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SIMB 45th Symposium on Biomaterials, Fuels and Chemicals

Practical and Economic Scale-up, Deployment and Integration Considerations for Lignocellulosic Chemicals and Fuels Processes

Portland, Oregon

April 30-May 3, 2023

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NEXT RUNG OVERVIEW

Since 2017 we have helped over **100** customers scale their emerging technologies.

Technology development, design, execution and operations, strategy and economics, we deliver what you need to commercialize!

- Pilot plant designs, delivery
- Conceptual through detail design & economics (FEL0/1/2/3)
- 3rd party outreach and production runs
- CMO & project development and cost estimation (+-20%)
- EPC outreach & selection
- Owners engineer & PM
- Detail design support
- Commissioning & startup

Longtime member of the Greentown Labs, **national** and **international innovation ecosystem.**

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OUR MISSION

400 M3 2nd Gen Feedstock
E. Coli Fermenters

Our vision is a healthy and sustainable planet, created by talented engineers and entrepreneurs.

Our mission is to support growth-stage companies creating sustainable technologies by integrating our diverse team of experienced engineers to deliver consistent, quality outcomes for complex challenges.

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LIGNOCELLULOSIC BIOMASS BIOCONVERSION INTEGRATION AND SCALE-UP THEMES

- Efforts in this area are part of a large overall program
- Progress & success are measured and achieved in many ways
- Opportunity is shifting from ebb to flow
- With (re)new(ed) opportunity and interest how can learnings from major programs guide us?
- Lignocellulosic Biomass program learnings align with general techno-economic and scaling principles
- Incorporating sustainability in sustainable process development
- Renewal is a constant

Reference Links:
U.S. Billion-Ton Update: Biomass Supply for a Bioenergy and Bioproducts Industry
Werpy, T, and Petersen, G. 2004. "Top Value Added Chemicals from Biomass: Volume I -- Results of Screening for Potential Candidates from Sugars and Synthesis Gas". United States. https://doi.org/10.2172/15008859. https://www.osti.gov/servlets/purl/15008859.

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SOME SUSTAINABLE PROCESSES OVER TIME

- MTBE (adding octane to replace lead)
- Mobil oil and gas zeolite technologies
- Tar and oil sands process development (addressing oil shortages/peak oil concerns)
- Corn ethanol (and its role as an oxygenate)
- Key Studies - DOE Billion-ton study(ies) and NREL Top Value-Added Chemicals from Biomass
- Cellulosic ethanol from woody biomass and energy crops
- Platform chemicals production from conventional, cellulosic or second gen sugars (grain sorghum)
- Next generation foods and animal proteins minimizing agriculture inputs and impacts

A program that builds upon itself, on technology, people, successes, challenges, learnings, focus

Reference Links:
U.S. Billion-Ton Update: Biomass Supply for a Bioenergy and Bioproducts Industry
Werpy, T, and Petersen, G. 2004. "Top Value Added Chemicals from Biomass: Volume I -- Results of Screening for Potential Candidates from Sugars and Synthesis Gas". United States. https://doi.org/10.2172/15008859. https://www.osti.gov/servlets/purl/15008859.

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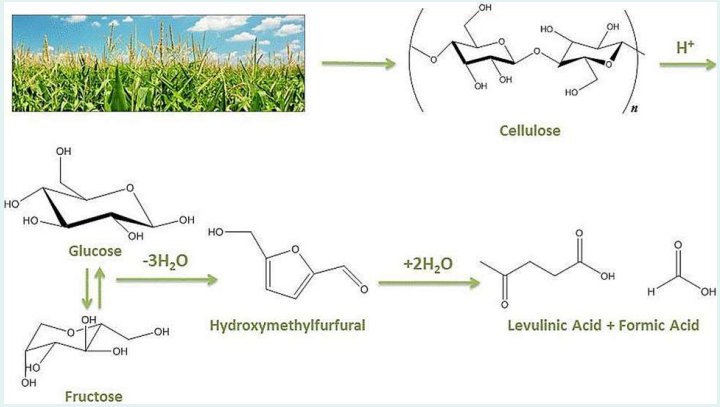
LIGNOCELLULOSIC PROJECTS REVIEW

