industry representatives to explore ways to build a sustainable bioeconomy for arid regions that will improve quality of life in rural communities and Native Nations.

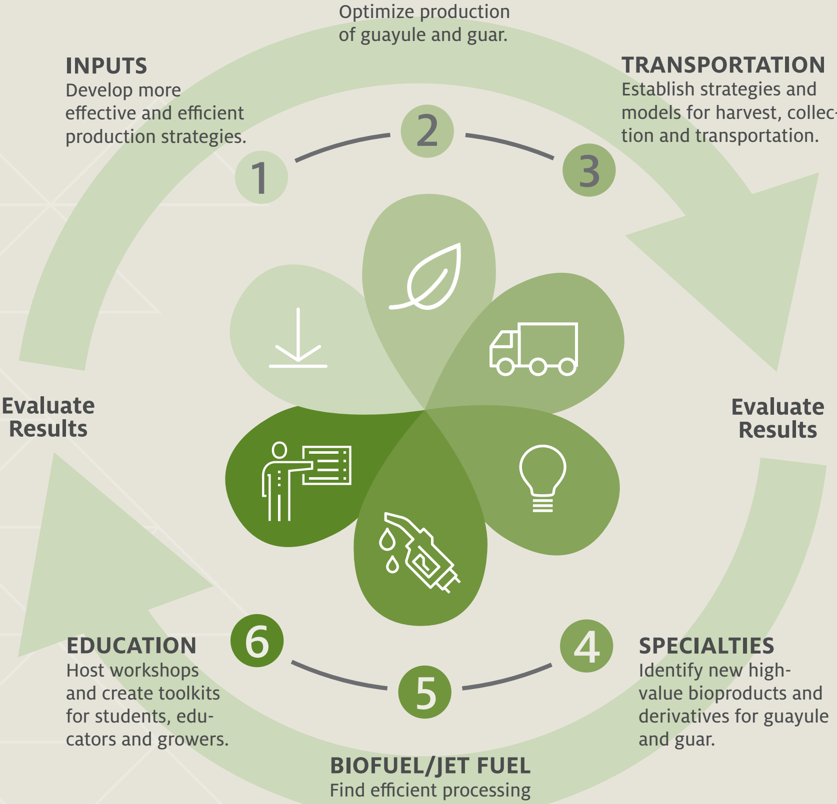
GOALS

- Improve feedstock through genetics and traditional plant breeding.
- Trans-disciplinary training for students and educators.
- Increase biofuel and bioproduct production in the Southwest.
- Expand extension, education and outreach programs in the Southwest.
- Match crop choice and yield per available water supply in semi-arid areas.

The University of Arizona

DEVELOPING A SUSTAINABLE FUTURE

Exploring Social, Economic and Environmental Options



PLANTS
Optimize production of guayule and guar.

INPUTS
Develop more effective and efficient production strategies.

TRANSPORTATION
Establish strategies and models for harvest, collection and transportation.

EDUCATION
Host workshops and create toolkits for students, educators and growers.

SPECIALTIES
Identify new high-value bioproducts and derivatives for guayule and guar.

BIOFUEL/JET FUEL
Find efficient processing techniques for guayule and guar bagasse.

The University of Arizona College of Agriculture & Life Sciences Cooperative Extension

NM State University

NM State College of ACES/CES

USDA United States Department of Agriculture — National Institute of Food and Agriculture

Colorado School of Mines — Earth • Energy • Environment

Bridgestone

Colorado State University

USDA ARS Agricultural Research Service

Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the view of the U.S. Department of Agriculture.
USDA NIFA Grant # 2017-68005-26867

For more information: **energy.arizona.edu/sbar**

Guar flower

Appendix 6. SBAR Fact Sheets

Documents Included

1. **Guayule Fact Sheet –** A 2-page fact sheet generated in March 2018 to highlight basic biology and information about guayule. This fact sheet is disseminated at events, conferences and other meetings by all project partners, and is available for download via the SBAR Project website.
2. **History of Guayule Fact Sheet –** A 2-page fact sheet generated in April 2018 to present some of the colorful and long history of guayule production and use across the Americas. This fact sheet is disseminated at events, conferences and other meetings by all project partners, and is available for download via the SBAR Project website.
3. **Guar Fact Sheet –** A 2-page fact sheet generated in April 2018 to highlight basic biology and information about guar. This fact sheet is disseminated at events, conferences and other meetings by all project partners, and is available for download via the SBAR Project website.

