# Anaerobic digestion feedstocks and opportunities for macroalgae conversion

David P. Chynoweth, Professor Emeritus

Agricultural and Biological Engineering

University of Florida

# Reference

Chynoweth, D. P. (2002). *Review of Biomethane from Marine Biomass*. A report prepared for Tokyo Gas Company. 2002.

http://www.agen.ufl.edu/~chyn/download/Publications

# Biomass Program Sponsors

- American Gas Association/Gas Research Institute
- US DOE/ERDA/SERI
- US Navy
- EPRI
- NYSERDA
- University of Florida IFAS

# Major Biomass Program Contractors

- University of Florida
- Institute of Gas Technology
- Syracuse University
- Texas A & M
- Cornell University
- Cal Tech. U.
- State University of New York
- Neushul Mariculture
- Harbor Branch
- Waste Management
- Walt Disney World
- General Electric
- Reynolds, Smith, & Hills
- Radian (URS)

# Gas Research Institute Biomass Energy Feedstocks

- Terrestrial Biomass
  - herbaceous:  sorghum, Napiergrass, energycane
  - woody:  poplar, willow
- Aquatic Biomass
  - kelps (*Macrocystis*, *Gracilaria)*
- Community Wastes
  - water hyacinth, biosolids
  - municipal solid wastes

# Energy Potential from Biomass and Wastes in the U.S.

| Resource | EJ/yr |
|---|---|
| Municipal Solid Waste | 1.5 |
| Sewage Sludge and Sludge-Grown Biomass | 0.8 |
| Biodegradable Industrial Wastes | 0.4 |
| Crop Residues | 4.1 |
| Logging Residues | 0.3 |
| Animal Wastes | 0.4 |
| Energy crops | |
| land-based | 22.0 |
| marine | >100. |
| **Total (excluding marine)** | **29.5** |

# Advantages of Anaerobic Digestion

- can process wet or dry feeds
- does not require pure or defined mixed cultures
- does not require pretreatment for depolymerization
- produces less microbial biomass
- reduces animal and plant pathogens
- Low process energy requirements

# Biogas Use Options

- Direct Combustion/Co-generation
  - » cooking/heating/hot water
- Light (gas lights)
- Appliances (refrigerator, freezer, A/C)
- Electricity Generation
- Vehicular Fuel
- Gas Pipeline

# Residue Use Considerations

- use as compost
  - » high in inorganic nutrients
  - » improves water retention
  - » low odor levels
  - » pathogens
    - – mesophilic digestion gives poor reduction
    - – thermophilic digestion give good reduction
    - – best to maintain at 70ºC for one hour
- should cure prior to use as compost
  - » removes volatile acids and sulfides
- use for refeeding (solids contain ~14% protein)

# Factors InfluencingFeedstock Selection

- biodegradability (biochemical methane potential, conversion rate)
- nutrient content
- total and volatile solids content
- inhibitors (e.g. salt, ammonia, industrial chemicals)
- growth properties

# Operating Parameters

- Inoculum
- temperature, 35C or 50C
- loading rate, kg/m$^3$
- start-up
- nutrients
- mixing
- inhibition

# Performance Parameters

- gas and methane yields, $m^3$/kg vs and production rates, $m^3/m^3$ dig vol
- organic matter reduction (VS, COD)
- organic acids, pH, alkalinity

# Factors Influencing Reactor Design

- chemical characteristics of feed
- concentration of biodegradable matter
- concentration of feed particulate solids
- scale of application
- continuity of feed availability
- desired products
- site

# Biomass Energy Program Elements

- biomass production
- harvesting, storage, processing
- conversion via anaerobic digestion
- residue use
- biogas processing
- systems analysis
- basic research

# Approach to AD Process Development

Biomass

↓

Chemical and Physical Feed Analyses

↓

Biochemical Methane Potential
(feed variation, process variable evaluation, pretreatment)

