Biobased and Degradable Plastics in California

Understanding New Packaging Materials and Their Management

Meeting Reminders

- Exits and Emergency Procedures
- Restroom Facilities
- Silence Phones
- Please Hold All Questions Until the End

Agenda

- Background
- Part 1 – Science and Economics of Bioplastics
- Part 2 – Bioplastics and CA Recovery System
- Part 3 – Conclusion
- Questions

Background

- Green Chemistry and Ocean Protection Council's 2007 Resolution on Marine Debris
- Bioplastics – potential to use waste as a resource in a closed loop system
- Work began in 2008 with Department of Toxic Substances Control (9 research contracts)
- Goal to educate public and understand impacts on California's recovery programs

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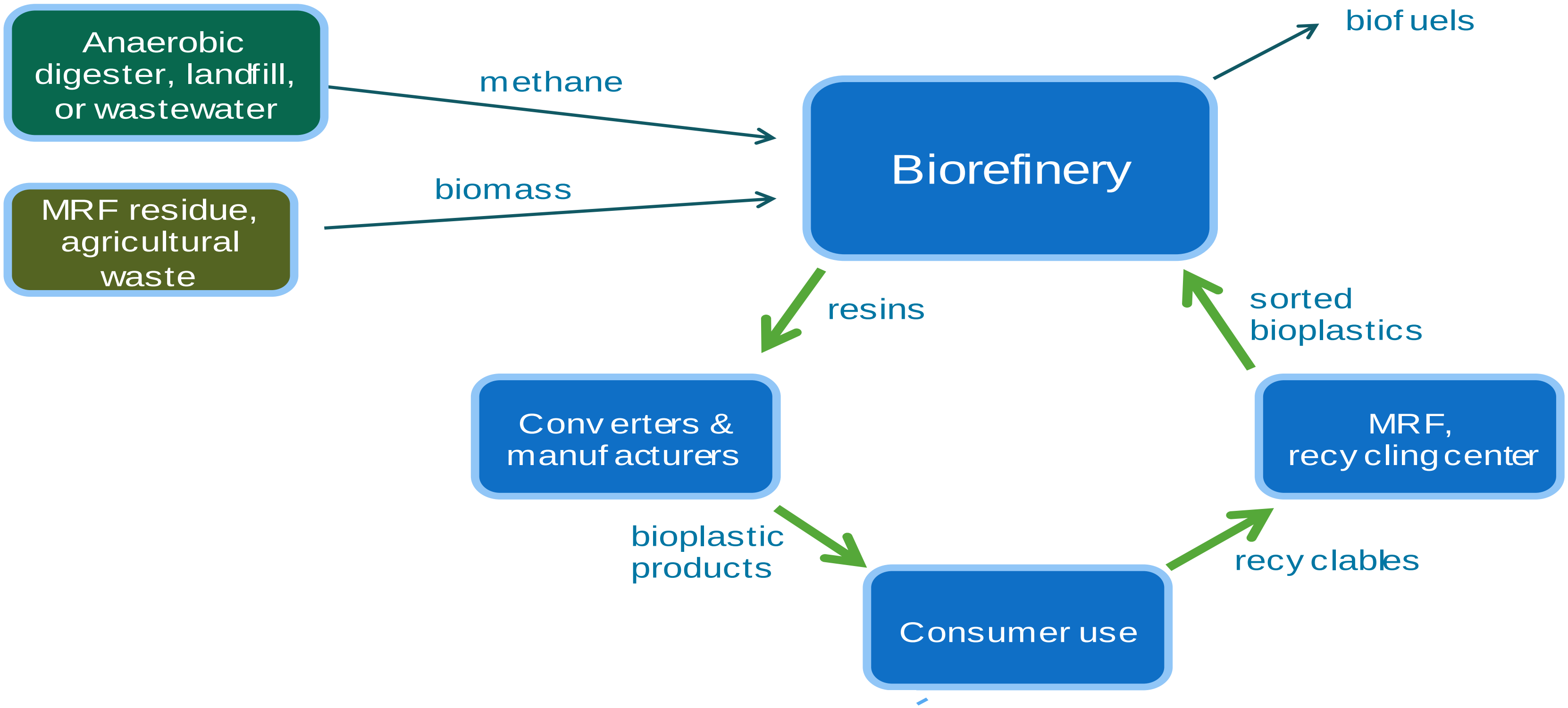
Cradle to Cradle Process