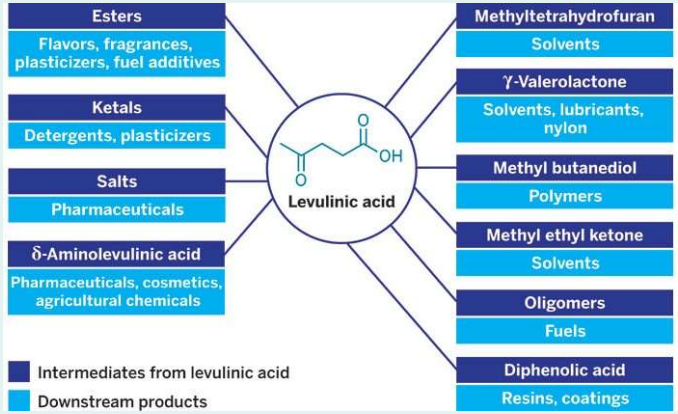
- BioMetics & BIOFINE process (*Caserta, Italy*) levulinic acid from cellulosics, including from Vinacchia (stems and leaves of the Italian wine / grape harvest)
- Mascoma cellulosic ethanol Pilot & Demonstration Plant (*Rome, NY*), Commercial Scale Designs (& continuing technologies applied to increase cellulosic conversion in conventional ethanol)
- Myriant succinic acid biorefinery (*MySAB Lake Providence, LA*) succinic acid production from conventional sugars, grain sorghum (second gen energy crop and cellulosics)

Discuss process, projects (subjectively), learnings as a forward facing lens to development today

PROJECTS & TECHNOLOGIES REVIEW

BIOMETICS CASERTA
AG WASTE TO LEVULINIC ACID





References:
One-Companys-Big-Plans-Levulinic (acs.org)

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BIOMETICS CASERTA - BIOFINE PROCESS
AG WASTE TO LEVULINIC ACID

Process: BIOFINE Process – Weak Acid Hydrolysis, two stage reaction, product esterification

cellulose -> sugars -> intermediates -> HMF -> Levulinic -> ethyl levulinate

- **Pilot Scale** (*1998–present*): various forms pilot plant (B2P2 Pilot Plant) University of Maine-Forest Bioproducts Research Institute-Technology Research Center in Old Town, Maine. Funding partners including NYSERDA / NY State, DOE, State of Maine.
- **Commercial Scale** (*2000–present; Caserta, Italy*): funding partners including BioEnergy International, EU, currently GF Biochemicals, Acquired Segetis (levulinic acid technology developer)

- **Feedstock(s):** Cellulose, Ag Waste, Paper Mill Sludge, MSW etc
- **Product(s):** Levulinic Acid, Formic Acid, Furfural, Biochar, Ethyl Levulinate
- **Derivatives / Downstream Conversion:** Biofuels, renewable chemicals, specialty chemicals, fragrances etc

- **Key scaleup economic & technical considerations:** presence of solids, erosion / corrosion, fouling from lignocellulosic feedstocks, byproducts / coproducts, esterification of product (xp), product recovery, highly energetic biochar, recycling of impurities, yield, market, wastewater production

References:
One-Companys-Big-Plans-Levulinic (acs.org)

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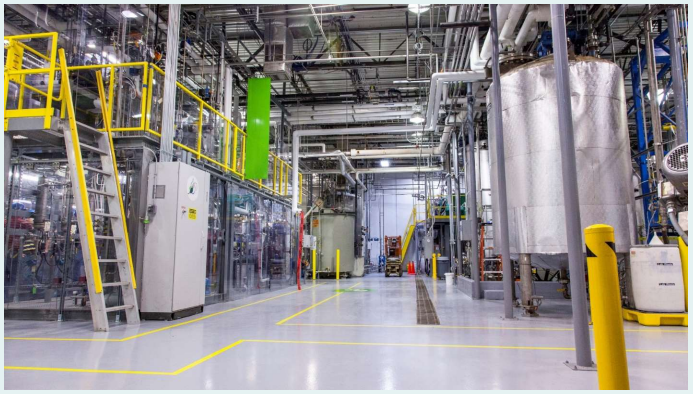
MASCOMA ROME
CELLULOSIC TO ETHANOL