SBAR
SUSTAINABLE BIOECONOMY
FOR ARID REGIONS

GUAYULE


COURTESY OF YULEX CORPORATION


COURTESY OF DAN BUCKLEY

BENEFITS OF GUAYULE

- Resistant to drought and enters a semi-dormant state until water returns
- All parts of the plant can be processed; there is little to no waste
- Herbicides and insecticides are only needed for seedling establishment

APPEARANCE & CHARACTERISTICS

> Guayule (why-*oo*-lee) (*Parthenium argentatum*) is native to the North American Chihuahuan desert, and it produces natural rubber. The rubber and resin produced by the plant are stored in the branches and roots, and both are extracted during processing. After extraction, the ground-up stems and branches left behind are called "bagasse," which can be a source for bioenergy and other by-products.

> Guayule is a small, woody, multi-branched perennial shrub, with relatively small grayish leaves. Flowers are at the branch tips, and are pollinated by wind and insects. Each flower head contains five seeds that are shed as the flower matures.

GROWING GUAYULE

> Traditionally established using transplants, guayule are directly seeded, which greatly reduces planting costs. Seedlings grow slowly and are susceptible to weed competition that is reduced by applying a registered preemergence herbicide.

> Guayule can be grown with standard cultural equipment for tillage, planting, cultivation, irrigation, harvest/ baling, and transport.

> It is a two-year crop. Intermediate harvests are possible at the end of year one, but the highest rubber content is found in year two harvests.


USDA-ARS

KEY CHARACTERISTICS

- Grows well under desert conditions
- Each flower head contains 5 achenes (seeds)
- Contains hypoallergenic rubber, unlike other types of natural sources
- Easy to harvest
- First harvest at two years; may be re-harvested

~682,000

ACRES OF AVAILABLE GUAYULE-FRIENDLY LAND ACROSS ARIZONA

~895,000

ACRES OF AVAILABLE GUAYULE-FRIENDLY LAND ACROSS NEW MEXICO

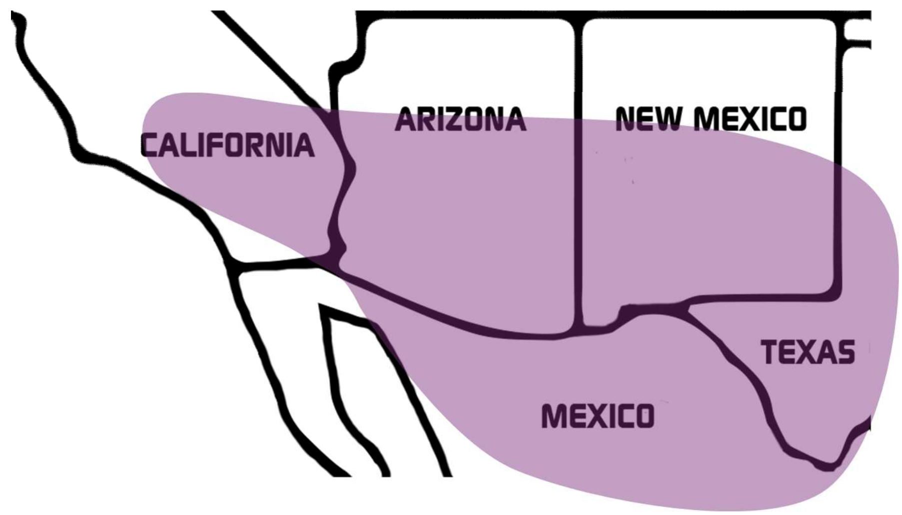
HISTORY IN NORTH AMERICA


LIBRARY OF CONGRESS

> Guayule has been known as a source of rubber since pre-Colombian times when native populations in Mexico used it to form balls for their games. In the early 1900s, it was an imported source of natural rubber in the United States.