PART 1

The Science and Economics of Producing Bioplastics

“Bioplastic”

- Plastic made from biobased, renewable materials
- Plastic that is biodegradable
- Can be both biobased and biodegradable

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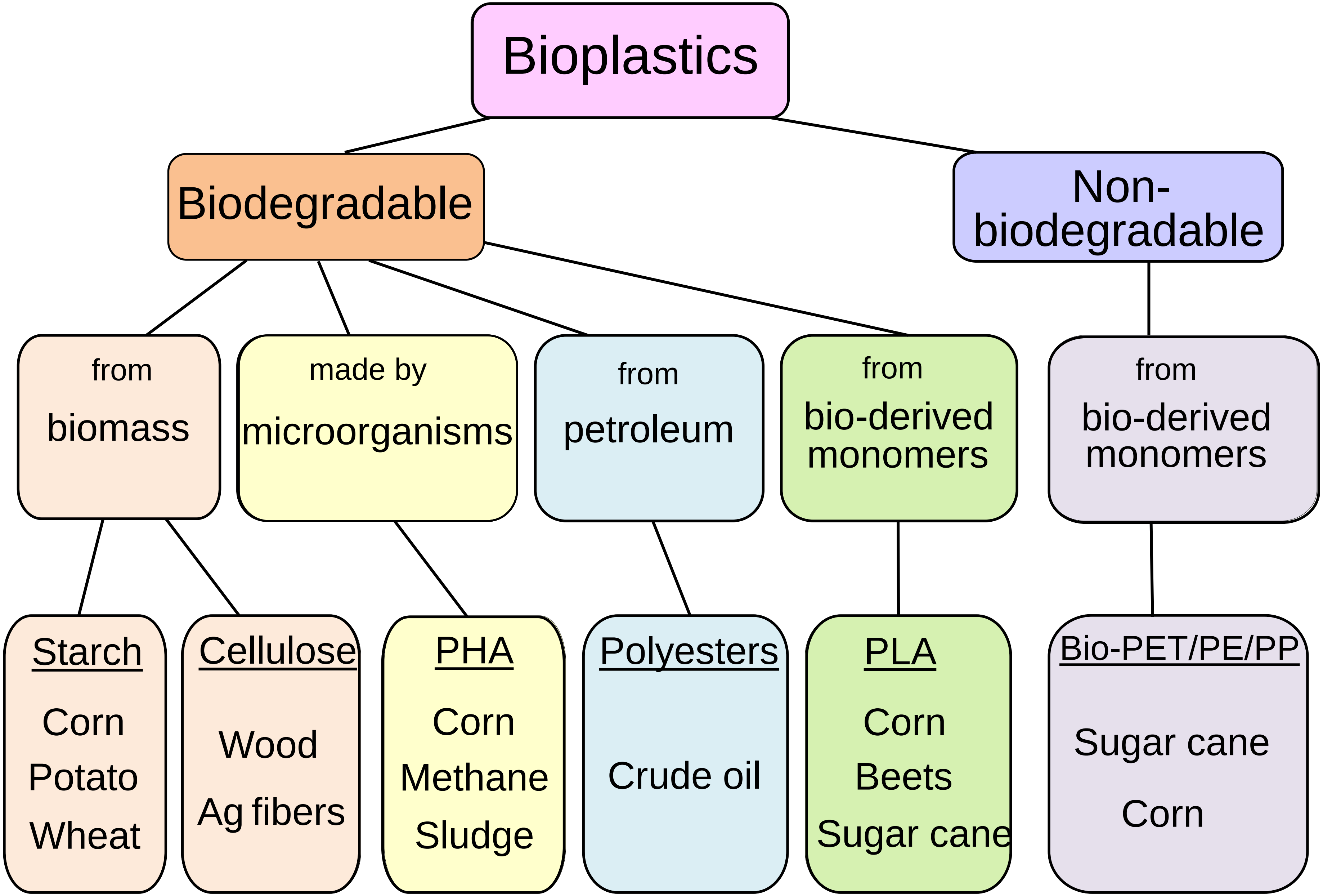
Bioplastic Categories