References:
A Step Toward Car Fuel From Wood Waste - The New York Times (nytimes.com)

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MASCOMA ROME
CELLULOSIC TO ETHANOL

Process: Consolidated Bioprocessing – Woody biomass feedstocks -> ethanol

lignocellulosic biomass -> pretreatment -> CBP (hydrolysis, fermentation) -> vaporization / distillation / dehydration with solids separation and dewatering

- **Pilot Scale** (*2009; Rome, New York*)
- **Demonstration Scale** (*2009; Rome, New York*): 0.125 - 0.5 MMGPY. Funding & partners incl. NYSERDA, DOE, GM. Currently operating as Renmatix.
- **Commercial Scale** (*Kinross, MI*): 20 MMGPY. Announced 2011/2013 not constructed. Funding & partners incl. DOE, MEDC, etc.
- Mascoma organization technology currently acquired in 2014 by / implemented by Lallemand Inc. (TransFerm)

- **Product(s):** Cellulosic ethanol, lignaceous / biomass solids
- **Derivatives / Downstream Conversion:** Biofuels, coproducts & byproducts from solids and lignin materials

- **Key scaleup economic & technical considerations:** presence of solids, erosion / corrosion / wear, fouling, byproducts / coproducts, sterility, recycling of contaminants, wastewater production, yield, selectivity, inhibition

References:
One-Companys-Big-Plans-Levulinic (acs.org)

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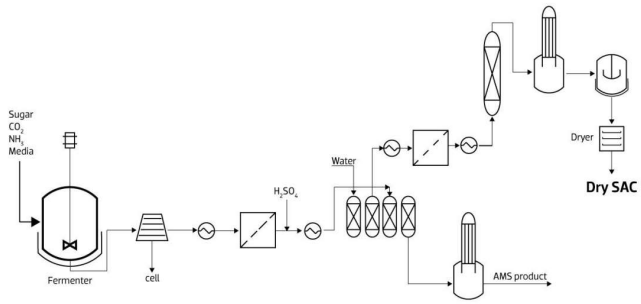
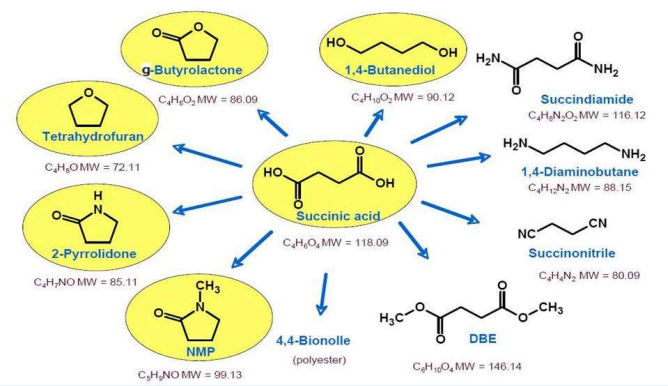
MYRIANT LAKE PROVIDENCE
CONVENTIONAL, 2ND GEN FEEDSTOCKS TO SUCCINIC

The Myriant Process

Myriant





References:
Myriant Succinic Acid BioRefinery (energy.gov)
Succinic acid (genetika.ru)

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MYRIANT LAKE PROVIDENCE (MYSAB) CONVENTIONAL, 2ND GEN FEEDSTOCKS TO SUCCINIC

Process: Conventional / 2nd Gen / Cellulosic sugars -> succinic acid via e. coli fermentation

sugars -> fermentation -> protonation -> broth separation -? crystallization & amm. sulfate conc.