> About 1400 tons of rubber were produced in the late 1920s, and again in the 1940s. After years of research and development, guayule is again a reliable domestic source of natural rubber.

GENERAL GROWING LOCATION



THE SBAR PROJECT

> The Sustainable Bioeconomy for Arid Regions (SBAR) project is evaluating raw material development, production, and delivery in the southwestern United States to generate a self-sustaining regional economy. Our approach is to optimize guayule and guar production to support the economies of the southwestern United States. As water becomes less available for agriculture, it is important to identify and test drought and heat tolerant crops that grow well in arid regions, and provide positive economic returns.

For more information: energy.arizona.edu/SBAR

THE UNIVERSITY OF ARIZONA COLLEGE OF AGRICULTURE & LIFE SCIENCES Cooperative Extension

USDA United States Department of Agriculture National Institute of Food and Agriculture

ARIZONA

NM STATE UNIVERSITY

NM STATE College of ACES/CES

COLORADO SCHOOL OF MINES EARTH • ENERGY • ENVIRONMENT

BRIDGESTONE

Colorado State University

USDA ARS Agricultural Research Service

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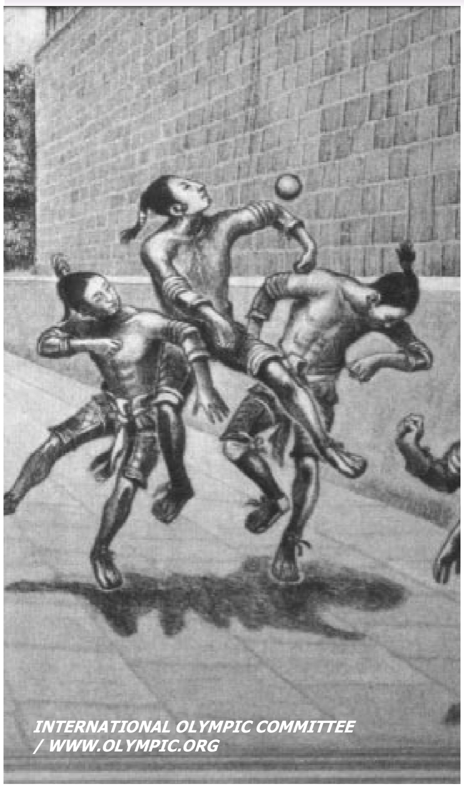
Kiela, C. 2018. Guayule. SBAR Project two-page fact sheet. March.

SBAR
SUSTAINABLE BIOECONOMY
FOR ARID REGIONS

History of Guayule

LIBRARY OF CONGRESS



INTERNATIONAL OLYMPIC COMMITTEE / WWW.OLYMPIC.ORG

USES THROUGHOUT TIME

> Chewed up guayule rubber was used to make ball games possible
> Used to fire smelters for raw ores in northern Mexico
> Currently used as an alternative, natural rubber source

PRE-COLUMBIAN ERA

> Guayule is native to the Chihuahuan Desert of New Mexico and Texas, and it has long been a source of natural rubber for the people of North America.

> In pre-Columbian times, the people of the area played a game somewhat similar to racquetball or soccer, with a heavy rubber ball. The ball was made of natural rubber, and in the northern semidesert highlands, guayule stems were chewed to release the rubber from cells just beneath the bark.

