
# Approach

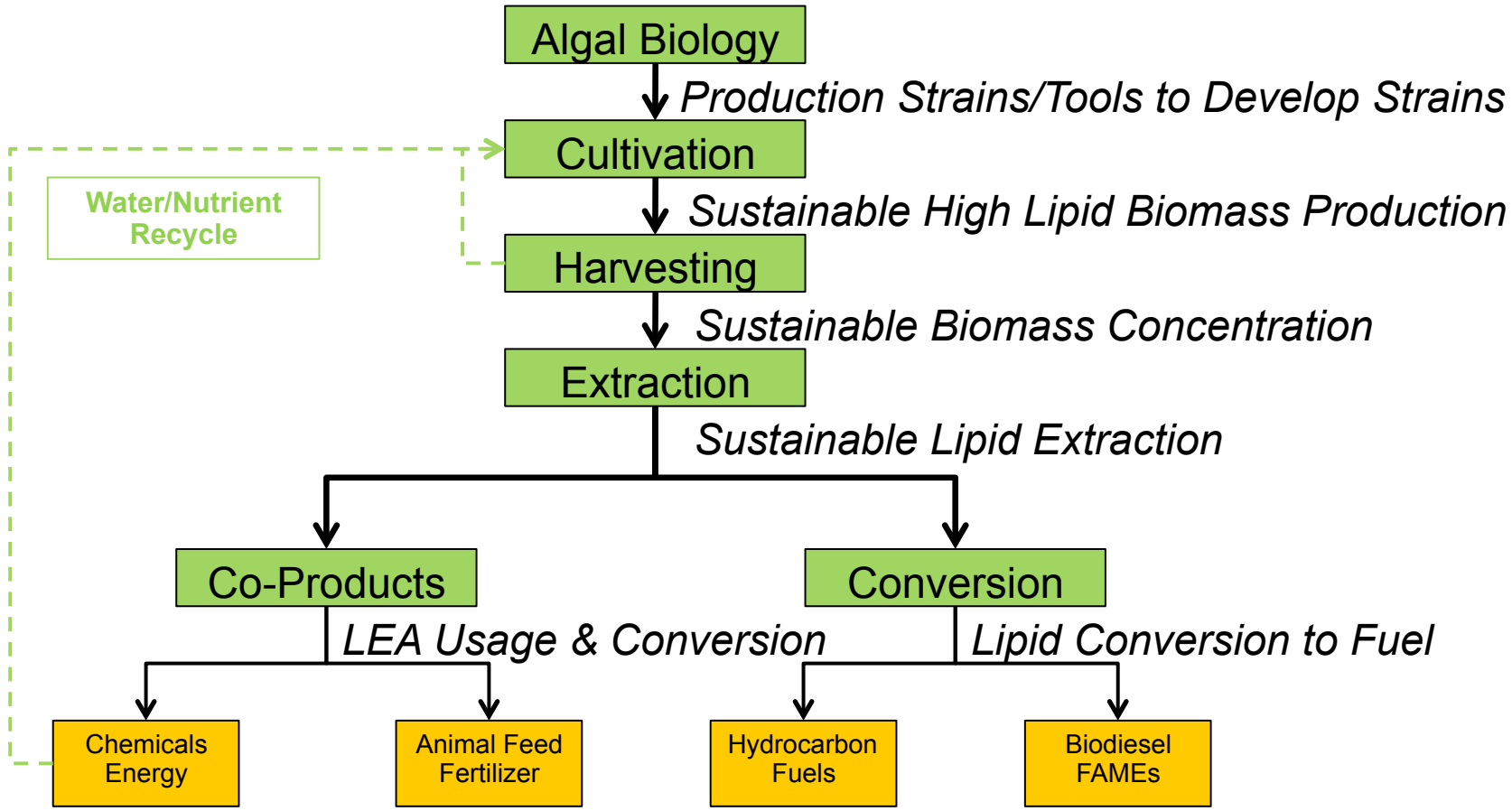
*R&D Framework*
*Milestones & Deliverables*
*Crosscutting Process Efforts*

Presented by Dan Anderson, NAABB Operations Manager

# R&D Framework

- **NAABB WBS is complex with 6 major task areas, multiple subtask areas and ~80 projects spread across multiple institutions**
- **NAABB management team translated a complex WBS into a R&D Framework to help with horizontal integration of work within tasks and to begin vertical integration of task areas**
- **The R&D Framework was tied to milestones, deliverables and decision points for each task area**
- **The R&D Framework was used to guide and manage R&D efforts across NAABB to achieve our objectives and meet key milestones and deliverables**

# R&D Framework with High Level Outcomes



# Algal Biology Task Framework

## Increase Productivity

- **Trait identification from research & production strains**
  - Genomics and transcriptomics
  - Systems biology
  - Genetics enabled trait screening
  - Lipid & isoprenoid genes and pathways
  - Growth and energy genes and pathways
- **Phenotypic characterization in PBRs**
- **Molecular biology tool development for production strains**
  - Genome enabled expression constructs
  - Transformation method development
- **Crop protection from competitors and predators**
- **Assessing traits for improved production**

**Research Strains**

- *Chlamydomonas reinhardtii*
- *Botryococcus braunii*

**Production Development Strains**

- *Nannochloropsis salina* (SW)
- *Auxenochlorella protothecoides* (FW)
- New or modified strains (*C. sorokiniana*)