- **Pilot & Demonstration Scale** (*various 2009–2013*): 40 / 500 / 5,000 / 20,000–50,000L scales.
- **Commercial Scale** (*Lake Providence, LA*): 30 MMLB/YR. 400,000L scale. Funding & partners incl. DOE, State of Louisiana, USDA (loan guarantee), PTTGC.
- Myriant and associated technologies acquired by PTTGC 2018, Lake Providence site acquired by Stepan Corp in process of reengineering and startup.

- **Product(s):** Succinic acid crystals' (high purity) with 94% lower carbon footprint, liquid amm. Sulfate.
- **Derivatives / Downstream Conversion:** Platform chemicals,1,4 BDO,

- **Key scaleup economic & technical considerations:** typical DSP challenges associated with fermentation products (incl presence of solids, many unit ops), corrosion, fouling, byproducts (min) / coproducts, recycling of contaminants, water / wastewater / wastes, production of high purity products via fermentation vs fossil fuel routes, market

References:
Myriant Succinic Acid BioRefinery (energy.gov)

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THEMES AND LESSONS LEARNED

	Presence of solids, high solids operation	Water use	Wastewater / wastes	Yield	Selectivity / Byproducts / Co-products	Erosion, corrosion, wear	Sterility	Fouling	Contam. (recycle)	Product purity, spec	Process Challenges / Dev.	Market Success / Accept.	Relatively High CAPEX	Relatively High OPEX
BioMetics Cellulose to levulinic	X		X	X	X	X		X		X	X	x		
Mascoma Cellulosic to ethanol	X	X	X	X	X	X	X	X			X		X	x
Myriant Conv. / 2nd gen / cellulosic sugars to succinic		X	X	x	x			X	X	X	X	x -> X		
Occurrences	2	2	3	2.5	2.5	2	1	3	1	2	3	1-2	Jury is still out	
Scaleup or Process Considerations	X	X	X	X	X	X	X	X	X	X	X		X	X
Techno-economic Considerations	X	X	X	X	X				X	X			X	X

SCALING LIGNO CELLULOSICS

GENERAL SCALE UP PRINCIPLES

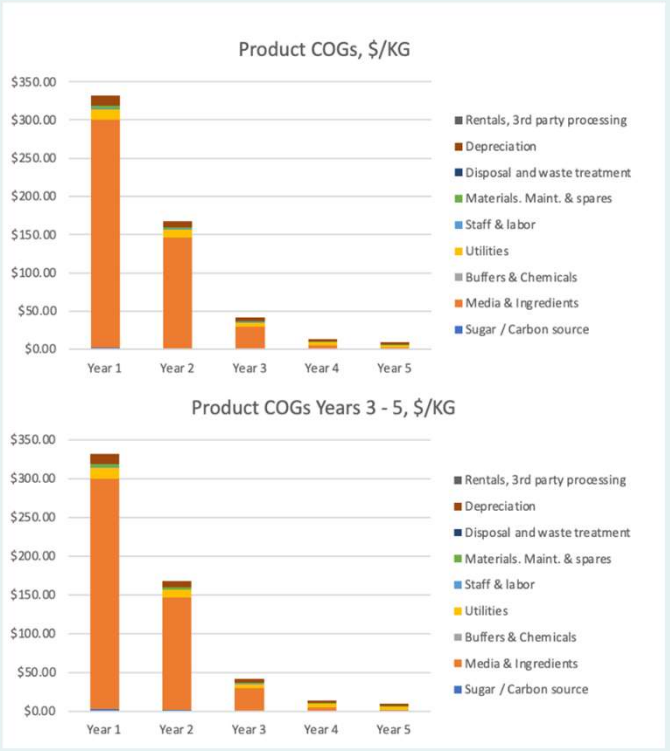
- Scaling up is a process of moving from easier lab based, organism and process-based conditions to harder industrial conditions, by necessity pushing towards requirements that are more economical (higher solids, lower grade water, commercial media and ingredients etc.)