	Biobased	Fossil-based
Degradable	**Bioplastic** NatureWorks Ingeo™ PLA corn	**Bioplastic** BASF Ecoflex™ oil
Non-degradable	**Bioplastic** Coke PlantBottle™ Bio-PET part sugar cane	**Petrochemical plastic** Dow Chemical HDPE oil and natural gas



Adapted from Platt, 2010

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Selected U.S. and California Bioplastic Producers

Producer	NatureWorks LLC	Cereplast Inc.	Metabolix Inc.	Mango Materials	Newlight Technologies	Micromidas	Back2 Earth Technologies	BASF	Meredian Inc.
Polymer	PLA	Starch-PLA blends, others	PHA	PHA	PHA	paraxylene (precursor for Bio-PET)	PHA	copolyester	PHA
Feedstock	Corn	Starch from corn, tapioca, potato; algae.	Corn	Methane	Methane, carbon dioxide	Cellulose from cardboard	Food waste	Oil	Plant-based fatty acids
Plant or lab Location	Blair NE	Seymour, IN (HQ in El Segundo CA)	Leon, Spain (HQ in Cambridge MA)	Palo Alto CA	Irvine, CA	West Sacramento CA	Fresno & Chico, CA pilots (Orinda, CA HQ)	Multiple sites (U.S. HQ in Florham Park, NJ)	Bainbridge GA

The Stanford Process - Converting waste to bioplastic

- Methane feedstock from anaerobic digester fed to microbes to produce PHA polymer (PHB)
- System designed for closed-loop cycling of plastic polymer
- End of life options explored to recycle PHB