Strains to Cultivation Task

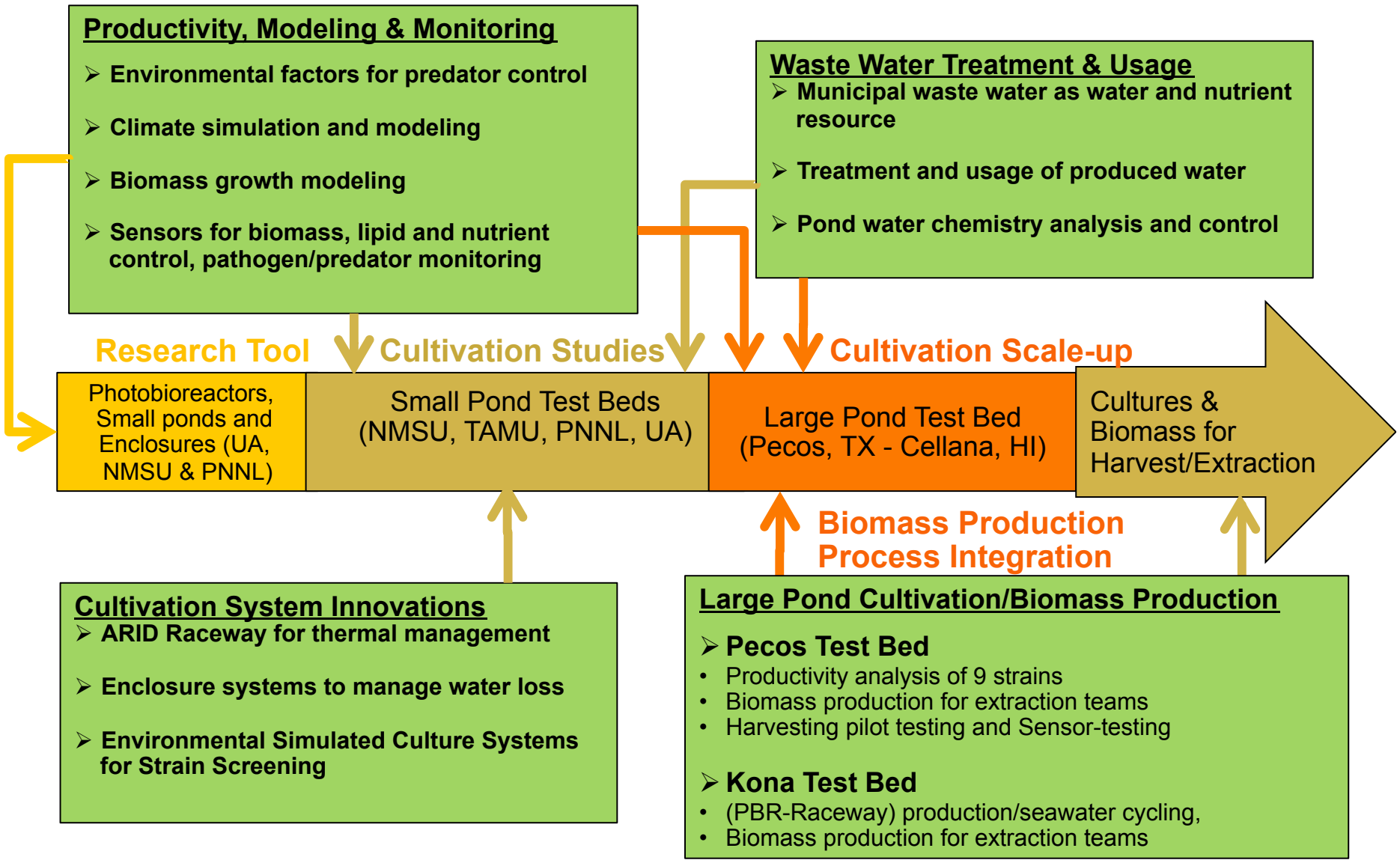
## New Strain Isolation and Development

- **Isolation of new strains**
- **Screening strains for biomass and lipid productivity**
- **Optimizing culture conditions for candidate strains**
- **Adaptive evolution for selection of new strains**
  - Flow cytometry for high lipid productivity
  - Chemostat selection for decreased nutrient requirements

# Algal Biology Milestones and Deliverables

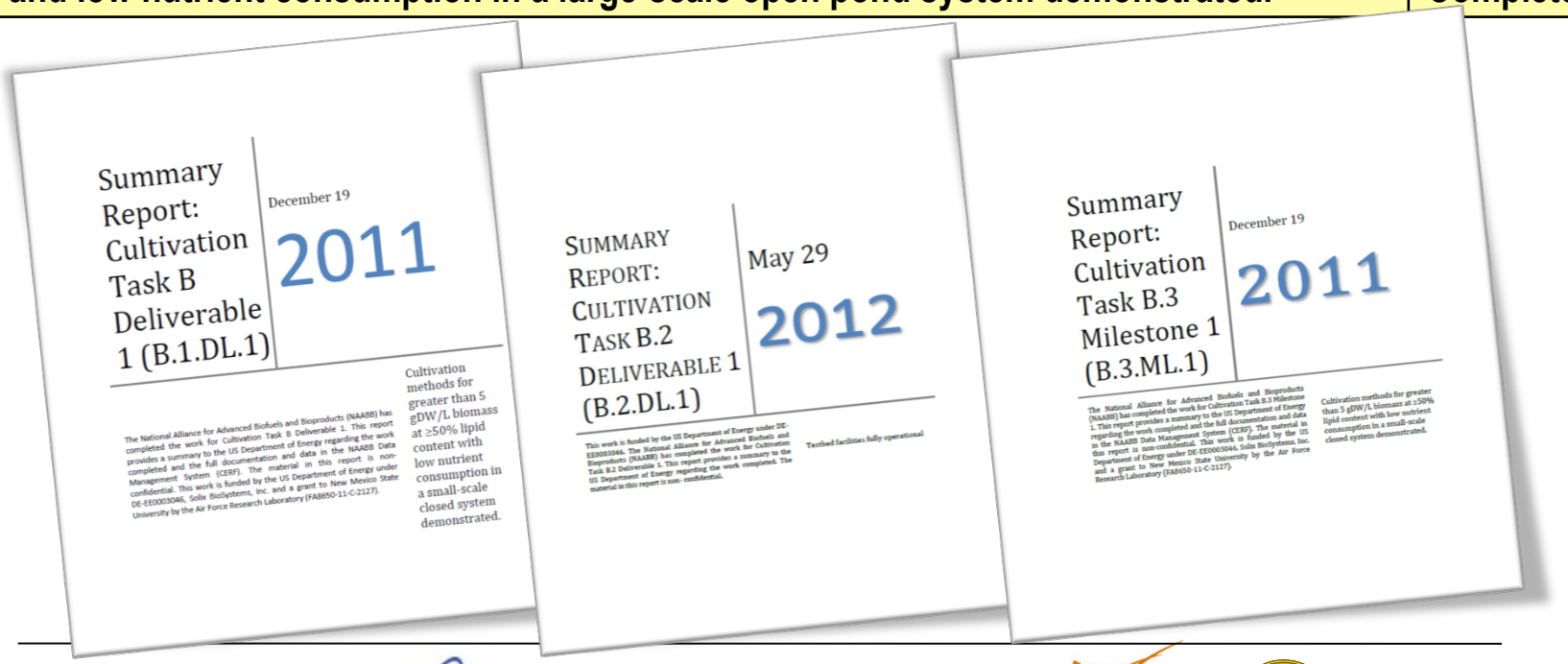
| Milestones (M), Decision Points (GN) and (DL) Deliverables | Time (mo) Status |
|---|---|
| A.4.ML.1: 500 algal isolates screened, ≥10 promising high lipid strains tested in culture. (report) | 18 Complete |
| A.1.DL.1: Genes for increased yield, productivity, nutrient utilization, or crop protection cataloged. Transgenic tools demonstrated for *C. reinhardtii, B. braunii, Chlorella*. (report) | 18 Complete |
| A.3.DL.1: 1st generation of *Nanochloropsis* & *Chlorella* strains obtained by adaptive evolution with demonstrated improvement in growth or lipid yield over parent strain. (report) | 18 Complete |
| A.4.ML.2: 1500 algal isolates screened, ≥30 best strains verified and deposited to UTEX (report) | 36 Complete |
| A.ML.2: Transgenic strains incorporating best trait(s) demonstrated in culture. (report) | 36 Complete |