↓

Bench-Scale Process Development
(convention and novel digester designs)

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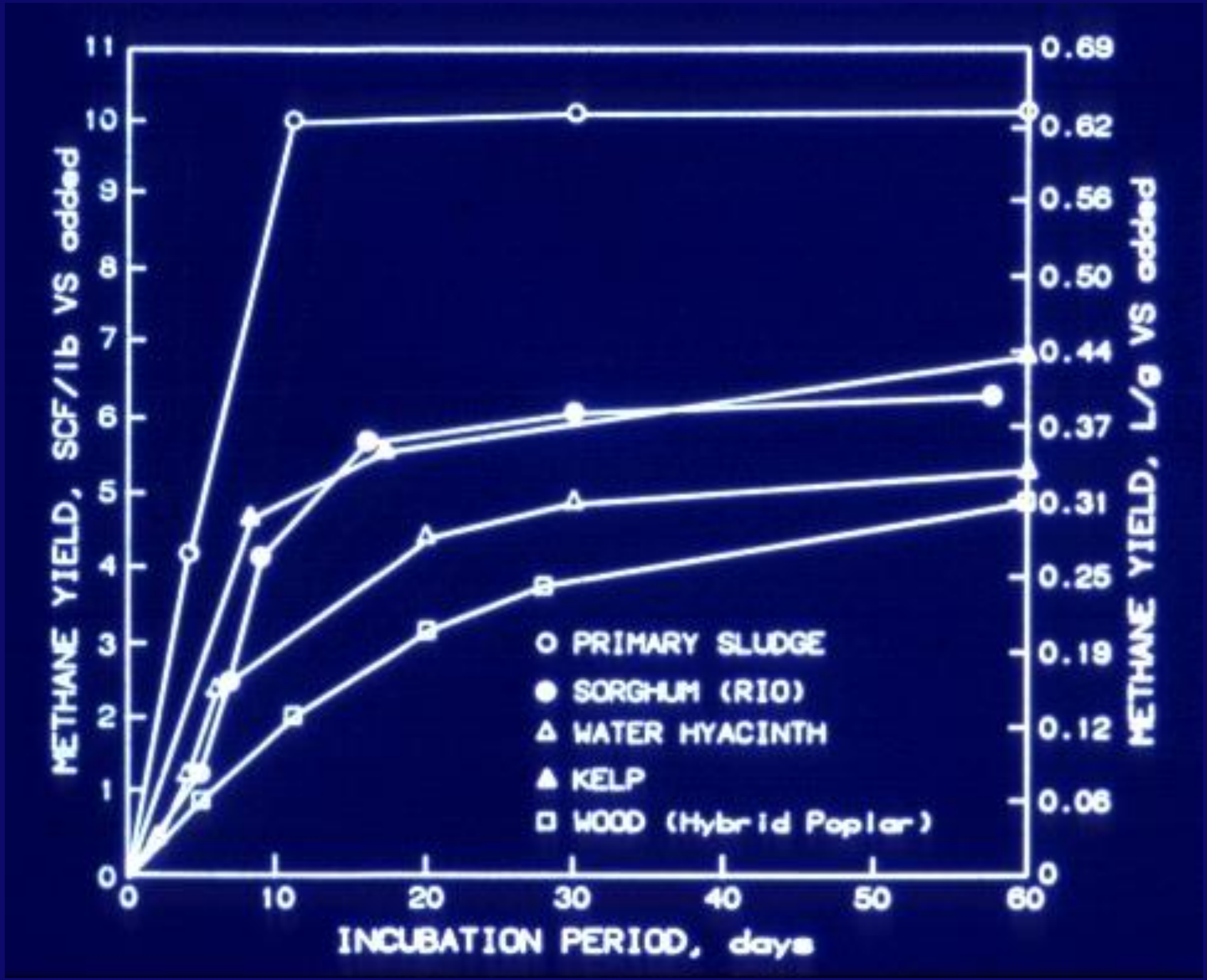
Process Scale-Up (pilot, demonstration commercial)