- Scaling up involves a thought process of looking ahead "where must I go to be commercial" and scaling back form there
  - e.g. scaling down
  - Design to Scale

- There is a competing consideration in scaling, things have to work
  - Design not to fail

- Integrating business and technical realities and needs
  - Designing a facility to work “Day 1 and Year 2”

UNDERSTANDING COMMERCIAL SCALE



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READINESS TO SCALE

- Risk Management process and program, critical reviews of all scales, modes, historic operations
- DOE 1000/2000 hr. pilot plant operations gold standard
- Key elements include "closing of recycles", dealing with wastes, water and wastewater
- What is not a product is a waste (yield loss, byproducts)
- Water is not infinite - Making sustainable processes sustainable
- Presence of solids as a difficulty factor

READINESS TO SCALE
TECHNOLOGY READINESS TEMPLATE

Parameter	Description	Note
Description of Area @ Commercial Scale		
Scaleup Factor	Planned vs other scales at which data has been generated and upon which scaleup is planned	May be more than one scale What scale is the design basis data from is important!
Description of Area at scale(s) demonstrated to date		
Description of results		
Readiness for scale / TRL Ranking / Tech Assessment		Applying an objective lens to readiness
Gaps - Identification of project design parameters not confirmed		
Overall assessment of readiness / risk level		Narrative, subjective as well as objective assessment
Reference information		
KPIs to track & address		
Other		

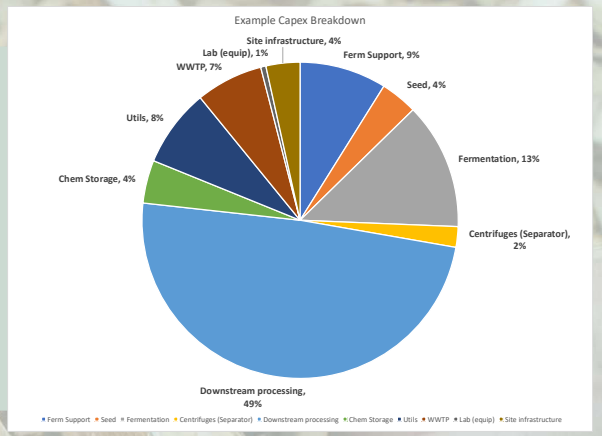
ECONOMICS & PROJECT DEVELOPMENT SUCCESS FACTORS

- Economics matter, must be understood fully and deeply along the way, in clear manners that can lead development, execution etc. technoeconomic modeling
- Global not local optimums
- Entire scope of a project, TEA is practical plant design not spreadsheet engineering, not just the process stuff (ISBL)

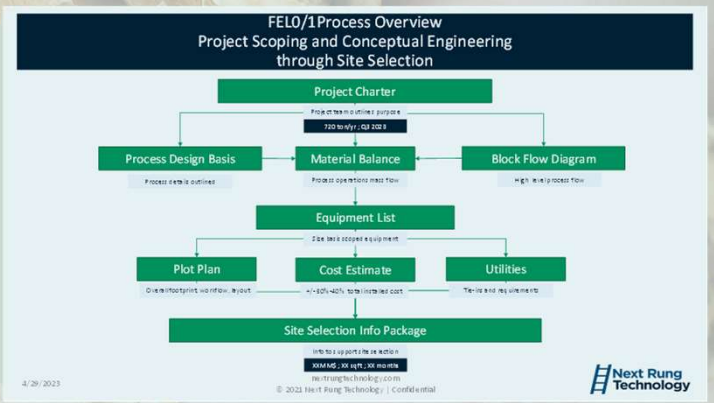
- Chartering
- Smart project development ... FEL process, chartering assessing, adjusting course, if need be rescoping / staging / phasing etc.
- Goals include: Managing change throughout execution, avoiding starting things that can't be finished

ECONOMICS & PROJECT DEVELOPMENT SUCCESS FACTORS

- Economics with clarity
- Global not local optimums
- Entire scope of a project, not just core process or ISBL



- Chartering
- Smart project development ... FEL process
- Managing change, Risk Management