THE FIRST EXTRACTIONS

> The Spanish used guayule as a fuel to power smelters to extract silver. Near the beginning of the 20th century, guayule began to attract attention as a potential source of natural rubber for automobile tires. In 1910, roughly half of the imported natural rubber to the United States was extracted from guayule plants in Mexico.

> Industrial leaders John D. Rockefeller, Bernard Baruch, Thomas Fortune Ryan, Nelson W. Aldrich, and Daniel Guggenheim invested a large amount into a guayule company, called the Continental-Mexican Rubber Company, which became a large exporter of guayule rubber.

>After the Mexican Revolution in 1910, the Continental-Mexican Rubber Company moved across the border to the United States (mainly into Arizona and California) and became the Intercontinental Rubber Company.

LIBRARY OF CONGRESS

FUTURE POTENTIAL

- Strengthen regional biofuel and high-value product markets
- Source of renewable natural rubber and co-products
- A reliable and valuable crop to farmers in semiarid regions

~100,000

LBS OF GUAYULE PROCESSED IN 1888

~24,000,000

LBS OF GUAYULE GROWN IN 3.5 YRS OF THE EMERGENCY RUBBER PROJECT

19.6%

OF DEMAND FOR NATURAL RUBBER IN THE AMERICAS FULFILLED IN 2015-16

WAR EFFORTS

> The price of guayule rose substantially in the 1920s, and sold profitability for several years, until the Great Depression when prices dropped and development stopped.

> In 1942, during the Second World War, when the United States was cut off from natural rubber supplies from Southeast Asia, the government purchased experimental records, seed stocks, and holdings of the Intercontinental Rubber Company.

> Significant research and development of guayule as a crop took place during the war, with over 3 million pounds of rubber produced. However, the program ended with the war, and ~21 million pounds of guayule rubber was destroyed in the field.

ONGOING RESEARCH

> Around 1975, guayule was re-examined as a source of renewable natural rubber. Since then research has been steady, resulting in higher yielding guayule lines and improved cultural practices.

> SBAR's research on guayule focuses on several topics: genetic experiments to find the best strain of guayule; irrigation and soil experiments to determine the most efficient growing conditions; herbicide and pesticide experiments to best protect the guayule seedlings; and chemical and molecular studies to develop value-added co-products that will use the entire plant.

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THE UNIVERSITY OF ARIZONA COLLEGE OF AGRICULTURE & LIFE SCIENCES Cooperative Extension · USDA United States Department of Agriculture · National Institute of Food and Agriculture · ARIZONA · NM STATE UNIVERSITY · NM STATE College of ACES/CES · COLORADO SCHOOL OF MINES EARTH • ENERGY • ENVIRONMENT · BRIDGESTONE · Colorado State University · USDA ARS Agricultural Research Service

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Kiela, C. 2018. History of Guayule. SBAR Project two-page fact sheet. April.

TON RULKENS/WIKIMEDIA COMMONS

GUAR


COURTESY OF KULBHUSHAN GROVER

BENEFITS OF GUAR

- Resistant to drought
- Restores depleted soil nitrogen
- Guar meal, the product after extracting gum, can be a source of protein-rich cattle feed

CHARACTERISTICS & USES

> Guar (*Cyamopsis tetragonoloba*) is a legume crop native to semi-arid and subtropical regions of India and Pakistan, and has been grown in the United States since World War II. The green pods are edible by humans and cattle, and the mature seeds contain guar gum that has many uses, such as: a thickener, emulsifier, bonding agent, or a soil stabilizer, among others. Guar gum is of special interest today for its application in natural gas extraction.

> Guar is a 3-4ft. tall, leafy, single- to multi-stemmed summer annual legume, with relatively large oval-shaped leaves. Flowers grow near the stem, and are most often self-pollinated. The seed pods grow in clusters, giving the plant its common name: cluster bean.

GROWING GUAR

> Guar and bean crops use similar equipment for planting, tillage, irrigation, harvest, and transport.

> Guar may be successfully established by using pre-emergence herbicides and pest control chemicals when needed.