# Biochemical Methane Potential (BMP) Reactors

# Typical Biochemical Methane Potential Plots






USDOE Workshop
October 2016

# Biochemical Methane Potential (BMP) Summaries

Table 65. Summary of biochemical methane potential ranges for several biomass and waste samples. (Chynoweth et al. 1993)

| Sample | $L\ g^{-1}$ VS |
|---|---|
| All samples | 0.014 - 0.94 |
| All seaweeds | 0.26 - 0.40 |
| All grasses | 0.16 - 0.39 |
| All woods | 0.014 - 0.32 |
| Samples with high values | |
| Vegetable oil | 0.94 |
| Primary sludge | 0.59 |
| Food waste | 0.54 |
| Samples with low values | |
| Eucalyptus | 0.014 |
| Pine | 0.059 |
| Bambo | 0.016 |
| Avicel cellulose | 0.37 |

# BMP Data for Marine Algae

| Genus | Decomposition % VS* redn. | L (g VS)$^{-1}$ | Methane Yield Mg-C (Mg VS)$^{-1}$ |
|---|---|---|---|
| Gracillaria | 50 - 85 | 0.28 - 0.40 | 0.15 - 0.21 |
| Laminaria | 46 - 60 | 0.23 - 0.30 | 0.12 - 0.16 |
| Sargassum | 12 - 30 | 0.06 - 0.19 | 0.03 - 0.10 |
| Macrocystis | 34 - 80 | 0.14 - 0.40 | 0.08 - 0.21 |
| Ulva | 62 | 0.31 | 0.17 |

*VS = ash-free dry wt. (550°C)