# Cultivation Task Framework

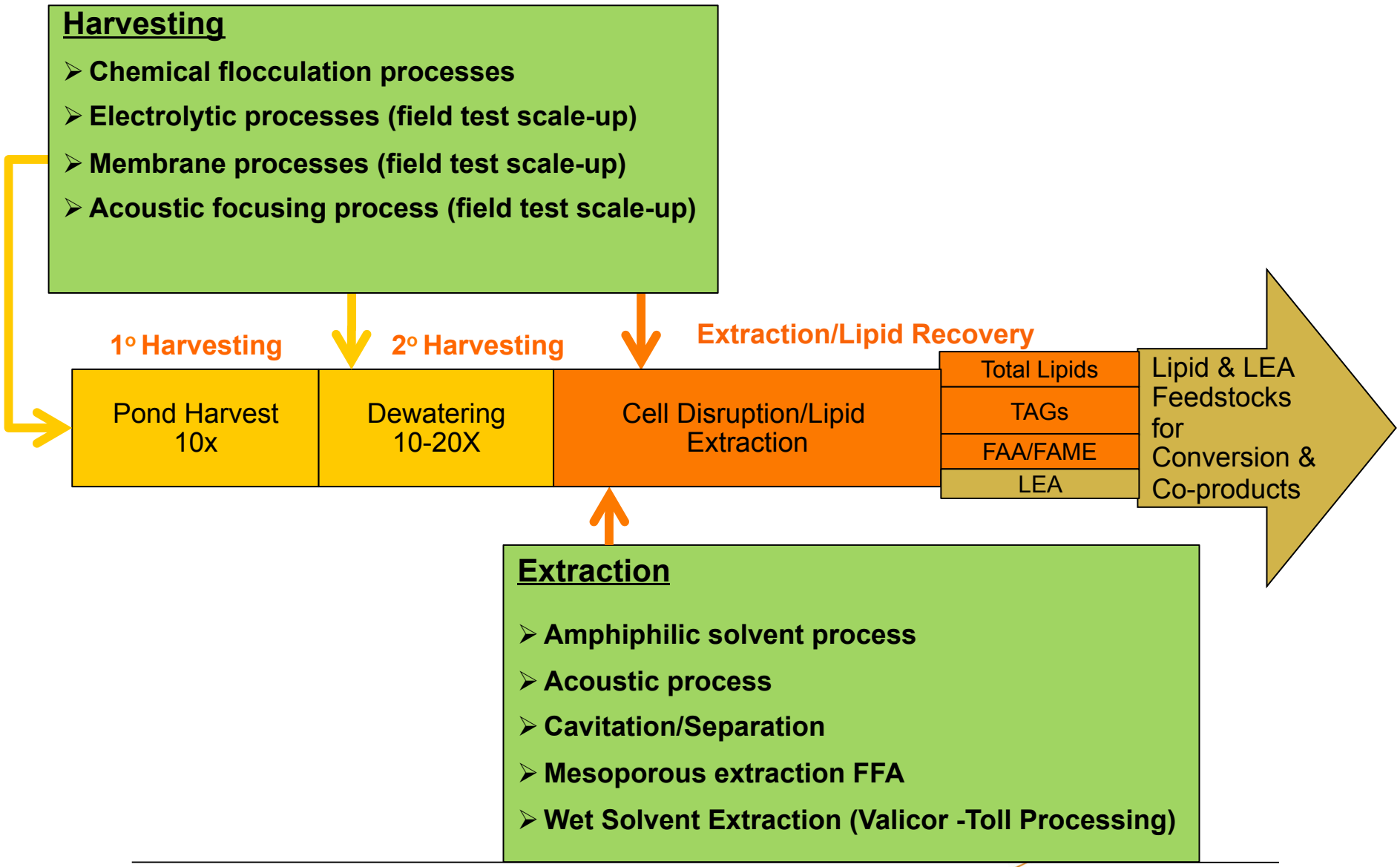


# Cultivation Milestones and Deliverables

| Milestones (M), Decision Points (GN) and Deliverables (DL) | Time (mo)<br>Status |
|---|---|
| B.1.DL.1:Cultivation methods for greater than 5 gdw/L/day biomass at ≥50% lipid content with low nutrient consumption in a small-scale closed system demonstrated (report) | 18<br>Complete |
| B.2.DL.1: Test bed Facilities fully operational | 24<br>Complete |
| B.3.ML.1: Cultivation methods for approaching target growth rates and lipid yield with best strain and low nutrient consumption in a large-scale open pond system demonstrated. | 36<br>Complete |

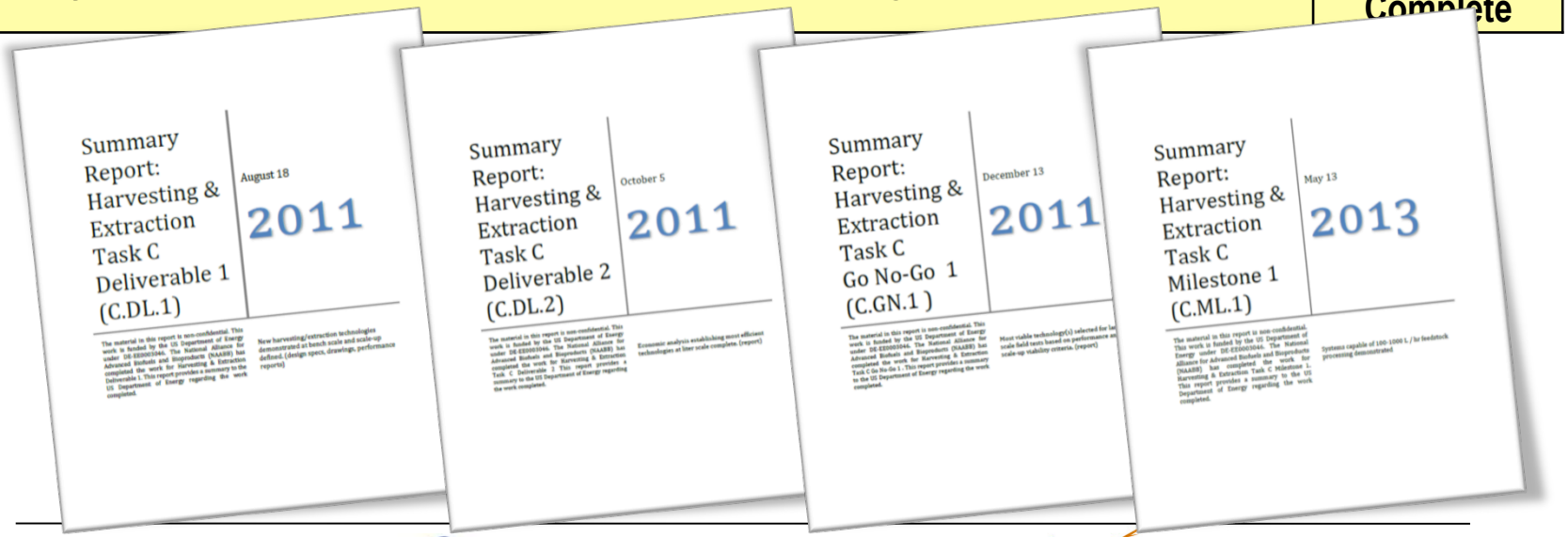


# Harvesting & Extraction Task Framework



# Harvesting/Extraction Milestones and Deliverables

| Milestones (M), Decision Points (GN) and Deliverables (DL) | Time (mo)<br>Status |
|---|---|
| C.DL.1: New harvesting/extraction technologies demonstrated at bench scale and scale-up defined. (design specs, drawings performance reports) | 15<br>Complete |
| C.DL.2: Economic analysis establishing most efficient technologies at liter scale complete. (report) | 18<br>Complete |
| C.GN.1: (Go/No Go) Most viable technology(s) selected for large-scale field tests based on performance and scale-up viability criteria (report) | 18<br>Complete |
| C.ML.1: Systems capable of 100-1000L/hr feedstock processing demonstrated. (report) | 36<br>Complete |