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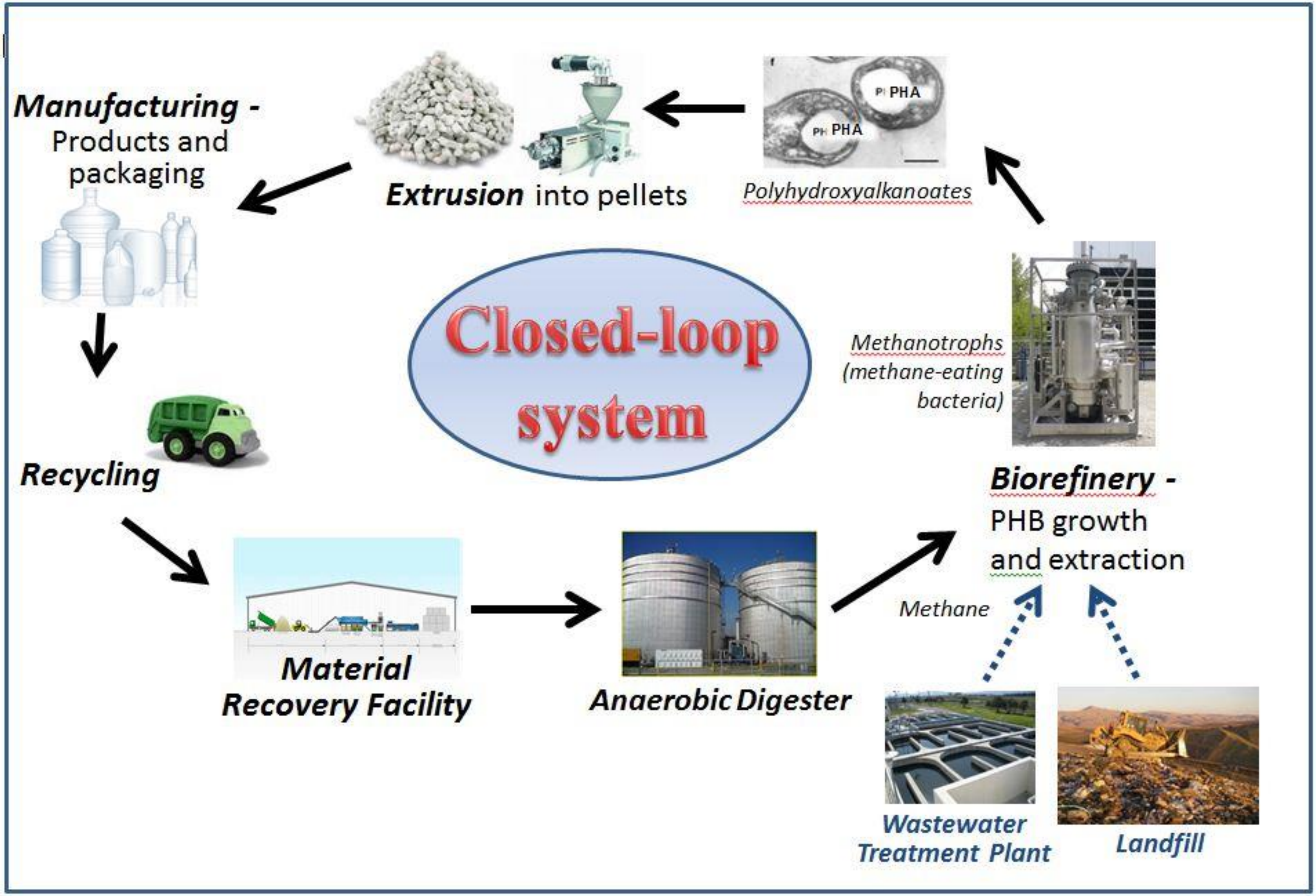
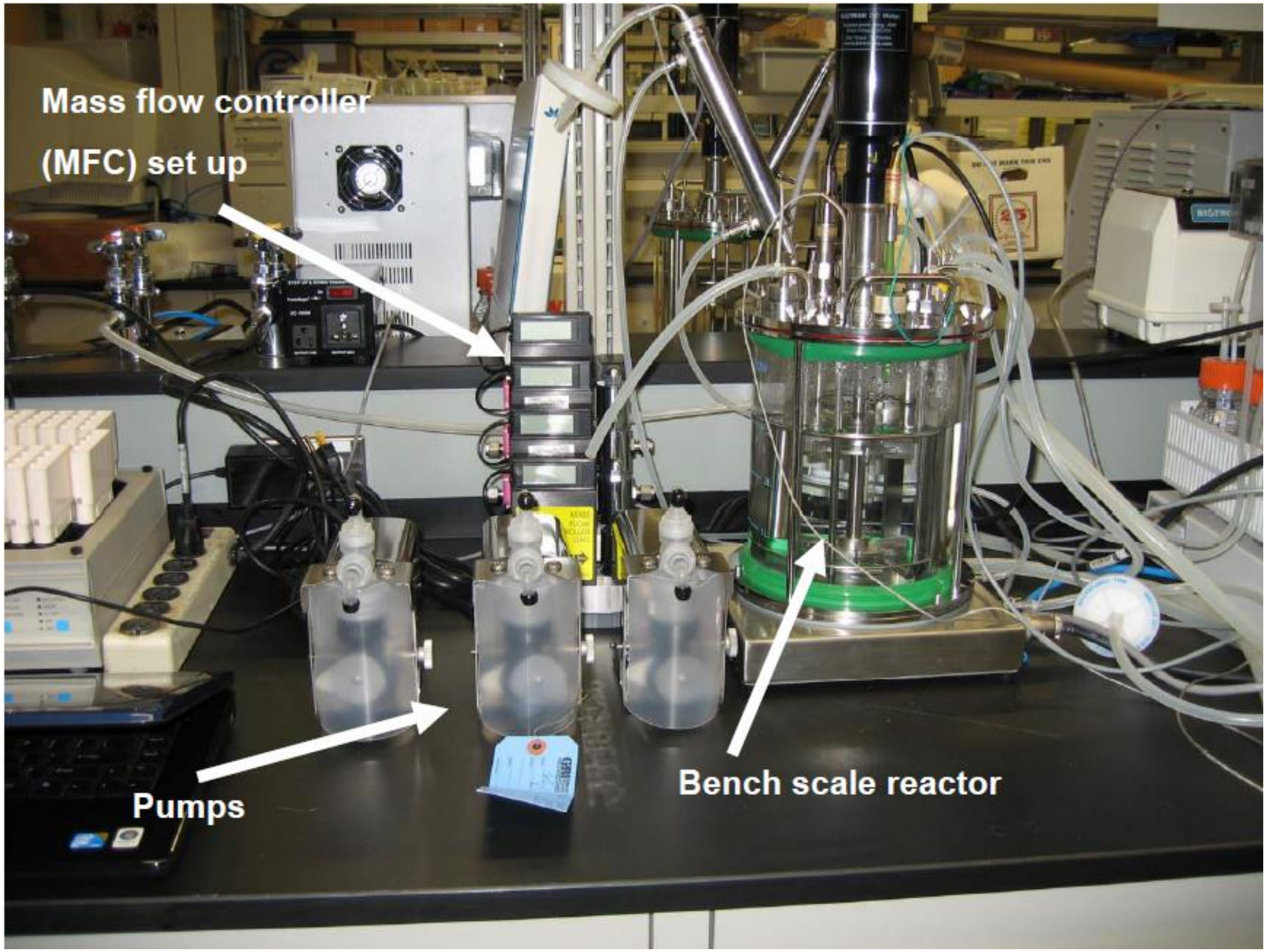