# Feed Nutrient Requirements

TABLE 7.1
Nutrient Ratios of Biomass and Waste Feedstocks*

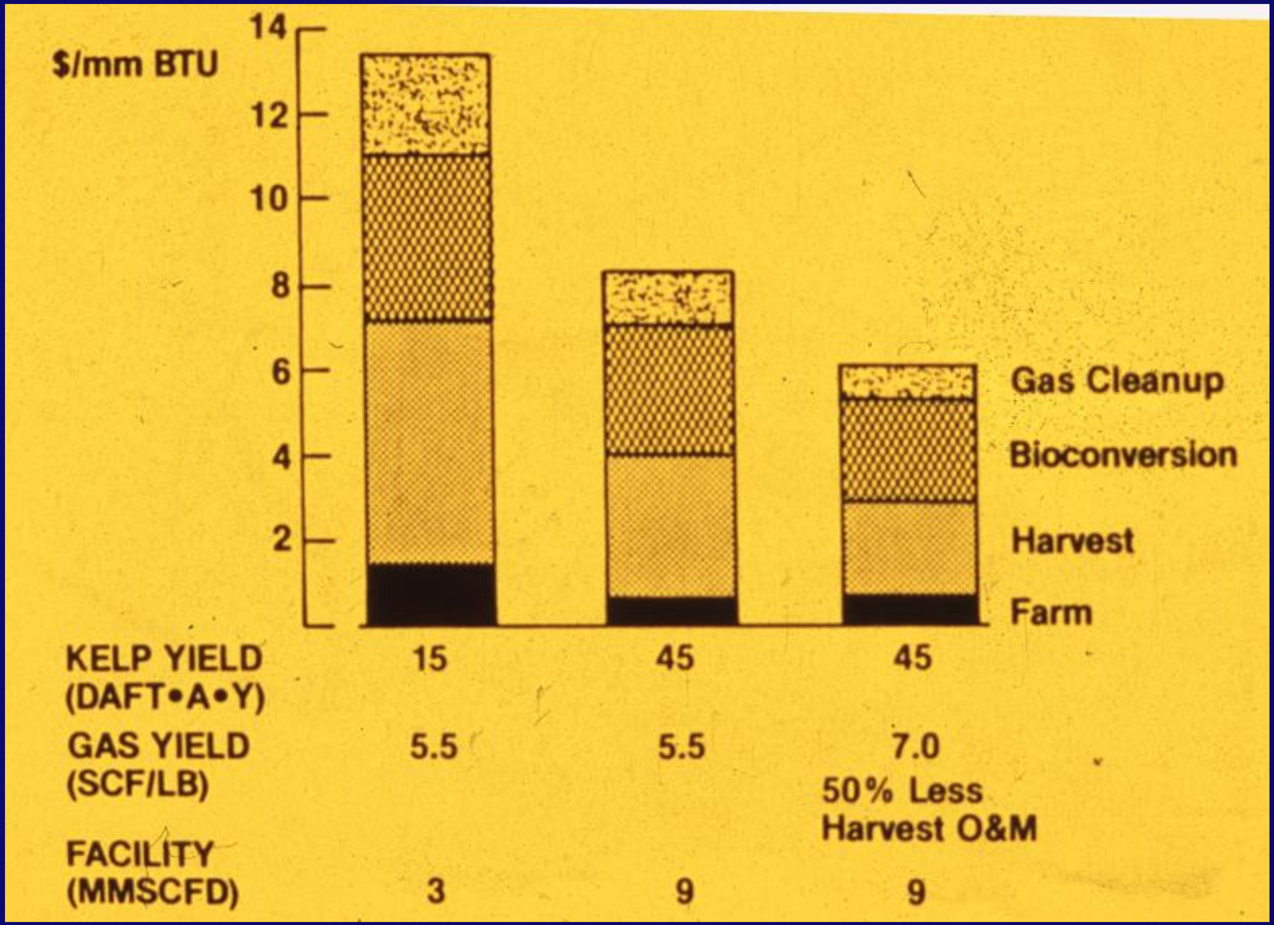
| Feedstock | Carbon/nitrogen | Carbon/phosphorus |
|---|---|---|
| *Aquatic* | | |
| Kelp | 15 | 84 |
| Water hyacinth | 10 | 94 |
| *Herbaceous* | | |
| Bermuda grass | 40 | 194 |
| Napier grass | 41 | 527 |
| Cattail | 41 | 278 |
| *Woody* | | |
| Eucalyptus | 490 | 446 |
| Sycamore | 178 | 2 480 |
| Loblolly pine | 432 | 2 600 |
| *Wastes* | | |
| Primary sludge | 8 | 50 |
| Municipal solid waste | 76 | 204 |

*Data from Ref. 5.