# Fuel Conversion Task Framework

National Alliance For Advanced Biofuels and Bio-products

**Lipid Conversion to Fuels**

- **Processes to produce Biodiesel fuels (FAMEs)**
  - Solid Acid Catalyzed
  - Sub-Supercritical
- **Processes to produce hydrocarbon fuels**
  - Hydrogenation
  - Decarboxylation

**Detailed Characterization**

- **Chemical & physical characterization of feedstock (lipid/LEA)**
- **Chemical & physical characterization of fuel products**
- **Quality/Performance evaluations of fuel products**

**Feedstocks**

- Various Lipid Extracts
- Algal Biomass
  - Whole Biomass
  - Various LEA
  - Macroalgae

**Lipid Conversions Processes**

- Biodiesel
- Hydrocarbon Fuels
- Methane/Power
- Ethanol
- Organic Acids/Gasoline
- Bioplastics
- Refinery Feedstock

**Product /Process Characterization & Evaluations**

**Biomass Conversions Processes**

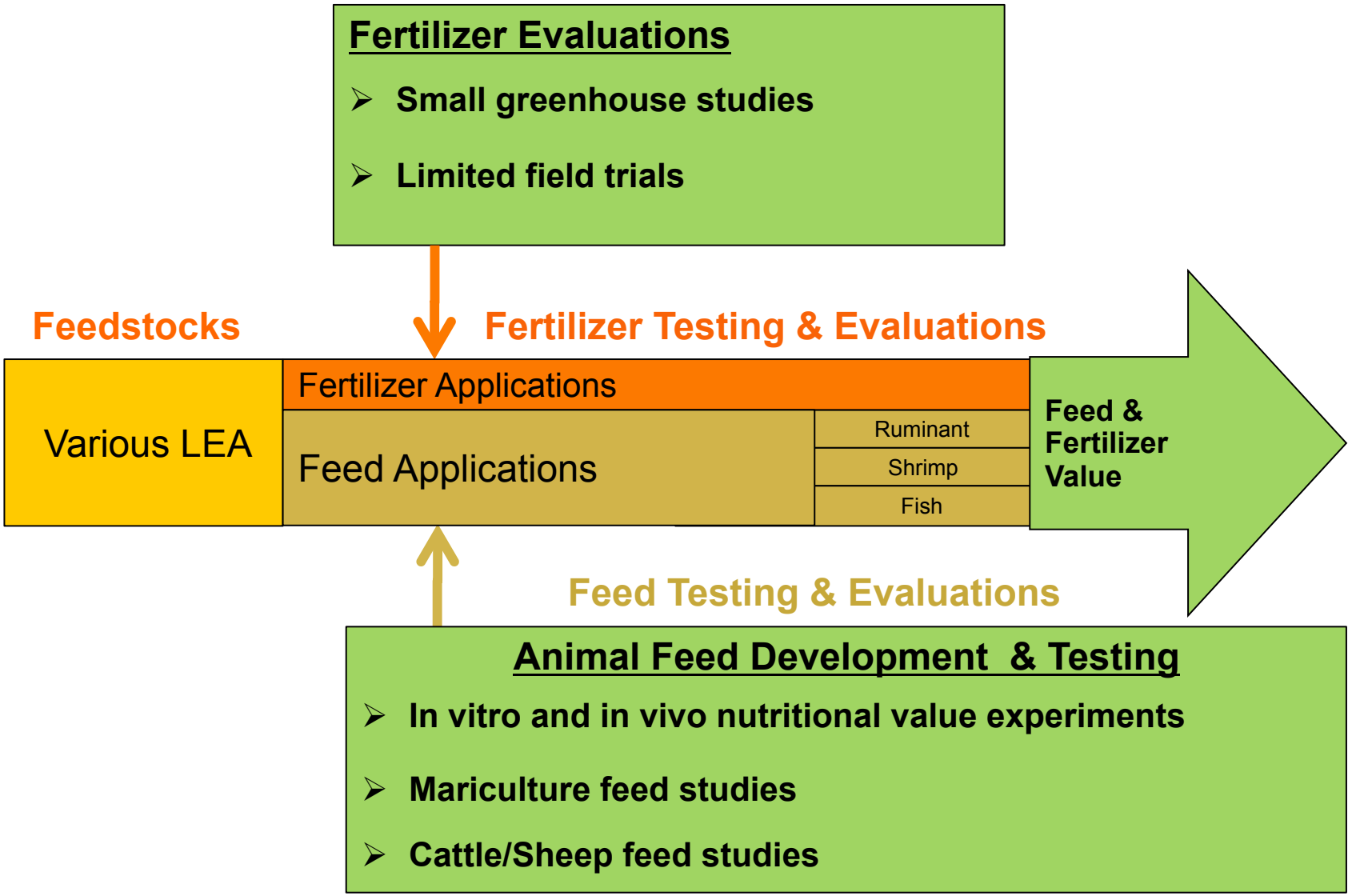
**Biomass/LEA Conversion to Fuels & Chemicals**

- **Hydrothermal gasification to methane for power**
- **Hydrothermal Liquefaction and upgrading to hydrocarbon fuels**
- **Biological conversion :organic acids to gasoline, ethanol**
- **Production of chemicals**

# Fuel Conversion Milestones and Deliverables

| Milestones (M), Decision Points (DP) and Deliverables (DL) | Time (mo) Status |
|---|---|
| D.DL.3: Preliminary cost analysis, bench scale rate data, and yield information obtained (report) | 24 Complete |
| D.ML.1: Select optimal conversion process for large-scale production and wide-scale use based on performance and scale-up requirements criteria (design specs, report) | 24 Complete |
| D.DL.1: Pollutant and greenhouse gas emissions from the combustion of algae-derived biofuels characterized. (report) | 30 Complete |
| D.DL.2: ASPEN process model of conversion technologies demonstrated. (report) | 30 Complete |