Manufacturing - Products and packaging
Extrusion into pellets
PHA
PHA
Polyhydroxyalkanoates
Closed-loop system
Methanotrophs (methane-eating bacteria)
Recycling
Biorefinery - PHB growth and extraction
Methane
Material Recovery Facility
Anaerobic Digester
Wastewater Treatment Plant
Landfill

Stanford Laboratory Bioreactor Set-up



PHB from Methane

Lab Experiments

- Identify the best methanotrophs for PHB production
- Establish operating parameters and nutrient levels to maximize PHB production
- Determine the most effective and least toxic method to extract the polymer from the bacteria
- Define the physical properties of the PHB produced for plastic applications

Research Findings

- Type II methanotrophs (*Methylocystis* and *Methyloparvus* genera) produce PHB
- Micro-plate screening method developed to test strains, PHB growth, nutrient levels
- N_2 fixation, low pH, no copper, dilute salts selected for Type II, but slowed PHB
- Methane limitation and alternating nitrogen sources maximized PHB production

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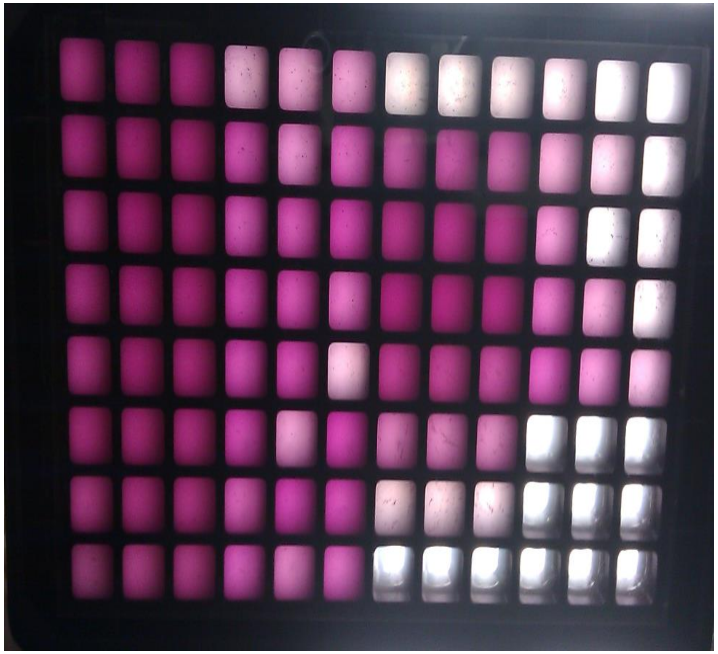
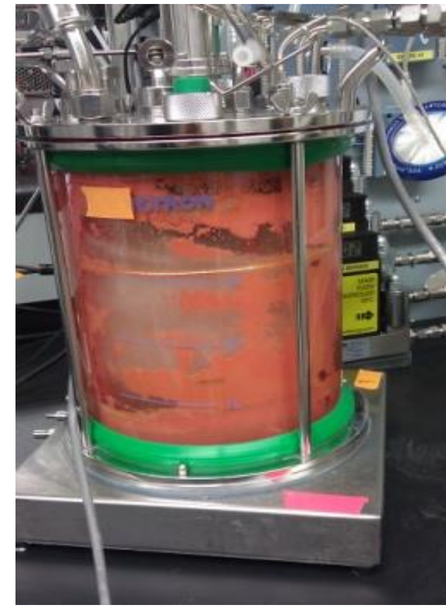