PROJECT CHECK-IN & CLOSING THOUGHTS

PROJECT &TECHNOLOGY CHECK–IN
CONSTANT RENEWAL

Biofine Technology

Renmatix

LALLEMAND

Stepan

ptt GLOBAL CHEMIC

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CONCLUDING THOUGHTS

- Overall, this is a major / massive program and progress comes in many forms
- With (re)new(ed) opportunity and interest learnings from major programs must guide us
- Lignocellulosic Biomass program learnings align with general techno-economic and scaling principles
- Incorporating sustainability in sustainable process development is a must have, includes not only low carbon, water, social objectives and impacts
- Renewal is both our objective, it is a constant

DISCUSSION

400 M3 2nd Gen Feedstock
E. Coli Fermenters

Our vision is a healthy and sustainable planet, created by talented engineers and entrepreneurs.

Questions, Discussion

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REFERENCE INFORMATION

DOE RECOVERY ACT PROJECTS

Recipient	Description	DOE Cost Share	Where the company is today	Where the plant is today
ClearFuels Technology Inc. ***(Commerce City, CO)***	This project will produce renewable diesel and jet fuel from woody biomass by integrating ClearFuels' and Rentech's conversion technologies. The facility will also evaluate the conversion of bagasse and biomass mixtures to fuels.	$23,000,000	Acquired by Rentech	Inactive as of 2013
Haldor Topsoe, Inc. ***(Des Plaines, IL)***	This project intends to convert wood to green gasoline by fully integrating and optimizing a multi-step gasification process. The pilot plant will have the capacity to process 21 metric tons of feedstock per day.	$25,000,000	Active	Des Plaines plant inactive as of 2014; built 15,000-ton/yr hydroprocessing-catalyst plant in Pasadena, TX, operational in 2023
ICM, Inc. ***(St. Joseph, MO)***	This project will modify an existing corn-ethanol facility to produce cellulosic ethanol from switchgrass and energy sorghum using biochemical conversion processes.	$25,000,000	Active	Operational 50-MGY ethanol biorefinery in St. Joseph
Logos Technologies, Inc. ***(Visalia, CA)***	This project will convert switchgrass and woody biomass into ethanol using a biochemical conversion processes.	$20,455,849		
Solazyme, Inc. ***(Riverside, PA)***	This project will validate the projected economics of a commercial scale biorefinery producing multiple advanced biofuels. This project will produce algae oil that can be converted to oil-based fuels.	$21,765,738	Shifted to food and nutrition under new name— TerraVia; acquired by Corbion after bankruptcy	Bought back by Merck in 2011; Merck plans to close Riverside Plant in 2024, plans for site are unclear
UOP LLC ***(Kapolei, HI)***	This project will integrate existing technology from Ensyn and UOP to produce green gasoline, diesel, and jet fuel from agricultural residue, woody biomass, dedicated energy crops, and algae.	$25,000,000	Parent company Honeywell (Honeywell UOP)	Decommissioned in 2017
ZeaChem Inc. ***(Boardman, OR)***	This will use purpose-grown hybrid poplar trees to produce fuel-grade ethanol using hybrid technology. Additional feedstocks such as agricultural residues and energy crops will also be evaluated in the pilot plant.	$25,000,000	Active— joint venture with Leaf Resources	Inactive as of 2015
Gas Technology Institute ***(Des Plaines, IL)***	This project aims to complete preliminary engineering design for a novel process to produce green gasoline and diesel from woody biomass, agricultural residues, and algae.	$3,489,127	Active	Active
National Advanced Biofuels Consortium ***(NABC; Golden, CO)***	This consortium project intends to develop infrastructure-compatible, cellulosic-based hydrocarbon fuels resulting in a sustainable, cost- effective production process that maximizes the use of existing refining and distribution infrastructure.	$34,949,784	Inactive	Golden facility active as of 2017-present
Bluefire, LLC ***(Fulton, MS)***	This project will construct a facility that produces ethanol fuel from woody biomass, mill residue, and sorted municipal solid waste. The facility will have the capacity to produce 19 million gallons of ethanol per year.	$81,134,686	Dissolved in 2016	Inactive as of 2014
Enerkem Corporation ***(Pontotoc, MS)***	This project will be sited at an existing landfill and use feedstocks such as woody biomass and biomass removed from municipal solid waste to produce ethanol and other green chemicals through gasification and catalytic processes.	$50,000,000	Active	Facility not completed; active plants in Canada, planned plants in Spain and the Netherlands