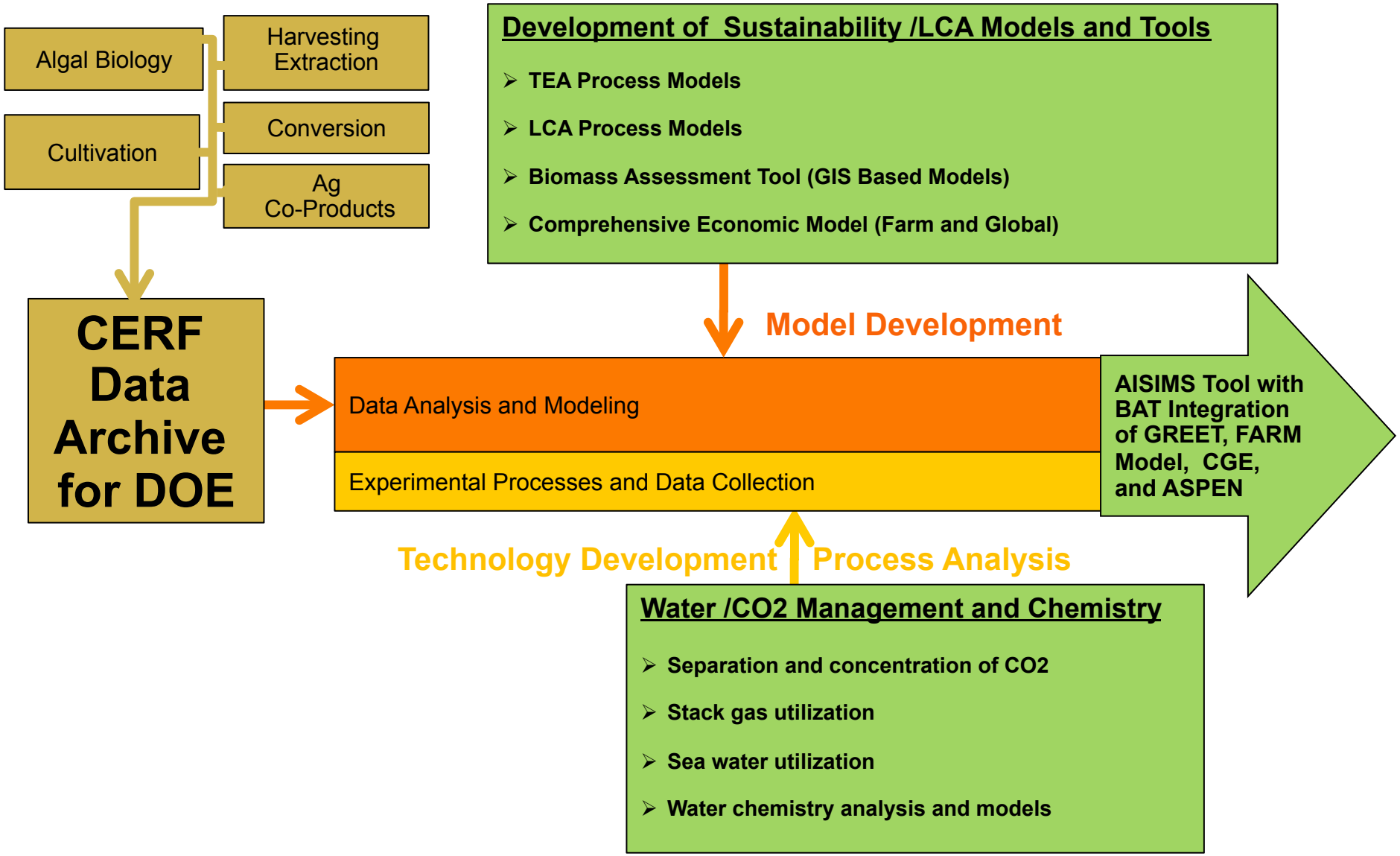
# Agricultural Co-products Task Framework



# Ag Co-products Milestones and Deliverables

| Milestones (M), Decision Points (GN) and Deliverables (DL) | Time (mo)<br>Status |
|---|---|
| E.1.ML.1: Feed Value for LEA Determined | 24<br>Complete |
| E.2.DL.1: Preliminary cost analysis, bench scale rate data, and yield information obtained for production chemicals | 24<br>Complete |
| E.1.DL.1: Best performing feed formulations determined(report) | 36<br>Complete |

# Sustainability Task Framework



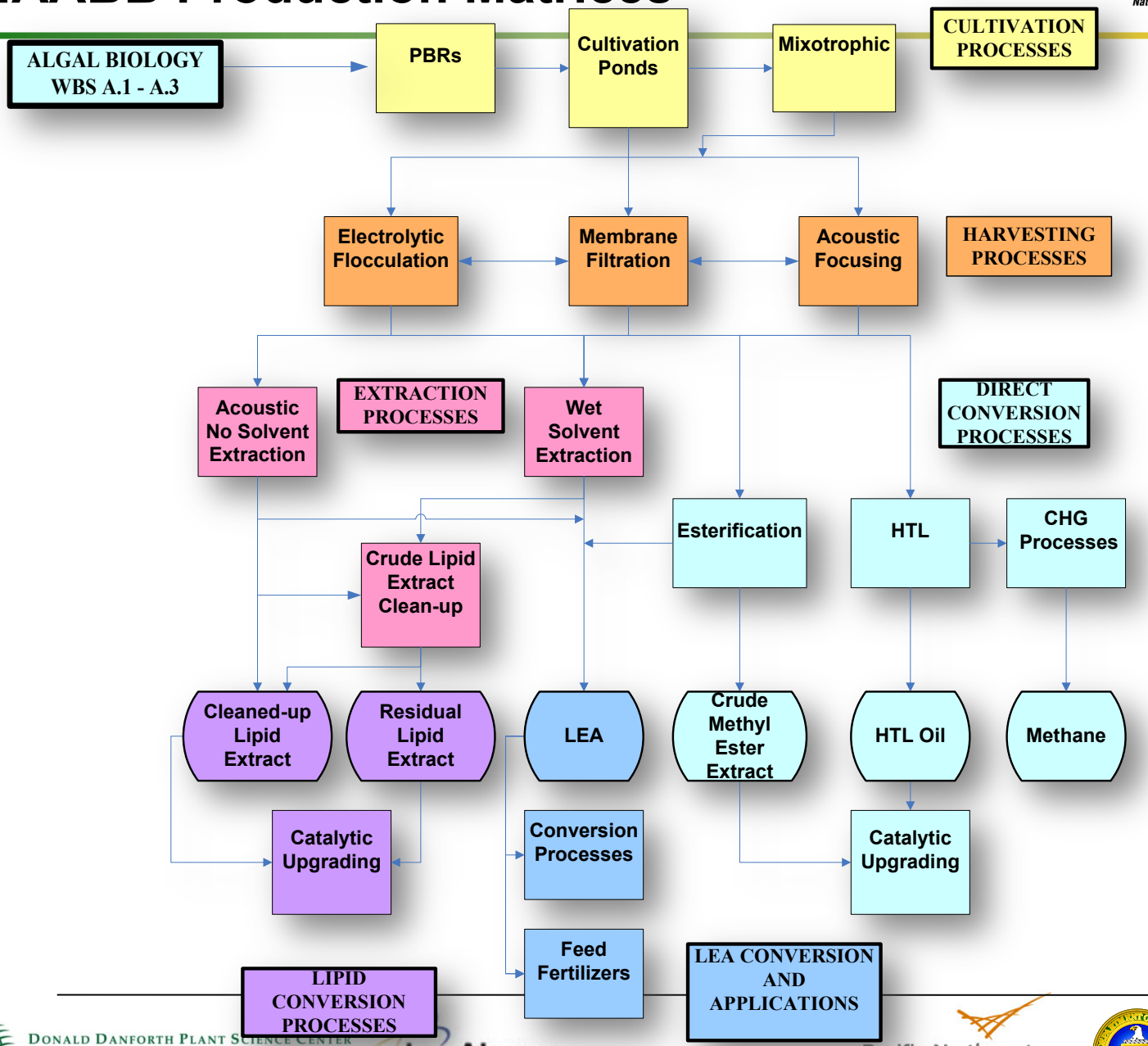
# Sustainability Milestones and Deliverables