Micro-plate System

Type II methanotrophs



Type I takeover event

Research Findings

- PHB acts as fuel for cell reproduction
- Use of surfactant (SDS) w/solvent (hypochlorite) effective extraction method
- PHB can be made into biocomposites for construction applications
- Inability to sustain production of PHB
- Difficult to find benign extraction method
- Unable to prove technology under optimized conditions at commercial scale

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Stanford's Bioplastics Recycling Research

- Utilized anaerobic digestion (AD), hydrolysis, and thermal depolymerization
- PHAs (including biocomposites) generate significant biogas in digesters
- Hydrolysis of PHA produces useful monomers
- PLA can be successfully depolymerized to lactide and certain enzymes show degradation potential

Stanford's PHB Cost Study

- Capital & operating costs - biogas-to-PHB at landfill or WWT locations
- Most CA landfills have biogas for 2K tons+/yr PHB
- PHB may generate more $ from biogas than electricity if priced $0.91/lb. or higher
- Costs start to level out at 5K tons/yr
- Medium-size PHB plant may be competitive with petro-resins; biogas used to power plant
- Ballpark estimates – limited data points

UC Berkeley Cost Study - PHB Produced in California

- Best sites for *small* biogas-to-PHB plant (1K tonnes)
- Data from Stanford lab, DTSC cost model, others
- 49 landfills and 10 WWT plants have “available” (not contracted) biogas supply
- “May be profitable under reasonable assumptions”: positive Net Present Worth if PHB over $.53/lb.
- Analyzed 5 drivers: results most sensitive to extraction costs and PHB price

UC Davis
PHA Cost Study - biorefinery using organic waste

- Hypothetical plant: PHA from organic MRF residuals (cellulosic biomass converted to sugars)
- Martinez, CA - best site for aggregated residuals
- 33 million lbs./yr. PHA plant would require $330 mil. investment and PHB priced at $2.73/pound
- Transportation costs minor vs. other factors
- Extremely limited data based on few studies

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Bioplastics
From Pellets to Products and Packaging

- *May* be molded & shaped on conventional equipment *if* performance specs met
- Many potential applications; some “drop-in”
- Additives may enhance processing & performance – strength, shelf life, etc.
- Scientific standards for measuring (e.g. ASTM)
- “Recipe” can affect end of life, public health

Labeling

- Advertising & “greenwashing”
- FTC Green Guides define “biodegradable,” “compostable,” etc.
- ASTM Resin ID Codes (#1 – 7) under review
- CA plastic labeling law uses current RIC

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Public Health Considerations

- U.S. EPA: TOSCA – est. 85,000 chemicals now in commerce
- FDA: food packaging review
- DTSC: Green Chemistry regs for Safer Consumer Products – upfront *design*
- DTSC: Toxics in Packaging Act – prohibits heavy metals (lead, cadmium, mercury, and hexavalent chromium)

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Lawrence Berkeley National Lab Leaching Study

- Quantified chemicals present in water bottled in PET and PLA at varied temperatures and storage times
- Water in bottles were tested overnight, 3 and 6 months at room temperature, 35 and 50 degrees C
- Used 3 sampling techniques to identify compounds and elements (GC/MS, LC/MS, ICP/MS)
- Completed preliminary human health exposure assessment of chemicals that migrated into water

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Research Findings

- Total of 29 compounds and 24 elements were identified and measured in tests – low concentrations (.001ppb – 1ppb)
- Distinct trend for increased concentrations in water from PET and PLA bottles for higher temp and longer storage
- List of prioritized chemicals for health hazard assessment included seven compounds and two elements
- Health assessment calculated exposure concentrations under storage conditions (3 mths/35ºC) based on daily water intake
- Preliminary assessment found the concentrations too low to pose significant risk to human health

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Chico PHA Bottle Study

- PHA resins from three manufacturers tested
- One bottle type was successfully blow-molded, others required additional additives (Ecoflex) – limited resin grades were available
- Determined key operational parameters and physical/performance properties
- PHA best suited for one-step extrusion blow mold process
- Metabolix bottles outperformed bottles made from Tianan and Tianjin PHA resins

Unsuccessful blow-molded bottles

Successful blow-molded bottles!