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DOE RECOVERY ACT PROJECTS

Recipient	Description	DOE Cost Share	Where the company is today	Where the plant is today
INEOS New Planet BioEnergy, LLC ***(Vero Beach, FL)***	This project will produce ethanol and electricity from wood and vegetative residues and construction and demolition materials. The facility will combine biomass gasification and fermentation, and will have the capacity to produce 8 million gallons of ethanol and 2 megawatts of electricity per year by the end of 2011.	$50,000,000	Active	Inactive as of 2017
Sapphire Energy, Inc. ***(Columbus, NM)***	This project will cultivate algae in ponds that will ultimately be converted into green fuels, such as jet fuel and diesel, using the Dynamic Fuels refining process.	$50,000,000	Inactive	Active; owned by Qualitas Health to produce algae omega-oil
Algenol Biofuels Inc. ***(Freeport, TX)***	This project aims to make ethanol directly from carbon dioxide and seawater using algae. The facility will have the capacity to produce 100,000 gallons of fuel-grade ethanol per year.	$25,000,000	Inactive	Freeport facility owned by Dow Chemical; Fort Meyers plant status unclear
American Process Inc. ***(Alpena, MI)***	This project will produce fuel and potassium acetate, a compound with many industrial applications, using processed wood generated by Decorative Panels International, an existing hardboard manufacturing facility in Alpena. The pilot plant will have the capacity to produce up to 890,000 gallons of ethanol and 690,000 gallons of potassium acetate per year starting in 2011.	$17,944,902	Acquird by GranBio in 2019	Active
Archer Daniels Midland ***(ADM; Decatur, IL)***	This project will use acid to break down biomass that can be converted to liquid fuels or energy. The ADM facility will produce ethanol and ethyl acrylate, a compound used to make a variety of materials, and will also recover minerals and salts from the biomass that can then be returned to the soil.	$24,834,592	Active	Active; planned $300-million expansion to be completed by 2025
Amyris Biotechnologies, Inc. ***(Emeryville, CA)***	This project will produce a diesel substitute through the fermentation of sweet sorghum. The pilot plant will also have the capacity to co- produce lubricants, polymers, and other petro-chemical substitutes.	$25,000,000	Active	Emeryville location active; commercial-scale facilities in Brazil and Leland, NC
Myriant ***(formerly Bioenergy, LLC; Lake Providence, LA)***	This project will biologically produce succinic acid from sorghum. The process being developed displaces petroleum based feedstocks and uses less energy per ton of succinic acid produced than its petroleum counterpart.	$50,000,000	Active	Active
Elevance Renewable Sciences ***(Newton, IA)***	This project aims to complete preliminary engineering design for a future facility producing jet fuel, renewable diesel substitutes, and high-value chemicals from plant oils and poultry fat.	$2,500,000	Active	72-gallon per year facility in Natchez, MS acquired by World Energy in 2016; active biorefinery in Newton, IA owned by Chevron REG
Renewable Energy Institute International ***(REII; Toledo, OH)***	This project by REII will produce high-quality green diesel from agriculture and forest residues using advanced pyrolysis and steam reforming. The pilot plant will have the capacity to process 25 dry tons of feedstock per day.	$19,980,930	Active	Inactive as of 2014

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DELIVERING SUSTAINABLE TECHNOLOGIES

Next Rung Technology provides engineering, execution, operations & consulting services to organizations developing and delivering sustainable technologies.

SERVICES INCLUDE

- Strategic planning, road-mapping, come to US Market, with an executionbias
- Technology development, scale-up and commercialization
- Project development, execution and management
- Organizational and operational leadership
- Manufacturing Sourcing and Scale-Up

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