| Milestones (M), Decision Points (GN) and Deliverables (DL) | Time (mo) Status |
|---|---|
| F.1.DL.1: ASPEN process model for producing synthetic natural gas, liquid algal biofuel and chemical feedstock completed. (report) | 12 Complete |
| F.DL.1: AISIMS data integration and standardization framework established. (report) | 24 Complete |
| F.ML.1: Web based AISIMS modeling and database system fully implemented. (report) | 36 Complete |

# Crosscutting Process Matrices

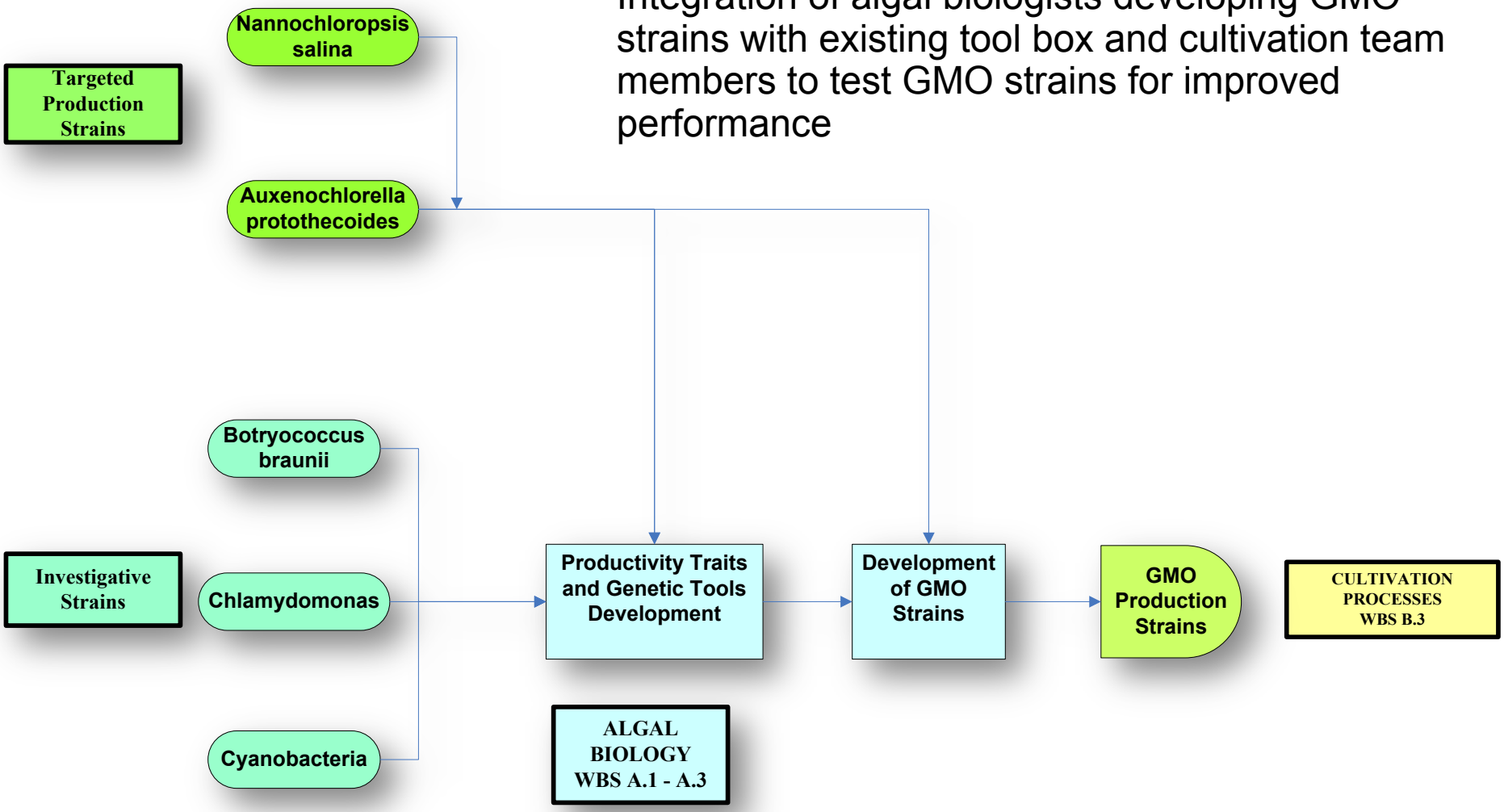
- NAABB recognized the R&D Framework could not address key gaps related to understanding the process requirements between various task areas
- Process Flow Matrices were developed to guide the flow of materials and data throughout the various NAABB processes from strain discovery/development through downstream extraction and conversion
- Several crosscutting process areas were identified to facilitate vertical integration within NAABB and workshops were held to use these to understand requirements and gaps
- NAABB was able to take several potential production strains through the entire process matrix developing one-of-kind data sets for modeling and scenario analysis