> Guar is relatively inexpensive to grow and is suited to marginal farmland. As a legume, guar works well in rotation with other crops.

> After bean pod harvest, the remaining plant material is incorporated into the soil, or may be collected and used as a co-product in different revenue streams.


DINESH VALKE/WIKIMEDIA COMMONS

KEY CHARACTERISTICS

- Grows well in hot and dry conditions
- Seed pods range from 1.5-2 inches long and contain six to nine seeds
- Used as a forage crop for cattle

DISEASES THAT POTENTIALLY IMPACT GUAR

- Southern blight, caused by *Sclerotium rolfsii* fungus
- Alternaria leaf spot, caused by *Alternaria* genus pathogens
- Texas root rot, *Phymatotrichum omnivorum*
- Bacterial blights
- Various viruses

ONGOING SBAR RESEARCH

> **Variety selection:** identifies varieties to expand the growing range; evaluate lines for higher gum and protein content; evaluate yield and disease resistance

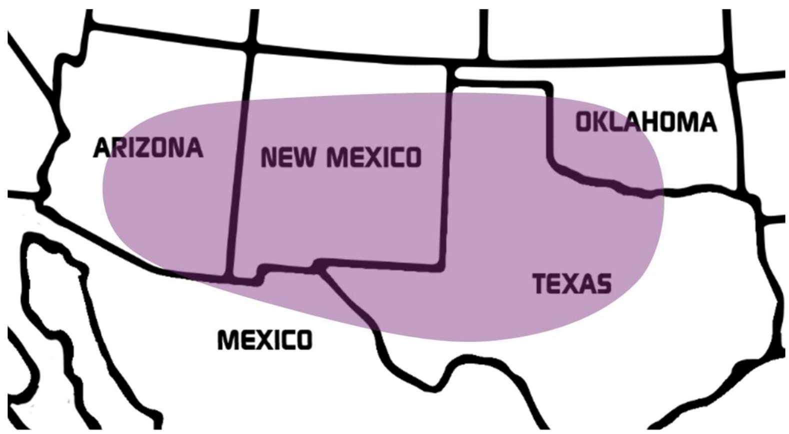

COURTESY OF KULBHUSHAN GROVER

> **Establishment:** determine best planting dates and densities for optimum yield; use in rotations with different crops

> **Irrigation:** optimize timing and amount of irrigation for best yields

> **New Uses:** enhance quality of guar meal; evaluate bagasse for biofuel production; develop new co-products

GENERAL GROWING LOCATION



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NM STATE College of ACES/CES
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COLORADO SCHOOL OF MINES EARTH • ENERGY • ENVIRONMENT
BRIDGESTONE
Colorado State University
GUAR RESOURCES, LLC
USDA Agricultural Research Service

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Kiela, C. 2018. Guar. SBAR Project two-page fact sheet. April.

APPENDIX 7. SBAR GRADUATE FELLOWSHIP RECRUITMENT FLYERS

Documents Included

1. **SBAR: USDA-NIFA Graduate Student Fellowship Flyer (AZ) –** A 1-page announcement flyer intended for recruitment of graduate students at the University of Arizona, Tucson, AZ.
2. **SBAR: USDA-NIFA Graduate Student Fellowship Flyer (NM)** – A 1-page announcement flyer intended for recruitment of graduate students at New Mexico State University, Las Cruces, NM.

SBAR

USDA-NIFA
Graduate Student Fellowship

A USDA-funded program to introduce K-12 students to the sustainable desert agriculture industry and careers in biofuels and bioproducts.

4-H and UA education specialists provide focused, small-group summer training for Science Teachers and Graduate Student Fellows to fit relevant experiments and lessons into the existing curriculum.