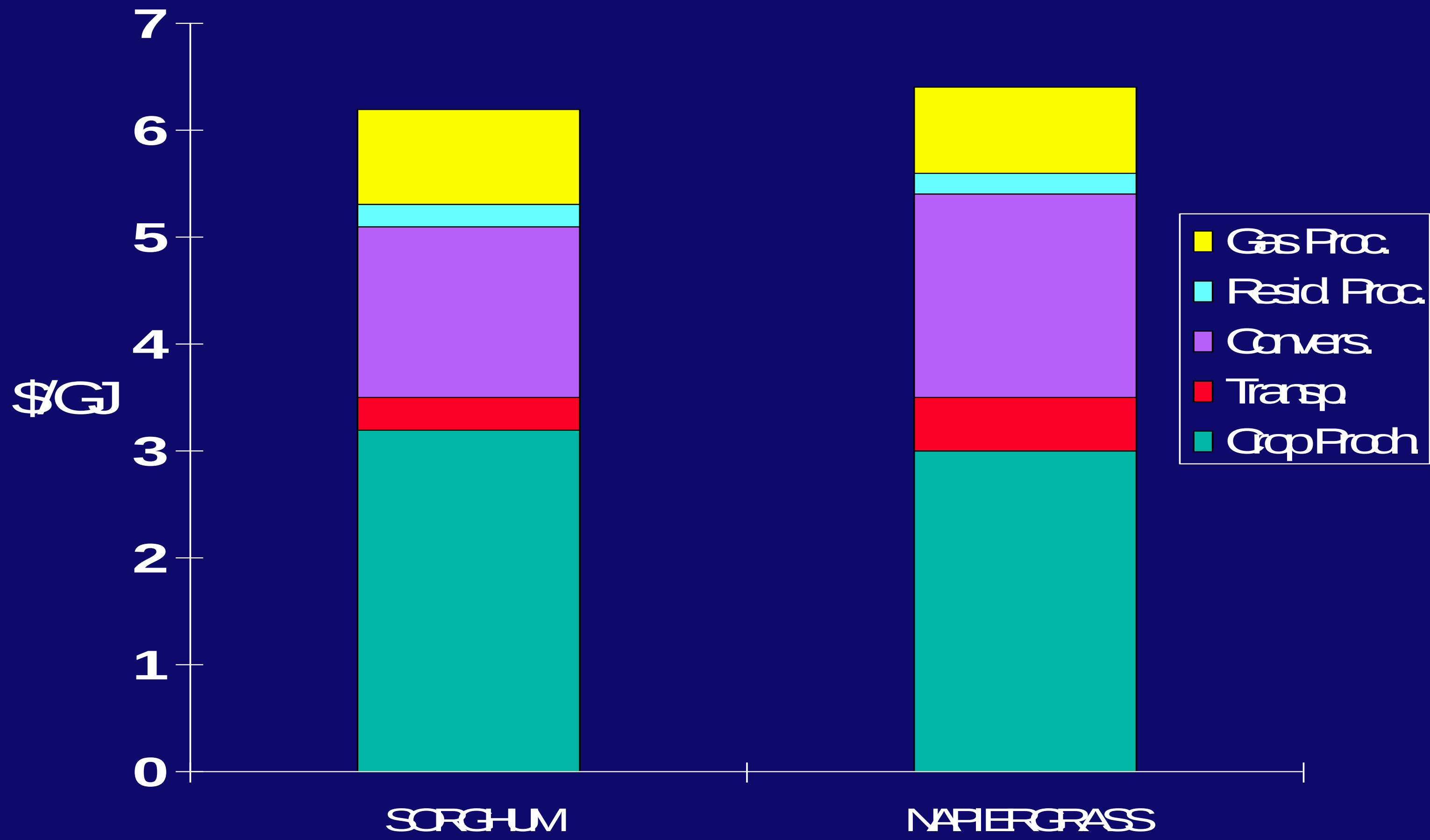
# Anaerobic Digester Designs For Different Feedstocks

| Feedstocks | Design Options |
| --- | --- |
| **Low Solids (<2% T.)**<br>sol. ind. wastes, biomass pressate, acid-phase effluent | anaerobic filter, fluidized bed, anaerobic contact, UASB |
| **Medium Solids (2-15% T.S.)**<br>sewage sludge, part. indust. wastes, aquatic/marine plants | CSTR, solids-concentrating, multi-stage |
| **High Solids (>20% T.S.)**<br>MSW, indust. wastes, grasses, wood | CSTR, leachbed, multi-stage |

# Kelp Economics



# Renewable Methane from Biomass



# Cost Estimates for Production of Biomethane from Energy Crops

| Energy Feedstock | Methane Cost U.S. $ per GJ |
|---|---|
| grass (sorghum) | 6-8 |
| wood (poplar) | 3-7 |
| seaweed (kelp) | 6-14 |
| wastes | 2-3 |