# NAABB Production Matrices

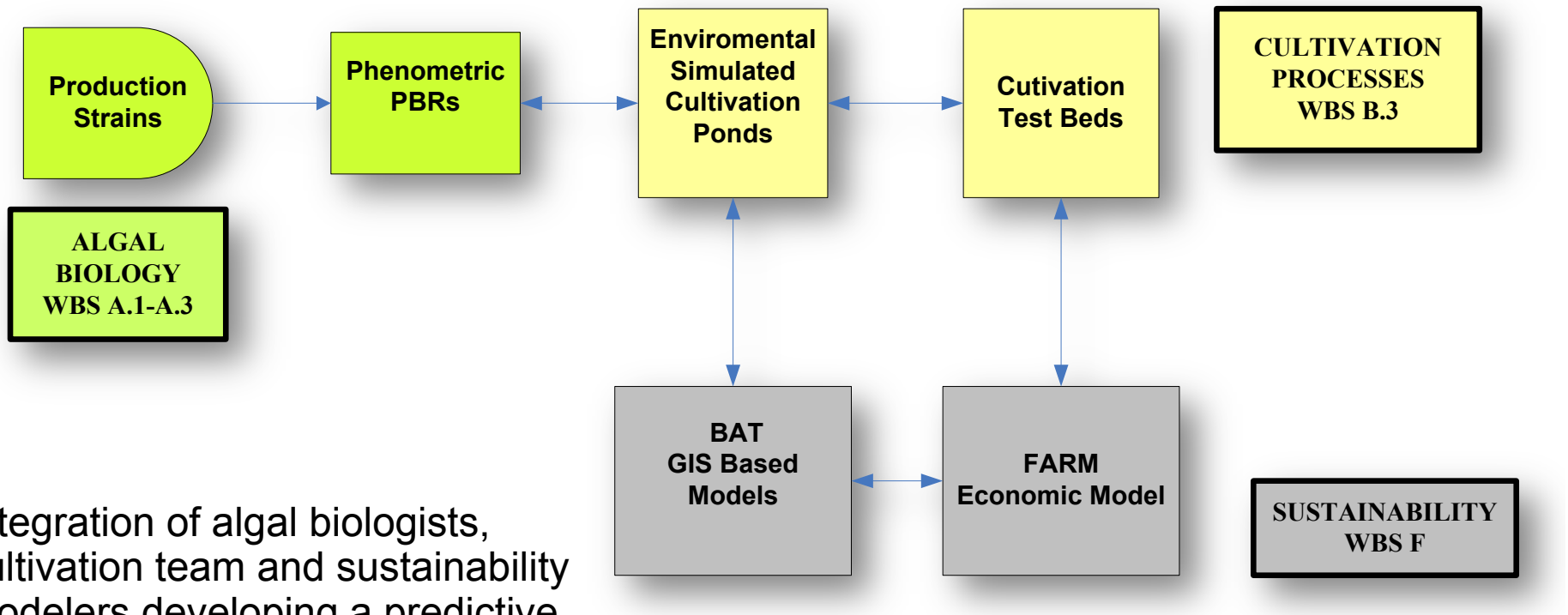


# Production Strain GMO Development

Integration of algal biologists developing GMO strains with existing tool box and cultivation team members to test GMO strains for improved performance