TRAINING PARTNERS

UNIVERSIY OF ARIZONA'S

Institute for Energy Solutions
Department of Chemical
& Environmental Engineering
College of Education
College of Agriculture
& Life Sciences -Cooperative Extension

NEW MEXICO STATE UNIVERSITY'S

College of Agriculture
& Environmental Sciences
Cooperative Extension
Department of Chemical
& Materials Engineering

SBAR: Sustainable Bioeconomy for Arid Regions

Information: energy.arizona.edu/SBAR

Applications Due March 23, 2018

Fellowship Commitments

- ◊ Dedicate 10 hours/week to K-12 classroom
- ◊ Intensive training June 19 – 28, 2018 at UA
- ◊ Create and teach science experiments/lessons

UA Fellowship Perks

- ◊ $10K stipend + tuition remission
- ◊ Mentoring from a K-12 teacher
- ◊ Classroom teaching experience

USDA United States Department of Agriculture
Agricultural Research Service
USDA United States Department of Agriculture National Institute of Food and Agriculture
The University of Arizona
NM State University
Colorado State University
Colorado School of Mines Earth • Energy • Environment
Bridgestone

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Grant #: 2017-68005-26867

SBAR

USDA-NIFA Graduate Student Fellowship

A USDA-funded program to introduce K-12 students to the sustainable desert agriculture industry and careers in biofuels and bioproducts.

4-H and UA education specialists provide focused, small-group summer training for Science Teachers and Graduate Student Fellows to fit relevant experiments and lessons into the existing

SBAR: Sustainable Bioeconomy for Arid Regions

Information: energy.arizona.edu/SBAR

Applications Due March 23, 2018

Fellowship Commitments

- ◊ ~10 hours/week graduate assistantship working with a K-12 classroom
- ◊ Summer training + 1 credit course/semester
- ◊ Create and teach science experiments/lessons

NMSU Fellowship Perks

- ◊ In-state tuition eligibility
- ◊ Mentoring from a K-12 teacher
- ◊ Classroom teaching experience

TRAINING PARTNERS

UNIVERSIY OF ARIZONA'S

Institute for Energy Solutions
Department of Chemical & Environmental Engineering
College of Education
College of Agriculture & Life Sciences -Cooperative Extension

NEW MEXICO STATE UNIVERSITY'S

College of Agriculture & Environmental Sciences Cooperative Extension
Department of Chemical & Materials Engineering

USDA United States Department of Agriculture Agricultural Research Service
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The University of Arizona
NM State University
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Bridgestone

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Grant #: 2017-68005-26867

APPENDIX 8. SBAR TEACHER RECRUITMENT FLYERS

Documents Included

1. **SBAR: Call for Middle & High School Science Teachers –** A 1-page announcement flyer intended for recruitment of professional teacher mentors in Arizona and New Mexico. Flyer was distributed through a variety of outlets for broad reach.

SBAR

Call for Middle & High School Science Teachers

A USDA-funded program to introduce K-12 students to the sustainable desert agriculture industry and careers in biofuels and bioproducts.

4-H and UA education specialists provide focused, small-group summer training for Science Teachers and Graduate Student Fellows to fit relevant experiments and lessons into the existing curriculum.

SBAR: Sustainable Bioeconomy for Arid Regions

Information: energy.arizona.edu/SBAR

Applications Due March 23, 2018

Teacher Commitments:

- ◊ Intensive training June 19 - 28, 2018 at UA
- ◊ Host a graduate student in your classroom
- ◊ Incorporate SBAR modules into your curriculum

Teacher Perks:

- ◊ $5,000 stipend
- ◊ Graduate student dedicated to your classroom
- ◊ Teaching modules fit into your curriculum
- ◊ All materials supplied

TRAINING PARTNERS

UNIVERSIY OF ARIZONA

Institute for Energy Solutions
Department of Chemical & Environmental Engineering
College of Education
College of Agriculture & Life Sciences - Cooperative Extension

NEW MEXICO STATE UNIVERSITY

College of Agriculture & Environmental Sciences Cooperative Extension
Department of Chemical & Materials Engineering

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