Chico - Bioplastics' Degradation in Marine Water Study

- Measured biodegradation rate of PHA film and PLA bottle and bag samples
- Followed ASTM Standards D7081 and D6691: requires 30 percent carbon conversion in 6 months and testing at 30 +/- 2 degrees C
- PHA degraded more than test limit; PLA did not
- Tested for chemicals during degradation; found none, but not tested for aquatic toxicity

PART 2
Bioplastics' End of Life and the California Recovery System

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The Back End: Collecting, Sorting, & Processing

- CA recycling programs – bottle bill, landfill diversion (AB 939), Rigid Plastic Packaging
- Public/private infrastructure for clean materials, steady feedstock supply
- AB 341 – new 75% recycling goal - must recycle more tons, more types
- China's Green Fence: exports curtailed

Contamination: Recycling Achilles' Heel

- Incompatible resins can ruin recycled pellet (wrong melt, discoloring, weaken, etc.)
- Recycled-content products in jeopardy
- Higher costs, yield loss
- "Degradable" additives controversy
  - *Not* bioplastic, but added to petro-plastics
  - Recyclers concerned about effects

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Contamination continued

- Separation: key to recycling (e.g. PET & PLA)
- Contaminants can be difficult to sort out, upset sink-float reclamation
- APR guidelines – Design for Recycling
- Some bioplastics *are* compatible: bio-PET

Contamination, Take 2: compost

- Organics must degrade rapidly (months)
- ASTM D6400: 90% carbon to CO^2 within180 days
- Organic certification: no synthetics
- More food waste recovery means more bioplastics likely

Optical Sorting of Bioplastics

- Future 500 grant – Feasibility of sorting bioplastics from waste/recycling stream
- Sorting tests conducted at MRFs throughout CA
- Pellenc Selective Technologies (France) designed optical sorting system
- Successes – cleaner streams for all plastics, quality materials recovered from MRF residuals
- Issues – Paper reduced accuracy, cost/space requirements
- Stakeholder meeting and input

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Selected Environmental Profiles of Plastic Packaging

- *Preliminary* look at waste-based plastics and a mature PET recovery system
- Cannot compare resins directly
- Bioplastic studies: “cradle-to-resin” (pellets)
- PET study: “cradle-to-grave” (bottles)

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Life Cycle Assessment - value & limitations

- Useful to understand areas for improvement, but *not* definitive
- Data gaps and quality, system boundaries, geographic limits, various assumptions
- Impacts outside scope (e.g. unknown effects of marine debris)
- Transparency – public data vs. proprietary

UC Santa Barbara
LCA of PET bottles in CA

- Modeled 2009 & hypothetical scenarios of CRV bottle consumption & recycling
- Original & previously published data
- Highest impacts – raw materials & mfg
- Materials recovery – relatively minor effects
- RPET had lower overall impacts vs. virgin
- “CA-only” scenario (no exports) even lower

Stanford methane-to-PHB LCA

- Cradle-to-resin LCA based on lab data & public inventories
- Energy use & solvent extraction of PHB showed highest impacts
- Using biogas from anaerobic digestion of used PHB could offset energy
- Actual industrial-scale production data not available

UC Davis LCA - PHA from MRF residuals

- Hypothetical plant – cellulosic fraction of organic MRF residuals otherwise landfilled
- Biomass hydrolyzed to produce glucose, then fermented to make PHA
- Data for main phases from 5 public studies
- Inconclusive results due to extremely limited data & wide variation in energy inputs

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UC Berkeley
Review of the LCAs

- Separately contracted for peer review of LCAs
- Examined scopes and goals, data limitations, appropriateness of methods
- Found Stanford, UCSB & UCD LCAs to be scientifically sound
- Cannot use these LCAs to compare plastic and bioplastic resins – different boundaries, etc.