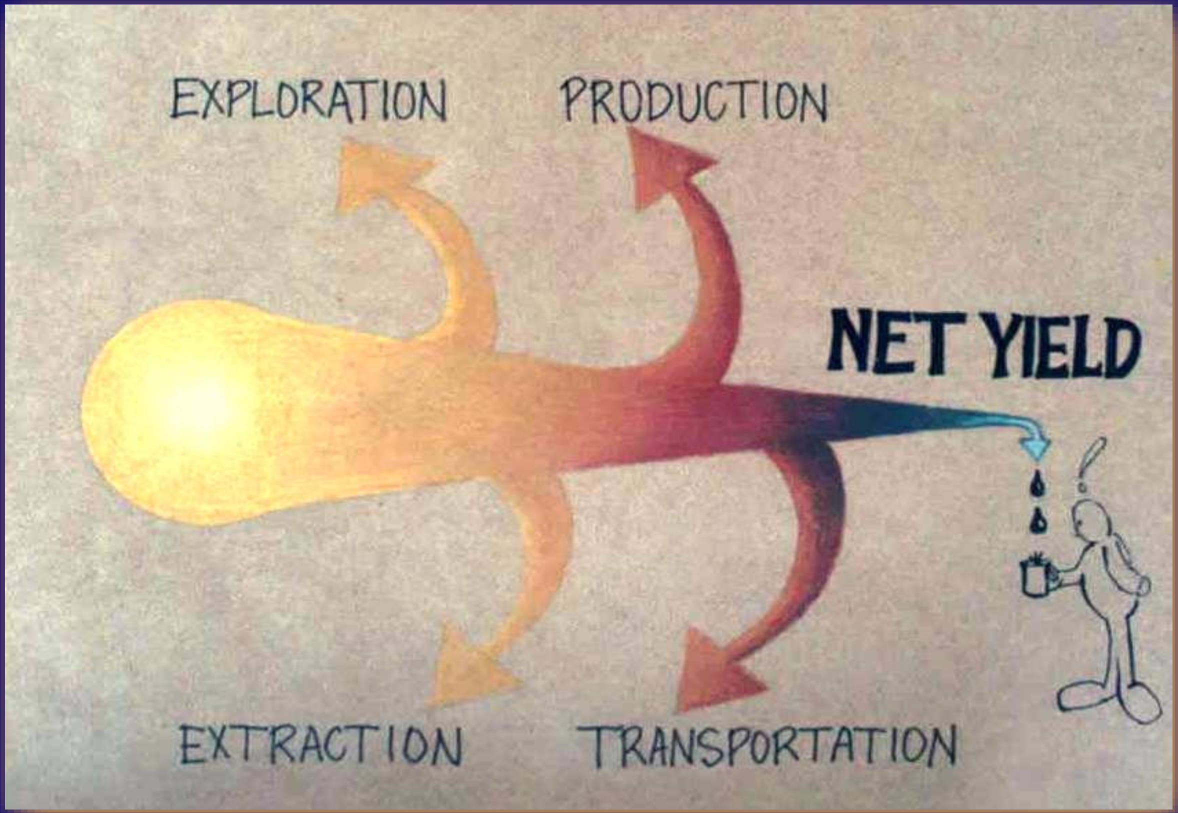
# Results and Conclusions for Marine Biomass

- Marine biomass has the potential for supplying all of our energy needs
- Conversion of marine biomass by anaerobic digestion is effective but requires enrichment of salt tolerant microbes
- The solids-concentrating reactor improves conversion kinetics
- Marine biomass energy costs 5-6 times that of fossil fuel energy
- Near-shore farms are more cost effective
- The major unknown is biomass yield in field conditions

# Results and Conclusions for Herbaceous Biomass

- Sorghum is ideal feedstock because of its high yields, geographic diversity, and high conversion rates
- Ensiling is a good method for preserving feeds without loss in energy potential
- Leachbed reactor is best design in terms of cost and stable performance
- Methane enrichment is possible using stripping and pH/pressure swing
- Cost is about 3X that of fossil fuels

# Net Energy




We believe that to maintain society's current level of infrastructure and information processing, a net energy of about 4/1 is required.