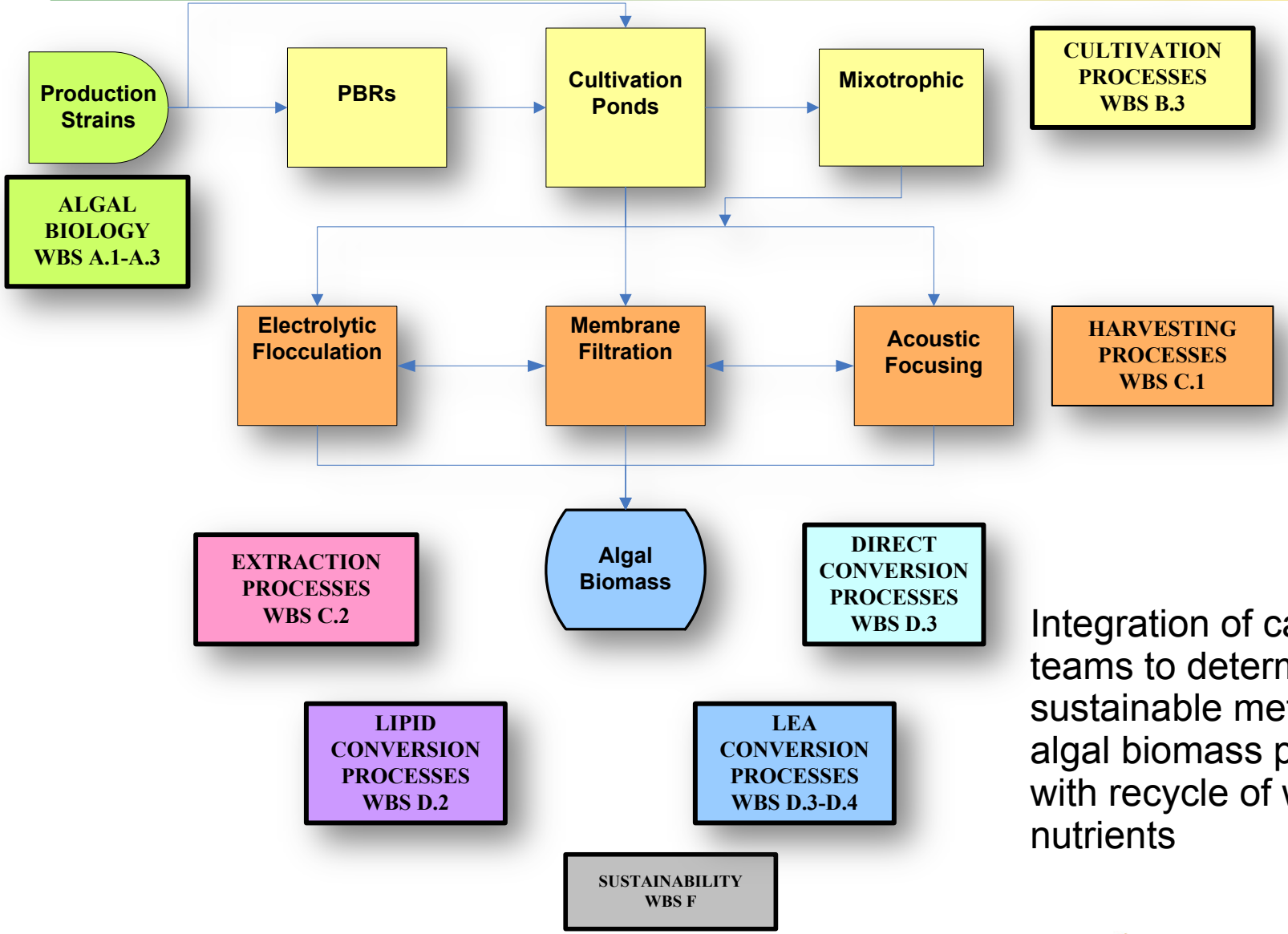


# Environmental Simulation Strain Screening



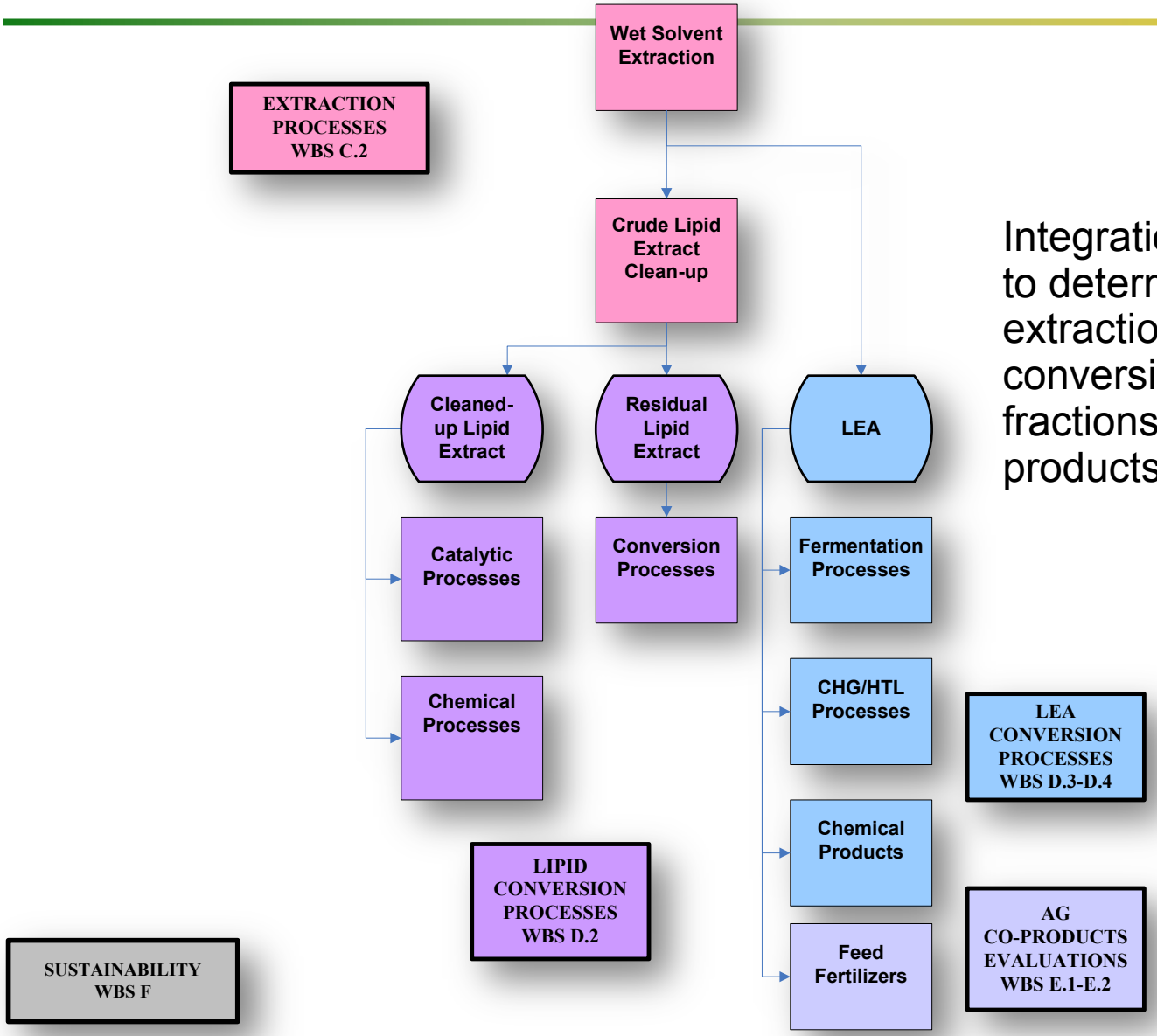

Integration of algal biologists, cultivation team and sustainability modelers developing a predictive method for strain performance in large scale cultivation across diverse environments and farm locations

# Cultivation/Harvesting/Water and Nutrient Recycling



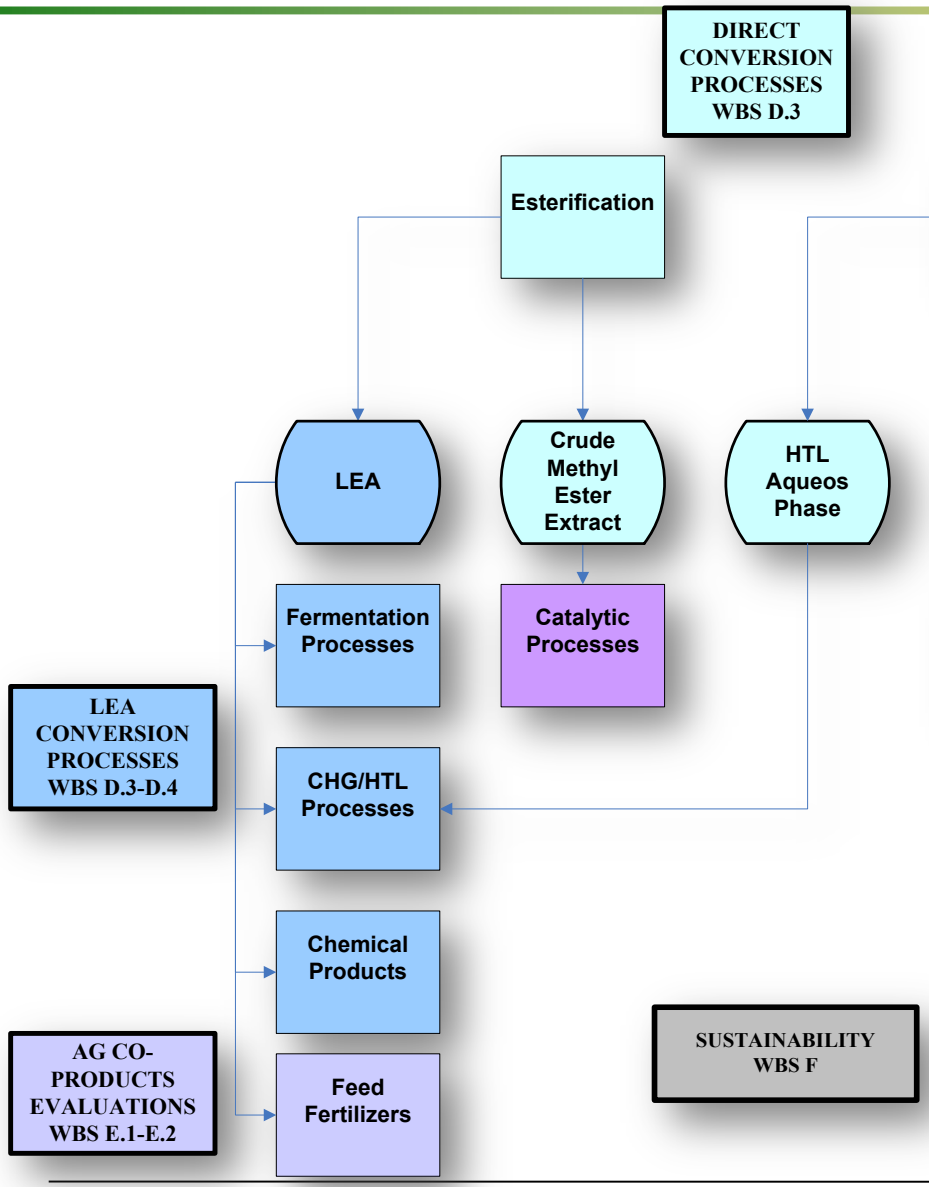

Integration of capability teams to determine sustainable methods for algal biomass production with recycle of water and nutrients

# Extraction/Lipid Clean-up and Conversion




Integration of capability teams to determine methods for lipid, extraction/clean-up and conversion of lipids/ LEA fractions to fuels and co-products and nutrient recycle

# Direction Conversion to Fuels and Co-products




Integration of capability teams to evaluate alternative process pathways for fuels, co-products and nutrient recycle

# NAABB R&D Approach Summary

- R&D Framework facilitated management R&D efforts across the NAABB consortium
- Milestone, deliverables and decision points were all achieved on schedule
- Crosscutting process matrices were used to facilitate the flow of materials and data across the various upstream and downstream processes
- NAABB has developed one-of-kind integrated process data from several potential production strains through multiple upstream and downstream processing scenarios