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PART 3

Conclusion

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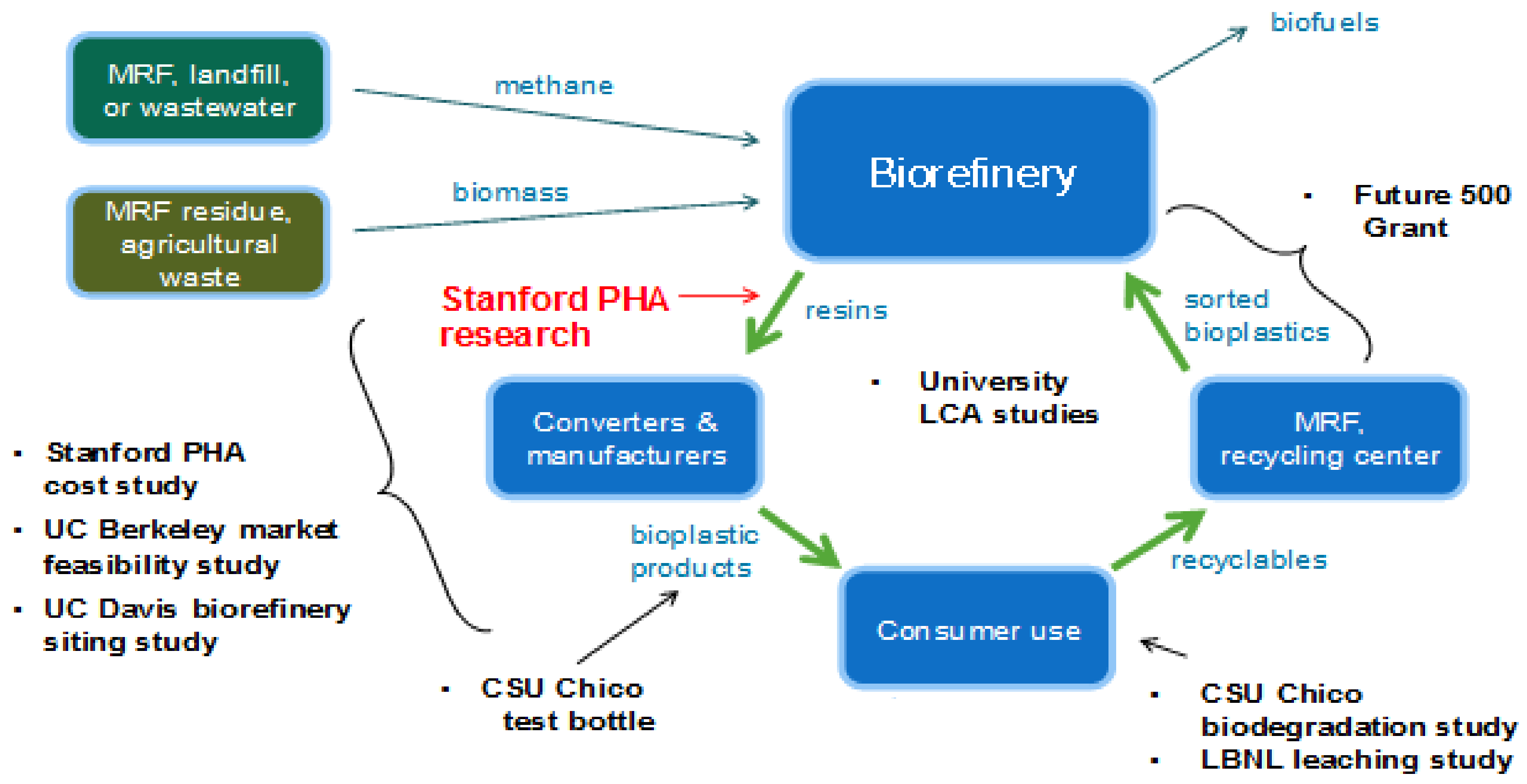
Diagram of Process



Introducing New Materials: the Front End

- Bioplastics from waste in CA *may* have benefits (lower GHG emissions, new jobs)
- Need to avoid disruption of recovery programs
- Small-scale and regional plants may be viable
- No “one size fits all” solution to plastic waste
- Bioplastics not “the solution” to litter or marine debris problem
- Preferred packaging applications unclear

Introducing New Materials: the Back End

- Feedback between all life-cycle phases
- Invest in separation methods & technology
  - Improve / lower costs of existing systems
  - R&D for new bioplastic recovery methods like anaerobic digestion
  - Market incentives for bioplastic recovery
- Explore regional plastic processing facilities
- Closed-loop events as testing grounds
- Improve labeling & education

In Conclusion

- Packaging constantly changing
- Growth of bioplastics is likely
- CA recovery framework must adapt
- Concerted efforts by stakeholders
- Effects of new materials in CA market will inform January 2014 report to the Legislature

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Thank you!

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California Department of Toxic Substances Control

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BERKELEY LAB

Lawrence Berkeley National Laboratory

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